A fuzzy reasoning system for evaluating the efficiency of cabin baggage screening at airports

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ABSTRACT
The growing threat of unlawful interference and terrorist acts has led to widespread implementation of screening systems for checking people and baggage at airports. Introducing limits regarding objects permitted to be transported and screening procedures themselves have decreased the comfort of travelling and reduced the capacity of terminals. It is therefore important to examine the efficiency of screening, whether carried out under regular circumstances or in a situation where threat level is high. The purpose of this study is to develop an effective method and calculation tool making it possible to quickly and exactly determine the effectiveness of cabin baggage screening, depending on the equipment available, the choice of screening staff, and the organisational solutions applied. What is more, the human factor is of great significance as far as cabin baggage screening is concerned. It introduces a certain amount of subjectivity, imprecision, and incompleteness of description. Due to this, fuzzy reasoning solutions have been employed. The results indicate that it is possible for the efficiency of cabin baggage screening to vary significantly at various screening checkpoints (SC), even within one airport. It is also demonstrated that it is possible to actually manage the level of screening efficiency, also in a situation where the risk of an attack is greater than usual. One should avoid taking global decisions and, instead, focus on assessing screening at particular SCs and take steps on the basis of the results of such an assessment. Results obtained with the use of a computer tool under the name of COBAFAS demonstrate that it is then possible to improve the efficiency of screening without hindering the capacity of the airport at the same time.

1. Introduction

Cabin baggage (also referred to as hand baggage) screening is one of the basic and most important elements of civil aviation protection against unlawful interference (ICAO, 2010). Whether or not prohibited articles and dangerous articles which could be used for a terrorist attack on board of an aircraft are detected depends on the thoroughness of such screening. In this context, the security of passengers travelling by air depends on the skills of security screening operators (SSO) called simply screeners, their psycho-physical ability, and the level of their training. To ensure that their work remains as effective as possible, SSO undergo continuous training and testing organised by competent authorities who sometimes even simulate threats.

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1.1. Hand baggage screening process

Security screening process is described in detail in European Union regulations and in domestic legal regulations which define certain minimum standards guaranteeing sufficient protection of passengers (European Commission, 2010a). While screening baggage, the security screening operators (SSO) have certain tools for making their work more effective at their disposal. According to the provisions of the law currently in force, hand baggage security screening may be carried out:

- using a roentgen device for scanning baggage,
- by means of manual control,
- using an explosives detection system (EDS),
- using dogs for detecting explosives,
- using devices for detecting trace amounts of explosives (ETD).

In practice, cabin baggage security screening usually comprises two stages:

- screening the interior of baggage using an X-ray device,
- manual inspection – resorted to whenever SSO has doubts as to the contents of the baggage and applied randomly to a certain percentage of bags defined by the law – if the X-ray device is not equipped with a Threat Image Projection system (TIP).

If the screener is not able to determine whether or not a given piece of cabin baggage contains prohibited articles, such baggage is rejected or screening is repeated until it is concluded that security requirements have been met. The list of prohibited articles is quite extensive and by no means exhaustive. In practical terms, this means that SSO has the right to refuse a passenger to transport in his/her bag articles or substances which SSO believes could be used for committing an act of unlawful interference. As far as security screening is concerned, two situations with substantial impact on the safety of aviation operations are possible and we take those into account in this study.

The first situation is when a passenger, oblivious of the regulations in force, attempts to transport statutorily forbidden articles in his or her cabin baggage. If this is the case, articles forbidden to be transported in cabin baggage (provided that they are not forbidden to be transported in checked baggage) can be (MoTCaME, 2012):

- placed in the hold baggage during check-in,
- marked by the aviation carrier as hold baggage and sent to the baggage hold during security screening,
- stored at the airport for a fee in a room especially meant for the purpose, to be received at a later date,
- after the removal thereof from cabin baggage, placed in a special container and destroyed at the expense of the aviation carrier or the airport operator.

The other situation, much less common, constitutes a serious threat to all who are near the security checkpoint – this is when a dangerous article such as a weapon or explosive material is detected. SSO has to act decisively and smoothly remove the threat. A very important part of steps to be taken in such a situation is familiarity with procedures and systematic practice – this makes it possible for all security screening operators to cooperate efficiently in the face of danger. An important part of the entire process is played by the TIP system installed in X-ray devices – 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.

During cabin baggage screening, particular attention should be paid to manual inspection, consisting in searching through the entire contents of baggage in order to make sure that it contains no prohibited articles. It should be performed whenever SSO has doubts as to the contents of baggage. Rule of thumb is that all doubts are decided not in favour of the passenger. If an image of an article which SSO is not able to recognise appears in the image of the screened piece of baggage, SSO has the right to and is obliged to carry out a thorough manual inspection of such piece of baggage. This is not always convenient for the passenger, especially for passengers with low awareness of security, but it is necessary and very important in view of ensuring the security of civil aviation. In this study, we will discuss both manual inspection performed as a result of the above-indicated sequence of events and manual inspection performed at random when the law requires so.

