Evaluation of the effectiveness of an airport passenger and baggage security screening system

Abstract Airport security managers need methods to quantify changes in security level to prevent terrorist attacks. This study presents a method using a fuzzy inference system to assess the overall effectiveness of prohibited items detection during passenger and baggage security screening. The results show that the screening system performance can be improved from *medium* to *high* by upgrading screening devices at hold baggage checkpoints and by increasing the frequency of training sessions. In the case of increased risk of terrorist attacks an obligation to control 20 per cent of passengers manually complemented by a 30 per cent increase in the sensitivity of metal detectors increases system performance to *very high* detection level. On the positive side our results show that these results can be achieved with minimum financial outlays, while on the negative sides system throughput is somewhat reduced. Overall our results show that screening performance can be improved substantially, but as the required performance level rises there is a trade-off with system throughput and personnel training costs

Keywords: security management, air transport, fuzzy inference, passenger and baggage screening, human factor

1 Introduction

In most airports in the world every air travel is preceded by passenger and baggage screening. There are many detailed solutions in different countries. In our study we have adopted the standards and legal regulations in force in the European Union. However, security is a global issue. Susceptibility of air transport to terrorist threats forces the airport management to take effective measures to ensure security to the passengers and personnel. These involve considerable expenses and pose a serious organizational challenge. Therefore, the security control becomes a significant part of airport budget and considerably affects the functioning of the entire company. At the same time, process management is difficult due to the lack of proper supporting methods. This applies particularly to evaluating the effects of the measures taken in relation to the achievable security levels. While resolving on the specific financial effects, a manager is willing to know how much the effectiveness of detection of prohibited objects, and thus the security level, will increase. That would make it possible to determine whether such decision is reasonable (whether the effect justifies the cost to be borne) or, possibly to compare two alternatives (which of two possible actions will have better results at a similar cost level). Regrettably, there is still a shortage of quantitative methods allowing for such analyses, particularly in the practical, managerial perspective. This study aims to bridge this gap. It summarizes the scholar's work made so far, which resulted in creating a quantitative method for evaluating the effectiveness of the airport passenger and baggage security screening system. It is difficult to accurately describe this ill-defined problem, so it often comes down to an intuitive or a 'trial and error' approach. Our approach allows us to formalize the expert knowl-

edge and achieve more objective results, and certainly makes it possible to carry out a comparative analysis. The method is based on fuzzy logic, more precisely on the fuzzy inference systems. The computer-aided tool FASAS (Fuzzy Airport Security Assessment System) enables practical support of airport management in terms of security control.

1.1 Managing the system of an airport passenger and baggage security screening

The security checks of passengers and baggage in airports is regulated by extensive regulatory system (European Commission, 2015). It applies mainly to the control methods, training and supervising the tasks performed by airport management in this respect. However, compliance with the regulatory requirements does not exclude the option of making individual managerial decisions that can significantly affect security, capacity or comfort of passengers. Such decisions usually refer to the scope of extensions beyond the minimum required by law. The legislation in force does not give an indication on how to practically organize the airport control system, which includes not only the physical activities visible to the passengers, but also a series of infrastructural, personal and procedural actions, requiring expenses relevant to the scale of passenger traffic. For example, there are many manufacturers on the market who offer passenger and baggage security screening devices that meet the minimum standards set in the regulations. However, these devices differ from each other in detailed technical parameters, ergonomics or available additional features, which ultimately have a significant impact on the effectiveness of screening and thus on the airport security. The system organization is a similar issue. For example, checked baggage screening requires examination using an explosives detection system (EDS) X-ray device and evaluation of the image. However, it is not specified how many levels of such screening is needed. Similarly in the case of security screening operators (SSO) – they can be sent to additional trainings beyond those required.

As already mentioned, a passenger and baggage security screening system is required to comply with valid regulations setting out the lower limits for the system operating parameters. On the other hand, it has to be scaled to the magnitude of traffic involved. It should also ensure, as far as possible, sufficient comfort to passengers, which will have a great impact on how the quality of airport services is assessed.

There are usually several key issues found in the passenger and baggage security screening management.

1. Choosing the number of security control areas (SCA). On making such decision, airport management takes into consideration the intensity of current traffic, but allowances must be also made for the planned airport development. Determination of the number of SCAs requires to establish the essential peak hourly passenger capacity. It may considerably exceed the average traffic intensity, also the off-peak traffic. The necessity for efficient management of traffic at peak hours results in that the security control systems are often oversized. This generates significant initial cost of equipping the SCAs, as well as the subsequent operating costs (including maintenance, inspections, energy consumed).

2. It also involves having a proper number of staff with all necessary qualifications and certificates to perform their duties. With simple calculations, it can be stated that the minimum staffing of a single SCA requires 4-5 employees in 24 hours. This is a factor that generates huge cost of an airport security system. To ensure continued operation of a single SCA, 12-15 workers have to be employed. The above-mentioned problem of oversizing the system and of the cost of recruiting and training the staff might be the case here. Since it is required to consider the possible diverted, delayed or additional flights, security checks of aviation operations are often necessary to be performed at different times than scheduled. This requires additional workforce.
3. Selection of SCA equipment. The most important criterion in the choice of the equipment with proper certificates is usually the balance between the price and the achievable passenger capacity. Both variables can be precisely given in numbers. Unfortunately, however, we are unable to give precise figures to represent the effectiveness of the equipment used for detection of prohibited objects and substances. Therefore, this criterion is difficult to consider and is often disregarded. It is all limited to the information that the system meets the minimum standards.
4. SCA organization. A large number of tasks to be performed by an SSO during security control operations, requires at the same time the SCA to be provided with special equipment for performing such checks. It is possible to designate dedicated SCAs to perform specific types of checks. It allows a cost reduction, since the management does not have to provide all SCAs with all types of equipment. However, this will compromise the versatility and may cause operating problems.
5. Dynamic modification of system operating parameters. The above issues are critical and are considered over a long time horizon. However, planning an airport security system is a very dynamic process. Legislation and the relevant requirements are often changed along with the security assessment on the national, regional and even global scale. Similarly, the technological advance requires the equipment and security measures to be adapted accordingly. This forces actions with medium time horizon to be taken. Refer to Section 3.2.1 for a more detailed description of those issues.
6. Operational management of the system. There are many detailed system performance parameters available in short term which can be adapted to temporary and current needs. An example of situations requiring such ad hoc actions is declaring the state of elevated risk of terrorist attack. Refer to Section 3.2.2 for a more detailed description.

For an airport with around 3 million passengers per year, the cost of security (equipment and staff) can reach about €4 million per annum. The airports mostly function as economic agents and attempt to achieve a positive financial result, which in turn is a determinant of the investments planned for airports. However, the managers responsible for planning investments (in security equipment or training, for example) would like to know the measurable effects of such actions. This also applies to the comparison of several alternative investment decisions. The lack of quantitative methods makes it impossible to evaluate their actual effects. Under such conditions, it is easy to make a wrong decision and to be accused of mismanagement. This may foster a policy of 'meeting only the minimum requirements'. Of course, such policy is not

always used in such a situation. Right investment decisions, such as better equipment for security screening checkpoints, may positively influence not only the security of performed air operations. They can also improve the capacity or comfort of passengers. This increases the competitiveness and attractiveness of the airport, which in turn may positively affect the financial performance of the airport. But the key issue is to make the right investment decisions. Thanks to them we may avoid the cost of reputational damage or even real losses as a result of terrorist attack.

The presence of numerous factors forcing the system upgrade, particularly the medium- and short-term ones, should lead to basing the possible decisions not only on the cost and possible capacity, but also on the effectiveness of detection of prohibited objects and substances. We believe that thanks to the tool for quantitative assessment of effects relating to effectiveness of security screening, on the one hand we give managers (regulators) the ability to reliably assess the expected results, on the other we make it possible to find non-investment solutions that involve only organizational improvements.

1.2 Overview of the studies

This section gives an overview of the literature on airport security management. This is a complex problem that can be considered with consideration of different aspects. The study (Cole, 2014) highlights the necessity of proactive approach, i.e. analysing risk scenarios for seeking appropriate remedial actions. An important issue is the scope of control operations and their effect on an airport capacity (Hainen et al. 2013; Butler and Poole, 2002; Leone and Liu, 2005; Van Boekhold et al., 2014; Kierzkowski and Kisiel, 2015) and the passenger comfort and satisfaction (Alards-Tomalin et al. 2014; Benda, 2015; Gkritza et al., 2006; Sakano et al., 2016). The approach combining several criteria is also applied (Wu and Mengerstern, 2013; Lee and Jacobson, 2011). Increasing the scope of control operations requires obviously increased expenditures which are not always reasonable (Stewart, 2010; Stewart and Mueller, 2014; 2015; Gerstenfeld and Berger, 2011; Gillen and Morrison, 2015; Prentice, 2015).

Attempts are made to develop new, alternative security control system solutions:

- integrating all types of control measures applied to passengers and their baggage (Yildiz et al., 2008; Leone and Liu, 2011);
- based on dynamic risk level assignment to a passenger (Nikolaev et al., 2012; Nie et al., 2012);
- based on risk estimation (Wong and Brooks, 2015);
- involving automatic tracking and classification of moving passengers (Wienenke and Koch, 2009).

The problem of hand baggage screening was dealt with among others the works of (Michel et al., 2014; Mendes et al., 2012; Bolfing et al., 2008). The problems of checked baggage were in turn tackled by Feng et al. (2009), Wells and Bradley (2012), Caygill et al. (2012) and Nie (2011). The passenger screening process organisation was analysed by Bagchi and Paul (2014), de Barros and Tomber (2007) Concho and Ramirez-Marquez (2012) de Lange et al. (2013) and Yoo and Choi (2006).

1.3 Concept of the study

This study deals with the problem of an operational quantitative determination of the effectiveness of an airport passenger and baggage security screening system. Such effectiveness is understood as the ability to detect substances and objects which are prohibited in air carriage. We have assumed the perspective of airport management and, more precisely, the person in charge of passenger and baggage screening, undertaking medium- and long-term upgrade actions. The literature overview indicates that there are no such methods available and they are essential for effective management of an airport security system.

The method developed will meet the proactivity criterion, which means that it will allow planning of actions before security risks are present. For the medium-term horizon, we will seek an action strategy that will increase the effectiveness of control without compromising the capacity, assuming that funds to pay for the actions are available. For the short-term horizon however, we will look for strategies to increase the effectiveness without the need of bearing additional cost. This will certainly involve some capacity limitation here.

This study summarizes the previous works, in which we proposed methods for evaluation of hand baggage (Skorupski and Uchroński, 2015a), checked baggage (Skorupski and Uchroński, 2015b) and passenger (Skorupski and Uchroński, 2016a) screening systems. All those methods are based on fuzzy inference systems. The objective of this paper is to integrate in hierarchical structure and demonstrate that the calculation tool FASAS created can be used for operational management of an airport security screening system. Said integration requires a collective approach to all three systems. It is a challenging task since it is difficult to evaluate the effect of individual subsystems on the effectiveness of the entire security screening system. To perform the task, a team of experts was employed, consisting of experienced security control operators and security control administrators from several Polish airports. The role of the experts was to create a base of fuzzy inference rules. The works required to solve an auxiliary problem of removing the inconsistency in a set of rules proposed by the experts (Skorupski, 2015).

Our model is based on the legal system in force in the European Union. However, the proposed approach and the developed FASAS software can be used regardless of the airport location and the civil aviation security regulations in force in the particular country. The software is based on objective premises and assumptions independent of legal acts. However, the model should be verified in this respect before the solution is applied in other legal environment.

The remaining part of the paper is organized as follows. Section 2 gives a brief overview of theoretical grounds of fuzzy inference systems and linguistic variables which are included in this study as decision variables used by the control system administrators. This section presents also an integrated fuzzy inference system which is the result of the study. Section 3 provides a comprehensive analysis of the passenger and baggage security screening system at Katowice International Airport (ICAO code: EPKT, IATA code: KTW), using the method developed and the computer-aided tool FASAS created. The possible upgrade actions are further presented in detail. Section 3.3 analyses several scenarios and determines quantitatively the effectiveness of the control relative to the upgrade actions taken in the medium-time horizon, while

Section 3.4 deals with the same for the short-time horizon in case of elevated risk of a terrorist attack. Section 3.5 proposes an entire upgrade strategy for Katowice International Airport. Section 4 contains the summary and conclusions.

2 Fuzzy sets in assessing the effectiveness of security screening in air transport

2.1 Uncertainty and subjectivity in making decisions in aviation security screening systems

In technical activities, including transport processes, the information available often tends to be inaccurate and incomplete. If this is the case, decisions are made in some uncertainty conditions. There are many types of uncertainty and various mathematical methods and ways to reduce its adverse effects on the decisions being made.

In airport passenger and baggage screening systems, the knowledge of the effectiveness of screening cannot be obtained from measurements. The only objective measurement method is to analyse the number of unlawful acts on board of aircraft using objects undetected by the security screening. Basing on such data is far from enough since it is obvious that the number of such incidents is only a small percentage of that of prohibited items which could get on the board.

For the lack of measurement possibilities, it is necessary to acquire the knowledge from experts in the field. They usually use informal language and their knowledge is expressed inaccurately and in approximation. This is therefore a typical example of acting in linguistic uncertainty conditions. In such situation, it is necessary to apply methods which make it possible to take into account the inaccuracy and uncertainty of input variables (Dubois and Prade, 1992; Greco et al., 2001; Zadeh, 1973). For that reason, fuzzy inference systems based on fuzzy logic were used in this study (Siler and Buckley, 2005). Given the size of the study, the formal description of theoretical grounds of the methods employed will be abridged, with references being made to the respective literature items.

2.2 General information on fuzzy sets

The theory of fuzzy sets was initiated in 1965 by mathematician Lotfi A. Zadeh (Zadeh, 1965, 2015). A practical motivation for the development of this field in mathematics was the need to create a mathematical apparatus that would allow processing linguistic information to support decisions to be made by human in complex situations. It allows a construction of automatic approximate inference systems. It is also applied in decision supporting systems in such fields as technology, medicine, economy and management. The fuzzy set theory has also a significant impact on the basic sciences which proves its great versatility.

As a fuzzy set we understand a set in a form

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

where μ_A is a function typical for this set.

The set X determines the co called consideration area, also known as the consideration space. The property that determines an element membership in a set can be unfuzzy or fuzzy. The first case represents a classic set, while the latter a fuzzy set. Therefore, every object in the consideration space can belong, not belong or belong to a certain degree to a fuzzy set. The element degree of membership in a fuzzy set is determined by the characteristic function, referred to as the membership function. They can have various shapes as the case may be.

2.3 Linguistic variables and fuzzy inference systems

The analysis of effectiveness of the passenger and baggage screening system was carried out with the use of a model as well as a fuzzy inference system that was based on linguistic variables. In colloquial terms, a linguistic variable refers to 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):

$$\langle L, T, X, G, M \rangle \tag{2}$$

where:

L - linguistic variable name;

T - a set of syntactically correct linguistic variable values L;

X - consideration space of a linguistic variable L;

G - syntactics of a linguistic variable, expressed most commonly by combinatory grammar, it generates linguistic values of the variable L;

M - semantics of a linguistic variable, determined by a set of algorithms allowing the assignment of every linguistic variable value of certain fuzzy set A defined in the consideration space X. The semantics M for each of the linguistic variables is determined based on airport security expert opinions or by measurements of physical properties dependent on the elements belonging to the consideration set $x \in X$. For details refer to individual sections describing the following linguistic variables.

The relationships between input and output values of a real-world operating system, and thus of the model, are often recognised as issues which are not suitable for objective quantitative assessment. This is also the case in systems analysed in this study. It is, however, possible to describe the relationships present in a subjective, approximate and quantitative manner. Those statements served as the grounds for using fuzzy inference systems for solving problems presented in this study (Siler and Buckley 2005). The fuzzy inference systems use the fact that accurate and precise knowledge cannot be often acquired, but imprecisely presented problem-related knowledge can be gained. What is important is not that the knowledge is inaccurate, but that there is no method available to formalise the notation of this knowledge.

Schematically, the fuzzy inference system is presented in Figure 1.

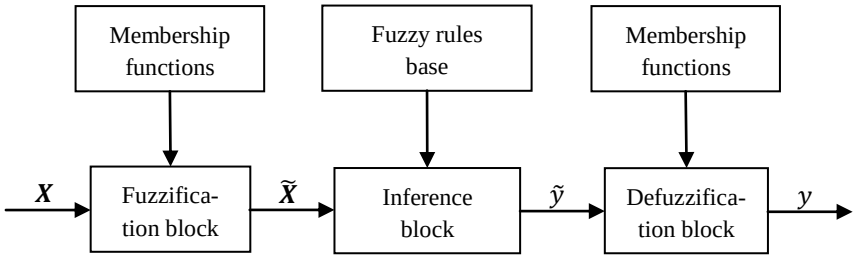

Fig. 1. General structure of the fuzzy inference system

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 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.

2.4 General structure of a fuzzy model *Screening system evaluation*

The general structure of the fuzzy model for evaluating the effectiveness of the passenger and baggage screening system is shown in Fig. 2. The input variables of the *Screening system evaluation* model are: z_h - effectiveness of hand baggage screening (linguistic variable *Hand baggage*), z_c - effectiveness of checked baggage screening (linguistic variable *Checked baggage*), z_p - effectiveness of passenger screening (linguistic variable *Passenger screening*). All the input variables are the outputs of other local models. They are presented in detail in the following sections.

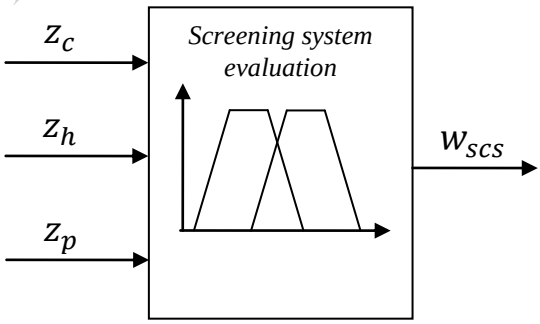

Fig. 2. General scheme of the fuzzy model of an airport passenger and baggage screening system

2.5 Input variable *Hand baggage*

Hand baggage screening has two aspects. The first one of them is scanning luggage with roentgen rays in order to learn what it contains without opening it. The second one is manual inspection carried out by the security screening operator (SSO). As far as the fuzzy model constituting the basis for the fuzzy reasoning system is concerned, three input variables correspond to those two aspects (Skorupski and Uchroński, 2015a). Two of them – *Device evaluation* (y_d) and *Type A Errors* (x_{eA}) – are related to the X-ray scanning of cabin baggage.

The first linguistic variable – *Device evaluation* makes it possible to express the impact of the technical factor on the possibility of effectively detecting a prohibited article in baggage (Skorupski and Uchroński, 2016b). For purposes of our study, we assumed that parameters taken into account when assessing devices would be: detectability of different materials, presence and efficiency of Threat Image Projection (TIP), the number of detection lines used, and the age of the device. Some of those parameters could be defined in an exact manner (e.g. the number of detection lines) while others (e.g. the efficiency of TIP) have to be expressed in the form of a description, as they are intuitive and cannot be precisely and formally defined. TIP system installed in X-ray devices plays an important part of the entire process. It combines the image of the baggage being scanned with a virtual image of forbidden articles. The SSO then has to detect such virtual forbidden articles and press the relevant button. On the one hand, it is a tool for employees work assessment and, on the other hand, it makes it possible for the employee to get familiar with images of prohibited or dangerous articles, more or less cunningly hidden in the baggage, and, consequently, to improve his or her skills and knowledge and the efficiency of tasks performed. Effectiveness of the TIP system depends on the number of embedded images of prohibited items and frequency of displaying them.

The technical potential of the X-ray device forms only one part of the assessment of hand baggage screening. Its other part are the actual skills of SSO, enabling SSO to use the X-ray device smoothly and efficiently. The other linguistic variable – *Type A Errors* – describes those skills. Type A error consists in failure to indicate (to notice) the virtual prohibited item interposed on the image of the scanned baggage by the TIP system.

The third variable used in the model is *Manual Inspection* (y_m). It is used to describe the efficiency of manual inspection carried out for some cabin baggage. It combines assessment of the quality of manual inspection carried out and the number of such inspections. In our model, we assumed that the quality of inspection depends on linguistic variable *Employee Evaluation* (y_p). It is, in turn, dependent on such factors as the experience of SSO, the amount of time since the last comprehensive or current training they have undergone, and their overall attitude to work they perform (Skorupski and Uchroński, 2015c). On the other hand, the quantity of baggage subjected to manual inspection also has an impact on the efficiency of such screening. Due to differences in technical equipment used at different SCA and due to legal regulations in force, we have broken down the concept of manual inspection into two types: type B manual inspection and type C manual inspection. Their number, expressed with linguistic variables *Number of type B manual inspections* (x_B) and *Number of type C manual inspections* (x_C) respectively, is an input variable for the model.

2.6 Input variable *Checked baggage*

Evaluation of the effectiveness of checked baggage screening depends on two factors: efficiency of X-ray equipment used for scanning the baggage and efficiency of the checks performed at SCA, particularly with participation of SSOs (Skorupski and Uchroński, 2015b). So the local model *Checked baggage* has two input variables. Both the linguistic input variable *SCO control* (y_o) and the linguistic input variable *Device's assessment* (y_d) are in fact output from other local models represented by fuzzy inference systems. *Device's assessment* is explained in Section 2.5. The variable *SCO control* depends on the employee evaluation, type A errors (variables *Employee Evaluation* and *Type A Errors* - Section 2.5) and an important variable *Control organisation option* (x_o). This variable describes the checked baggage screening organisation, which may generally include the automatic screening, check made by SSO, using X-ray equipment and manual checks.

2.7 Input variable *Passenger screening*

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). This fuzzy inference system creates a hierarchical structure as the *WTMD's evaluation* and *Manual control* are outputs of local fuzzy models (Skorupski and Uchroński, 2016a).

A mandatory element of the security control is the passing of the passenger through the WTMD. They are primarily used to detect metal object 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. An evaluation of the effectiveness of WTMD in the passenger security control process at the SCP depends on: 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 input variable *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 third input variable for the *Passenger screening* model is the *Manual control* variable which is in fact an output of the local fuzzy inference model. 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 (Section 2.5).

2.8 Output variable *Screening system evaluation*

At the last stage of evaluating a passenger and baggage screening system the inference rules for a fuzzy inference system are determined. The three above-mentioned variables, i.e. *Passenger screening*, *Hand baggage* and *Checked baggage*, are the

input values of this system. A general evaluation of the effectiveness of a security screening system at an airport is described by the linguistic variable *Screening system evaluation*. Its membership function which is the same as the one presented in Fig. 3, is the output value.

A group of four experts were asked to define the rules. These experts are practitioners with extensive experience in airport security management. The following problem has been brought before them. If we assume that the purpose of the whole security system at the airport is a safe flight (in which there is no explosion, hijacking or an assault on another passenger), which of these three types of screening is the most important to achieve this objective? The experts' evaluations were conflicting. Especially as there are many criteria for the evaluation of these three types of screening. And the importance of these criteria is subjective. This caused the need for integration of assessments, which was described in (Skorupski, 2015). Finally the knowledge base consists of 125 fuzzy rules. Some of them are presented in Table 1. The rules have been developed for a typical mid-sized regional airport that is subject to the EU law. However, individual countries may establish different requirements than those implemented in our study. As a consequence, security checks on other airports may be carried out in slightly different manner. Thus, the effectiveness of individual control areas (hand baggage, checked baggage, passengers) may also be slightly different. In that case, the fuzzy inference rules should be adapted to local conditions.

Table 1. Fuzzy inference rules for the model *Screening system*

Rule	*Passenger screening*	*Hand baggage*	*Checked baggage*	*Screening system evaluation*
6	*low*	*low*	*very low*	*very low*
17	*average*	*high*	*very low*	*low*
54	*very high*	*very low*	*average*	*average*
93	*high*	*high*	*high*	*high*
120	*very high*	*high*	*very high*	*very high*

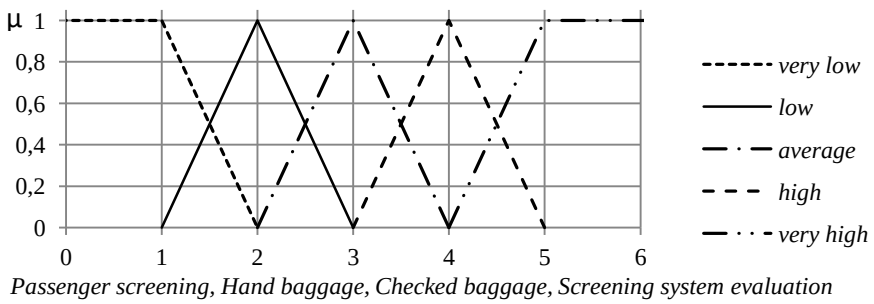

Fig. 3. Membership functions of the linguistic variables: *Passenger screening*, *Hand baggage*, *Checked baggage*, *Screening system evaluation*

2.9 Validation of the model *Screening system evaluation*

In our previous studies evaluating passenger and baggage screening, the fuzzy rules base verification was quite obvious, because in most cases we are dealing with measurable values. In the final stage there was the need to integrate the knowledge on a very general level. Unfortunately, these data are not measurable. 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.

To validate the rules of *Screening system evaluation* model and also to remove any inconsistencies the method described in (Skorupski, 2015) was used. It consists in using expert opinions expressed in terms of multiple criteria in the form of both numerical and linguistic assessments. Experts define the conclusions of rules as so-called half-marks in order to increase the method's flexibility. Given the way in which information is obtained, the weights (importance) of the premises are unambiguous for the group of experts who are consulted. This makes it possible to automatically determine the conclusions of rules for any combination of the premises' values. Automatically generated rules are compared to the rules that were provided by experts in order to detect inconsistencies. As a result of using a new concept of half-marks (both by the experts and the automatic system), it is possible to perform not only the verification, but also automatic selection of the final form of a conclusion. It is consistent both with the experts' assessments and with the automatically generated rules. Inconsistent rules were re-examined by the experts. This procedure resulted in final version of the rules, partially presented in Table 1.

2.10 Computer implementation - FASAS tool

Based on the models created, the computer-aided tool FASAS was created and used for simulation experiments to show the effectiveness of the method in managing the security screening system in an airport. The software was created with the use of SciLab 5.4 engineering package with appropriate extensions, in particular Fuzzy Toolbox 0.4.6 fuzzy logic package.

3 Evaluation of the effectiveness of an airport passenger and baggage security screening system

This section describes the experiments with the use of the method described, intended to demonstrate its effectiveness in supporting a real-world security screening system in an airport. At first, the reference variant will be examined, then, general principles for the selection of system operating parameters will be presented to allow analysing the benefits of various actions: extending the scope of training, equipment change and organisational activities. The possibility for improving the effectiveness of the system in case of elevated risk of terrorist attack will be analysed, when the capacity factors are less important.

3.1 Example of a security screening system effectiveness assessment in Katowice airport

This section will present the reference variant that will serve for comparisons and analyses of the effects of various possible decisions changing organisation of the security screening system. It corresponds approximately to the situation in Katowice International Airport in 2014. Certainly, the starting point in various airports may differ considerably, however the solutions proposed below constitute a kind of a standard that can be assumed as a typical situation.

The basic scenario S_0 assumes that all SCAs are provided with one type of equipment type SH 6040si (in hand baggage screening areas) and Smith Detection 100100 V-2is (in checked baggage screening areas), which have no explosive detection function and has been already in use for some time (9 and 5 years respectively). In the hand baggage screening equipment, there are TIPs installed with the rate of 6000 pieces presented with the frequency 2.8%. There is no TIP system present in the equipment for checked baggage screening. The equipment is operated by SSOs having worked in the profession for 3 years on average, with comprehensive training in accordance with applicable legislation every 3 years for proper analysis of images of scanned equipment. In addition to that, every 4 months their work is reviewed and those who have not achieved TIP detection rate of 80% are given additional training. Walk-Through Metal Detectors (WTMDs) in those SCAs are provided with operator support function (selection for additional manual check), set to the frequency 13% which means that 13 per 100 passengers who have not activated the gate because of a metallic item carried are additionally checked manually. The sensitivity of the gate is set to 60-80 which corresponds to a standard situation, when there is no need to increase security levels at airports. The gates are set according to the standard 2 of the manufacturer (European Commission, 2015).

All parameters required are compiled in Table 2.

Table 2. Input parameters of scenario S_0

Parameter	Passenger screening	Hand baggage screening	Checked baggage screening
Security screening operators			
Experience [mth]	36	36	36
Comprehensive training [mth]	18	18	18
Ongoing training [mth]	2	2	2
Attitude	2 (average)	2 (average)	2 (average)
Type A errors	-	15 %	20 %
X-ray equipment			
Age [yrs]	-	9	5
Number of TIPs	-	6000	0
TIP frequency	-	2.8 %	0
Number of lines	-	1	2
Detectability	-	6	6
Walk-Through Metal Detectors			
Visualisation	20	-	-
Detection areas	20	-	-
Sensitivity [g]	165	-	-

Support	1 (yes)	-	-
Other parameters			
Organisation variant	-	-	4
Number of employees	4	-	-
Additional checks	13%	-	-
Checks B	-	9 %	-
Checks C	-	0 %	-

The airport operation was analysed in moderate terrorist threat situation. All the parameters and procedures provided comply with the requirements of the relevant legislation in such situations. Simulation analysis carried out for typical values of parameters listed in Table 2, using the FASAS tool, provided the results as given in Table 3.

Table 3. Evaluation of the passenger and baggage screening system in the scenario S_0

System	Defuzzified rating	Linguistic rating
Passenger screening	3.16	> *medium*
Hand baggage screening	2.30	*low / medium*
Checked baggage screening	2.72	*low / medium*
Total	2.95	*medium*

The final, defuzzified rating value of the entire passenger and baggage security screening system is 2.95, which corresponds to the value *medium*. This is in line with the expectations and typical for most airports. Meeting the regulatory requirements and acting in typical threat levels causes the system to be configured so as to achieve the average effectiveness in detection of prohibited items. This allows of course for maintaining the passenger capacity sufficient to the current needs.

3.2 General rules for choosing parameters of airport security screening systems

This section presents the principles adhered to by the managers of security screening systems in airports. This allows us to identify decision variables in the process analysed. There are naturally quite a number of actions possible, so we will limit ourselves to those with the greatest practical importance. We will also present the management process limitations to allow a comparison of different operating variants.

3.2.1 Standard situation

Security screening systems in airports are aimed at detecting the attempts to place prohibited items and substances on board of an airplane. Therefore, a screening system manager will seek to maximise the effectiveness of detection of such items. However, it should be noted that the system does not act independently, and it is a part of the airport whose objective is to achieve the greatest possible passenger traffic. These objectives are contradictory. This is because highly efficient screening means detailed checking of all passengers and luggage, which makes it impossible to achieve great terminal's capacity. Therefore, the security screening managers try to take only such actions which could improve the effectiveness without compromising the capac-

ity. They will constitute the decision making variables in the simulation analyses described further on. Such activities can include:

- replacing the equipment with more up to date and more advanced devices to enable more effective detection of prohibited items;
- proper selection of SSOs with high aptitude to such work;
- increasing the frequency and scope of training which improve the skills in detecting prohibited items, but may also raise the awareness of the importance of the SSOs' work;
- application of organisational and technical solutions allowing continuous monitoring of conditions of critical elements of the system: equipment and staff;
- application of organisational and technical solutions to relieve the workers from additional tasks, formalities, reducing their mental workload.

It is obvious that the effects of individual actions will differ also due to the individual features of an airport. So will differ their implementation cost. The elements will be further described while discussing individual simulation experiments.

It is worth mentioning here that there are some limitations preventing from complete freedom in application of the solutions discussed. The most important ones include:

- the necessity to meet standards and international recommendations intended to maintain high safety level of air transport;
- financial limitations, important particularly when resolving on the replacement of equipment;
- the necessity to keep the system running permanently, which makes it impossible, for example, to quickly train all employees when new solutions are implemented;
- metal and perception limitations of the staff, also related to security culture;
- formal limitations related to the introduction of new solutions which may violate passenger privacy, such as the use of body scanners;
- spatial limitations which may reduce the application of some equipment or the potential for increasing the SCA staff;
- pressure from the society and passengers themselves who might object to some types of control or its being too rigorous.

The solutions proposed below, under the simulation experiments, take into account such limitations. Therefore, no extreme solutions were studied, which are little probable due to the presence of said limitations. When the limitation concerned depends highly on the local situation, appropriate discussion is given.

3.2.2 Increased risk situation

The above ways of influencing the airport security system give a strong representation of the strive to maximize the terminal passenger capacity. However, there are situations when this aspect is set aside. This is particularly in case of the elevated risk of terrorist attack. As commonly known, operation of proper services enable identification of the states of increased risk. In such cases, the airport management will not hesitate to implement measures aimed at increasing safety levels which might, even quite significantly, reduce the terminal's capacity.

Such measures employed in case of increased risk situations include:

- imposing an obligation to perform a certain number (given in percentage) of manual checks of passengers and baggage;
- giving additional training aimed mainly on raising the SSOs' awareness and thus motivating them to be more alert and meticulous in their work, and therefore making checks even in case of the slightest doubt as to baggage contents or passenger intentions;
- temporary deployment of additional equipment or controls which are not used at a given airport on daily basis, for example explosive detection dogs (EDD) or explosive trace detection (ETD);
- using higher sensitivity of WTMD gates to allow detection of metallic items with a smaller weight at the passenger's body;
- increased staffing of security control areas, and managing human resources in such a manner that the most competent employees be delegated to the most critical jobs;
- extending the list of prohibited objects and substances;
- limiting access to the terminal;
- initial security checks at the terminal entry.

It is worth mentioning that these measures are taken in case of exceptional situations, when intelligence agencies obtain information of plans to commit an act of unlawful interference at a particular airport. In this case, exceptional precautions adequate to the threat are implemented. This type of activity is temporary and stops after some time. Furthermore, such actions should be taken quickly which excludes a number of solutions listed in the previous section, as they require lengthy procedures.

3.3 Analysing the possibilities of influencing the effectiveness of airport security screening

This section analyses the effects of implementing some of the measures mentioned in section 3.2.1. These are in succession: shortening training intervals, partial or complete replacement of equipment, greater emphasis on the system condition monitoring.

3.3.1 Greater emphasis on training and staff awareness

As commonly known, the effects of human factor on safety-critical systems is of utmost importance. One of the most effective decisions of a system manager is therefore laying more emphasis on staff training and raising their security awareness. This section analyses the effect of increased spending on training on the effectiveness of security systems in an airport. Such concept is apparently very reasonable, since the SSOs are highly committed and play an important role in all three subsystems of an airport security screening system. On the other hand, it is difficult to implement as it requires expenditures and time.

Adopting the strategy of greater spending on staff training can take up the form of shortened comprehensive training intervals. Training, as a standard, is given every 3 years which results in a situation that the average time from the last comprehensive training is 18 months. In the simulation experiment described below (scenario S_1) it

was assumed that the training intervals were reduced to 6 months, which means that the mean time, and therefore the value of the *Comprehensive training* variable (for all three systems) is 3 months.

Shortening the training intervals has also positive effects on the number of type A errors made by the SSOs. An operator with up to date knowledge on the rules and principles of the job performed works more confidently, which is also visible in the results of his or her work. Measurements using the software available in TIP system were performed for quantitative assessment of the parameter changes. For the measurements, several employees were picked who were referred for additional training due to the failure to meet the requirement of at least 80% detected TIP images. The training was given in March 2016, and type A error data from February 2016 (prior to the training) and from April 2016 (after training) were used for comparison. The studies performed showed that immediately after comprehensive training of operators, the rate of correct detection of TIP images had increased from 7 to 16 percent. This corresponds to a decrease of type A errors form 5 to 12 percentage points. These results are slightly overstated in relation to average values (used in experiments), since the measurements were made for the employees making excessive number of errors. In case of more competent staff, this improvement can be less noticeable. It was therefore assumed that a comprehensive training results in a decreased number of type A errors on average by 3 percentage points for hand baggage screening operators, and on average 8 percentage points for those screening the checked baggage. Comparing that to the data given in Table 2, it means that, in further calculations, it was assumed that all employees after comprehensive training make on average 12% of type A errors.

The results of evaluation of the passenger and baggage screening system in the scenario S_1 are given in Table 4.

Table 4. Evaluation of the passenger and baggage screening system in the scenario S_1

System	Defuzzified rating	Linguistic rating
Passenger screening	3.24	> *medium*
Hand baggage screening	2.51	*low / medium*
Checked baggage screening	2.72	*low / medium*
Total	2.98	*medium*

As can be seen, the actions involving reduced training cycles do not give satisfactory improvement of the rating of an airport security screening system - the grade is 2.98 vs. 2.95 for a standard training system. It is basically understandable, as already for the initial parameters the ratings of staff in all three subsystems are at the level *very high* (defuzzified grade 5.25) and there is not much room for improvement any longer.

At the same time, organising comprehensive training in semi-annual intervals involves additional cost. If the training is performed individually, they include the cost of the services of special security trainers, license for using special software (Tutor, OTS and the like), the cost of putting a trainee off work etc. An alternative solution is to use the services of special training centres. It can be estimated that for a facility of the size as that of Katowice International Airport, the strategy of training given every

6 months would involve the cost of €200 thousand per annum (around 200 staff times €500 per training, two cycles per annum).

3.3.2 Equipment change

Given in Table 2, the specifications of the equipment used at Katowice Airport indicate that it is not very advanced. Such negative intuitive grades are proven in the evaluation made with the use of FASAS system. They vary between *low* and *medium*.

Having found the training system change ineffective, the quite obvious solution for increased effectiveness of screening seems to be the replacement of equipment for more technically advanced one. The effects of the decision to replace half of the X-ray equipment with more advanced devices type ATiX (in hand baggage screening areas) and Smiths Detection 10080 EDX-2is (in checked baggage screening systems) will be analysed. Their technological advantage is the possibility of detecting explosives. The software installed in that equipment, in combination with a larger number of generators emitting X-ray beams, enables automatic content verification of luggage being scanned, indicating suspicious-looking points for further analysis to the operator. Let Scenario S_{2a} denote replacing half of the equipment. A more robust approach to upgrading the equipment to be investigated is the replacement of all X-ray equipment with more advanced devices type ATiX and Smiths Detection 10080 EDX-2ia. This will be marked as Scenario S_{2b}. Spreading the process of equipment replacement in time is a standard approach due to financial possibilities.

A fragment of input data that has been changed in relation to the reference variant is shown in Table 5.

Table 5. Input data for the equipment upgrade decision (Scenarios S_{2a} and S_{2b})

Parameter	Passenger screening	Hand baggage screening	Checked baggage screening
Age [yrs]	-	0	0
Number of TIPs	-	6000	1000
TIP frequency	-	2.8 %	2.8 %
Number of lines	-	4	2
Detectability	-	10	10

The simulation experiments carried out indicate a noticeable improvement in the assessments of those systems which had been provided with new equipment, and also the overall rating of the entire passenger and baggage screening system in an airport. The results are listed in Table 6.

Table 6. Evaluation of the passenger and baggage screening system in the scenarios S_{2a} i S_{2b}.

System	Scenario S_{2a}		Scenario S_{2b}	
	Defuzzified rating	Linguistic rating	Defuzzified rating	Linguistic rating
Passenger screening	3.16	> *medium*	3.16	> *medium*
Hand baggage screening	2.9	< *medium*	3.67	*medium*/*high*
Checked baggage screening	3.68	*medium*/*high*	4.0	*high*

Total	3.25	> *medium*	3.75	*medium/high*

As it can be noted, the effect of an upgrade activity is considerable. This is particularly true for the replacement of all equipment. However, attention should be drawn to quite a considerable cost of such project. For example, for an airport of the size as that in Katowice, having 9 hand baggage and 2 checked baggage screening areas, the replacement of half of the equipment would involve the cost of around €700 thousand. The replacement of the entire equipment would of course mean the cost to double.

3.3.3 Combined activity - equipment replacement and changing the training system

The results of the experiment discussed in Section 3.3.1 indicate that shortening training intervals for employees working on low standard equipment does not give the desired outcome. Let us discuss Scenario S_3 involving this solution to be implemented as the second stage of the upgrade, after upgrading the equipment. It is therefore assumed that in Scenario S_{2b}, we change the value of parameter *Comprehensive training* to 3 months and *Type A errors* to 12%. Table 7 presents the experiment results.

Table 7. Evaluation of the passenger and baggage screening system in the scenario S_3

System	Defuzzified rating	Linguistic rating
Passenger screening	3.24	> *medium*
Hand baggage screening	4.0	*high*
Checked baggage screening	4.0	*high*
Total	4.0	*high*

In this case, further improvement of grades to *high* is noticeable. It is worth mentioning here that this does not prevent the possibility to improve the effects of security screening system management, as the changes in equipment did not affect the passenger screening system at all. There is further potential for growth in it.

3.3.4 Emphasis on the diagnostics of personnel status

Among the possible upgrade actions listed in Section 3.2.1 let us discuss an important aspect of the security screening system which is continuous supervision and diagnosing the level of training of personnel. While the role of the ongoing diagnostics of a facility condition is very important, when analysing reliability of anthropotechnic systems, it seems that it is slightly underestimated in diagnosing the personnel status.

The task of diagnosing personnel status in a security screening system is performed in many ways. One of them include the use of TIP system. Under the experiment showing the importance of this form of diagnosing the screening system condition, the effects of resignation from using that system were analysed (Scenario S_4). This is practically reasonable, since when there is low passenger traffic, or in little used staff passages, so called open tests can be applied which involve evaluation by an SSO of a set of several pieces of luggage, with only some of them containing prohibited items. Such actions enable an objective employee assessment with minimum cost and use of the existing equipment.

In the study, it was assumed that the X-ray equipment in hand baggage screening areas is entirely of ATiX type, while in the checked baggage areas, Smiths Detection

10080 EDX-2is devices are used. In relation to WTMD, high technology standard was also assumed, involving the provision of a large number of prohibited items detection zones, supporting the operator work by selecting passengers for additional manual checks or by precisely indicating the location of a prohibited item hidden at the passenger body. At the same time, in the experimental conditions corresponding to Scenario S_3, it is assumed that the X-ray equipment does not have TIP system, and thus it is impossible to assess the work of an SSO. The lack of TIP requires the C type checks to be performed. The assumed frequency of such checks will be 10%. Table 8 presents the results of Scenario S_4.

Table 8. Evaluation of the passenger and baggage screening system in the scenario S_4

System	Defuzzified rating	Linguistic rating
Passenger screening	3.24	> *medium*
Hand baggage screening	3.5	*medium/high*
Checked baggage screening	3.5	*medium/high*
Total	3.66	*medium/high*

As can be seen, resignation from using TIP system results in lowering the grades to somewhere between *medium* and *high*. The extent of the reduction can be even greater since an SSO who is aware of not being evaluated may work carelessly, and take a very light-hearted approach by investigating minor doubtful issue less carefully or not at all. The above issues will be subject of further studies.

In contrast to the resignation from the TIP system, let us consider how the effectiveness of the screening system will change if more stringent standards are established, for example that an SSO is to make no more than 10% of type A errors (Scenario S_5). Such organisational solution is feasible. It requires simply referring for additional training those employees who, during ongoing diagnostics of their work (with TIP system), were found to have exceeded the established standard. When no improvement is made through additional training, the person concerned should be moved away from work at the security control area and given other tasks to perform. The simulation experiment proves that imposing so high requirements does not result in further improvement in the effectiveness of the screening system. Reducing the type A error rates to 12% proves to be sufficient to achieve the best assessment of a worker. It is impossible to completely eliminate the errors in recognising images of prohibited items, and moreover, the parameter discussed is not the only, but still very important, factor describing the quality of screening.

The last scenario (S_6) of actions taken in the normal terrorist threat conditions to be considered is the influence on the alertness (suspicion) of the SSOs in relation to the persons and baggage being checked. This factor is critical for the percentage of people and luggage checked manually by the SSO if in doubt about the behaviour of passengers or contents of the luggage. In the study (Skorupski and Uchroński, 2015a) it is referred to as the B type checks. In short, this involves performing the checks even if the WTMD gate does not indicate presence of metallic objects, and no prohibited items are found in the image of scanned baggage, but the SSO subconsciously and intuitively feels that such a check is necessary.

Simulation experiment for Scenario S_6 was performed by modifying the input data for the Scenario S_3 in such a manner that we increased the number of B type checks

from 9% (as observed and measured in real work conditions at Katowice Airport) to 15%.

The results of the experiment for the Scenario S_6 show that this relatively long little increase of this parameter results in an overall effectiveness grade of 4.41, which corresponds to somewhere between the *high* and *very high* rating. The result is so much interesting that it means a relatively high increase achieved by 'soft' actions involving influencing the SSO psychology. A completely different issue is to what degree we can act that way.

3.4 Analysing the possibilities of acting in an increased risk situation

The increased terrorist risk situation poses great challenges to airport management and the personnel executing the decisions in practice. Even though such situation has to be included in the operational action plans beforehand, the stress related to the risk (also to one's health and life) and the uncertainty about the dynamics of events makes it difficult to take and implement decisions. It is therefore even more advisable to apply quantitative methods to support them.

This section investigates the effects of some actions described in Section 3.2 on the general effectiveness of passenger and baggage screening in an airport.

3.4.1 Increasing the awareness and alertness of SSOs

As a reference point let as assume the Scenario S_0 corresponding to a situation without upgrade activities. Its parameters are listed in Table 2 and evaluation is given in Table 3. Let us discuss the Scenario S_7 to study the effects of increasing the awareness and alertness of SSOs because of declaring the state of increased threat. In this model, this will translate into the change of the value of parameters *Attitude* and *Checks B*. The changes do not result from any detailed decision, but the declaration of the state if increased risk should cause a higher alertness and a more restrictive attitude of SSOs to their duties (the value of the parameter *Attitude* was assumed to increase from *average* to *restrictive*). Due to this fact, even little doubts will result in meticulous luggage check (the parameter *Checks B* was assumed to increase from 9% to 15%). The results of evaluation of screening system in the Scenario S_7 are given in Table 9.

Table 9. Evaluation of the passenger and baggage screening system in the scenario S_7

System	Defuzzified rating	Linguistic rating
Passenger screening	3.24	> *medium*
Hand baggage screening	3.11	> *medium*
Checked baggage screening	2.72	*low / medium*
Total	3.29	*medium/high*

As can be seen, the increase of the final rating of the security screening system is achieved, but it is highly possible that this increase may be considered insufficient.

3.4.2 Introduction of obligatory manual checks

Let us now consider the Scenario S_8 which investigates the effects of introducing an obligatory manual check of a predefined number of passengers and hand baggage

in increased terrorist risk situation. Therefore, the system performance will be modelled for the parameters changed according to Table 10.

Table 10. Input data while introducing the obligatory checks (Scenario S_8)

Parameter	Passenger screening	Hand baggage screening	Checked baggage screening
Attitude	3 (restrictive)	3 (restrictive)	3 (restrictive)
Additional checks	20 %	-	-
Checks B	-	15 %	-
Checks C	-	30 %	-

Compared to the reference variant, the number of additional personal checks using WTMD was increased. This requirement is usually present in average risk situation, mainly to increase the detection rate of prohibited items made of materials not detected by WTMD (non-metallic). In increased risk situation, we assumed an increase of the number of such checks to 20%. Regarding the C type checks of hand baggage we assumed the requirement to check 30% of the baggage. The other two parameters (*Attitude* and *Checks B*) take the values as in the Scenario S_7. The results of evaluation of screening system in the Scenario S_8 are given in Table 11.

Table 11. Evaluation of the passenger and baggage screening system in the scenario S_8

System	Defuzzified rating	Linguistic rating
Passenger screening	4.0	*high*
Hand baggage screening	4.24	*> high*
Checked baggage screening	2.72	*low / medium*
Total	4.0	*high*

As can be seen, introducing simple organisational decisions, which do not generate additional cost to the system, results in considerable increase in the effectiveness of detection of prohibited items in the entire system.

Clearly noticeable is a lower grade for the checked baggage screening, where the only effect of declaring the emergency state is increasing the restrictive attitudes of the SSOs. However, as discussed in Section 3.3.1, influencing the SSOs does not bring the expected results when working on low-class equipment. Should the equipment be upgrades as per Scenario S_{2a} (replacing half of the equipment), the rating achieved for the checked baggage screening is 3.68, and 4.29 for the entire system. Improving the equipment class as per Scenario S_{2b} (replacing all the equipment) enables an increase in the checked baggage screening rating to 4.0, which means the increase to 4.41 for the entire security screening system.

3.4.3 Increasing WTMD sensitivity

A relatively simple measure with a positive effect on the effectiveness of passenger screening is increasing the sensitivity of WTMD gates. In normal conditions they are calibrated to detect a standard test sample. In this section, we will study the Scenario S_9 to check the quantitative effect of increasing gate sensitivity on the assessment of the security screening system. According to (Skorupski and Uchroński, 2017) the WTMD sensitivity is expressed as the minimum weight of a manganese brass (M-

Mn) sample which is detected by the device. In the Scenario S_9, we will assume the change in relation to the Scenario S_8, in which the value of parameter *Sensitivity* will equal 120 g. According to the results published (Skorupski and Uchroński, 2016a), such gate sensitivity causes that about 15% of passengers activates it, which increases the number of manual check, and thus the effectiveness of passenger screening. Table 12 presents simulation results for the Scenario S_9.

Table 12. Evaluation of the passenger and baggage screening system in the scenario S_9

System	Defuzzified rating	Linguistic rating
Passenger screening	5.02	*very high*
Hand baggage screening	4.24	*> high*
Checked baggage screening	2.72	*low / medium*
Total	4.28	*high/very high*

Increasing the WTMD sensitivity results in a *very high* rating of the passenger screening system, which in turn makes it possible to achieve the overall rating of the security screening system of much above the *high* grade.

3.5 Changes proposed to the security screening system at Katowice International Airport

Taking into account the analyses presented in Sections 3.1-3.4, and the relevant cost analysis, several variants can be proposed for such activities aimed at improving the effectiveness of the security screening system performance.

The grades for an average terrorist risk level are *medium* which can be considered satisfactory, particularly in the context of compliance with all provisions of international law. That could make us abandon the upgrade activities. However, the analyses performed for the increased risk situation indicate the lack of tools to quickly influence the screening level in the checked baggage system, and there are limited possibilities of acting on the security level of the entire system. In such situation, care should be taken to adjust the performance of the weakest link so that, when the state of increased risk is declared, it does not impede effective actions. It is worth mentioning that in average conditions, the lowest rating (2.30) is given to the hand baggage screening system. However, it is not the hand baggage to focus on, since there is a great potential for improvement in an increased risk situation.

Therefore, we propose the following sequence of measures.

1. Introduction of a part of the changes described in the Scenario S_2. Bearing in mind the resultant cost, we propose to apply the Scenario S_{2b}, but only in relation to the checked baggage screening system. By the application of said solution, we will increase the rating of the security screening system assessment in average terrorist risk conditions to the level 3.25 (above the *medium* grade).
2. In increased risk situation, by changing the attitude and alertness of the SSOs, an automatic increase of the final rating of the system to the level 3.48 will be achieved (grade between *medium* and *high*).

3. Introduction of the changes described by the Scenario S_8 (obligatory manual checks) in the increased risk situation. This allows to achieve the effectiveness of security screening level of 4.41 (grade between *high* and *very high*).
4. Should the effectiveness level achieved still be considered low, then increasing the sensitivity of the WTMD equipment can be taken into account (Scenario S_9), which results in the security screening rating of 5.24 (the maximum grade at the level *very high*).

4 Summary and conclusions

In many areas of activity the priority of security is declared as the governing rule. Beyond all doubt, these areas include transport, particularly the air transport. Surprisingly, however, introducing innovations intended to increase security levels is often delayed in those areas and forced mainly by effective legislative procedures and enforcement methods. In our opinion, one of the major causes of that is the lack of tools providing an objective and quantitative assessment of the effects implementation of a given solution.

The method developed, together with the FASAS computer tool enables quantitative assessments of the effects of various decisions related to airport management on the effectiveness of an airport security screening system. Simulation experiments performed highlight the importance of the quantitative assessment in the management of complex anthropotechnic systems. It is this quantitative approach based on fuzzy methods that has enabled determination of the proper sequence of upgrade measures in an airport passenger and baggage security screening system, based on the example of Katowice International Airport. It was discovered that, for the personnel training to bring a positive effect, the equipment needed an upgrade first. Of course, the equipment replacement alone contributes to the improved system effectiveness. A reverse approach, which is more intuitive proves to be less effective. Possible effects are delayed and, if the upgrade process is interrupted, they are not visible at all.

Analysis for the situation of increased risk of terrorist attack showed significant interactions between individual subsystems (passenger, hand and checked baggage screening), and the need for taking upgrade measures in advance. It also made it possible to show the location of the measures which, in the case in question, should be the checked baggage screening system.

An important observation from the study carried out is the importance of personnel diagnostics in anthropotechnic systems. While monitoring of technical equipment condition is quite common, the ongoing diagnostics of the human factor in those systems is rare. Perhaps, it is because there are no proper methods and tools to do so. An example of such a tool in an airport security screening is the TIP system. It is not always possible to directly use similar solution in other areas, however, such attempts should be made and the role of diagnostics in management process should be increased, which is proven by the results of analyses made using FASAS system.

As part of future works, our fuzzy reasoning system should be extended to include the rules applicable to the situation after implementation of Standard 3 (European Commission, 2015). This issue applies to two types of devices (described in the paper): walk-through metal detection equipment (WTMD) and X-ray equipment for

checked baggage screening. The current EU regulations do not provide Standard 3 for WTMD. Standard 3 for checked baggage screening is based on the introduction of Computer Tomography X-ray (CTX) equipment. Although Standard 3 has already been implemented at some airports, it officially enters into force in 2020.

The preliminary analysis of the challenges of moving from Standard 2 to Standard 3 indicates that the adopted approach based on fuzzy logic will be adequate to solve the problem. This will require the inclusion of new types of devices in the *Checked baggage* part of the model, especially in the *Device's assessment* and *Control organization option* linguistic variable, since the quality of solutions in Standard 3 devices will have a greater impact on the variable on the assessment of effectiveness of the entire checked baggage screening system. Likewise, in the *Passenger screening* part of the model it will be necessary to make changes within the *WTMD's evaluation* linguistic variable. Relatively small changes will be required in the *Hand baggage* part of the model. It will also be necessary to supplement the knowledge base by including the rules resulting from the expected increase in the role of the areas covered by Standard 3 in the final evaluation of the system effectiveness expressed by the *Screening system evaluation* linguistic variable.

An important aspect of activities in airport security screening system is the passenger capacity issue. This subject is not covered in this study. Further works, including multi-criteria analyses, are required taking into account the overall security and capacity maximisation. In general, activities in average risk situation should focus on increasing security levels without compromising the capacity. Regrettably, for most of the solutions possible, this involves great cost and is time-consuming, while in increased risk conditions, the capacity issue is set aside. If this is the case, very simple and effective actions are possible, but definitely reducing the capacity. This may be inconvenient for the passengers and airport management, but essential for security reasons.

To conclude, we believe that simulation experiments using the method developed indicate the importance of quantitative methods for evaluating the effectiveness of airport security control systems on the process of implementation of innovative solutions. The lack of such methods makes it difficult to provide reasoning for their implementation. A commonly observed attitude is that if ones activity complies with the standard and regulatory requirements, a possible innovation is expensive and its implementation does not affect the financial result of the organisation, there is not much sense in introducing it. A hypothetical quality improvement in the quality of one's activity (in this case the security level) is difficult to prove. However, the quantitative methods, similar to that presented herein, make it possible to not only demonstrate positive effects of the innovation planned, but also to compare the results from various possible innovative activities what is critical for sound management.

The proposed method is closely related to the concept of Smart Security (IATA, 2017). This concept assumes the use of latest technological developments based on, among other things, artificial intelligence, networking of information between key elements of the overall security control system, and wider adoption of risk-based passenger screening. Examples of such solutions may be EDS devices or body scanners which automatically, with the use of automated target recognition algorithms assess a controlled person or luggage, and then send accurate information to SSO. Computer tool FASAS is an example implementation of an expert system that uses fuzzy infer-

ence technique. Such systems may become an important part of the Smart Security solutions.

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