In practice, there have been many instances of people trying to hide articles which could be used for committing an act of unlawful interference in especially prepared concealed compartments of cabin baggage. Consequently, the screening of cabin baggage is one of the most important elements of airport security system. The safety of passengers and the overall evaluation of the security of a given airport depend on its efficiency. In our study, we present a fuzzy model and a fuzzy reasoning system making it possible to assess the efficiency of cabin baggage screening in quantitative terms.

The implementation of an efficient method for assessing the effectiveness of baggage screening performed by the screeners into the daily work will allow 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 other personnel, equipment, modifications of the devices’ settings. 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 performed screening tasks, 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.

1.2. Overview of state of research

Analysis of literature on the organisation and assessment of airport security management systems indicates that there are several important areas of such research. These include:

- capacity of screening systems,
- the technical aspect of baggage scanning process,
- the possibility of proper image interpretation,
- scope of screening activities,
- subjectively understood passenger comfort.

In the course of research, very significant emphasis is put on investigating the issue of security screening systems capacity. Important works on the subject include (Butler and Poole, 2002; Leone and Liu, 2005). Van Boekhold et al. (2014) presented a microscale model, making it possible to estimate waiting time depending on screening procedures used. Passengers who try to “negotiate” the mode in which the screening is to take place are particularly problematic. Passengers’ individual properties are very important during screening but also during other stages of passenger service at the airport, e.g. the boarding process (Tang et al., 2012). Kirschenbaum (2013) demonstrated that such passengers have the greatest impact on delays concerning the screening process and, at the same time, the greatest share of the ever-increasing costs of maintaining security at an airport. The problem of security cost was also researched by Oum and Fu (2007). Sewell et al. (2013), on the other hand, proposed an interesting approach, presenting a model in the form of a non-linear integer programming in which the issue of capacity was taken into account as a limitation. Wu and Mengersen (2013) proposed analysing screening systems in terms of both capacity and efficiency. Zografos and Madas (2006) go even further, proposing the concept of total airport performance analysis. The approach of Lee and Jacobson (2011) is similar but all those studies focus on capacity without exactly defining the manner in which the efficiency of screening is to be determined. We take up this challenge in our study and push research further, dealing with the latter criterion, with efficiency. The method we propose provides tools for effectively determining the efficiency of cabin baggage screening systems.

In literature on the subject, technical matters related to devices for scanning baggage are often analysed. An interesting introduction to the screening technology can be found in a study authored by Wells and Bradley (2012). Similar aspects of EDS systems were analysed by Singh and Singh (2003). Another type of devices used for cabin baggage screening are devices for detecting trace amounts of explosives (Sekhar et al., 2011). We do not take such devices into account in our study – they are in use in the USA but are not commonly employed in Europe. An extensive overview of the available methods of explosives detection can be found in (Caygill et al., 2012). In our study (Skorupski and Uchoński, 2015a), we take the following factors into account: the number and frequency of TIP (Threat Image Projection) images displayed, the overall capability of detecting prohibited substances dependent on the technological advancement of the device, the number of X-ray generators and detection lines associated with them, and the age of the X-ray device which could result in its usefulness deteriorating. The TIP system makes it possible to view the work performed by a given SSO and to verify their level of skill in interpreting the image of the scanned baggage (Neiderman and Fobes, 2009). TIP is also a convenient source of information about the efficiency of prohibited article detection in cabin baggage.

The issue of SSO’s capability to properly interpret the image generated by roentgen devices was taken up by Michel et al. (2014). As far as cabin baggage screening is concerned, densely built electronic devices, such as laptops, are particularly problematic. Mendes et al. (2012) conducted an experiment demonstrating that the efficiency of cabin baggage screening is dramatically reduced if a device such as a laptop is left inside a given piece of baggage. Factors such as baggage size, its position, and the mutual shielding of particular articles also have an impact on the possibility of detecting a prohibited article inside baggage (Bolfing et al., 2008). However interesting all those conclusions may be, their significance is lesser than that of the measurements we conducted for purposes of our study, as those took place at an actual security checkpoint during the screening of passengers. This research made it possible for us to move away from the underlying causes of errors made by SSO because we take errors made in the environment of a particular airport subjected to our analysis into account.

Another matter dealt with in the literature on the subject is the scope of screening activity and interference with the contents of the screened passenger’s baggage, sometimes even infringing their privacy. The basic tool for determining the scope of security screening is profiling, i.e. estimating risk which a given passenger poses on the basis of such factors as his/her behaviour, the results of subsequent stages of security screening and flight direction. An interesting method is dynamically assigning a risk level to a passenger (Nikolaev et al., 2012; Nie et al., 2012). Attempts are being made at developing alternative solutions which would integrate all types of security screening to which a passenger and his/her baggage is subjected...
(Yildiz et al., 2008). An overview of new methods can be found in (Leone and Liu, 2011). All those methods assume that passenger profiling and dynamic determination of the scope of security screening increase the security and capacity of the system. In our study, we extend such research, taking up the issue of mandatory manual inspections and defining two types of manual cabin baggage inspection, each with a different efficiency level.

Most passengers consider activity related to security screening unpleasant and even a sort of nuisance. This sometimes leads to tension, conflicts, and even aggression between screeners and passengers. In general, the security screening is a component of a function which describes the level of service (Correia et al., 2008) and should be considered as a part of passenger facilitation in a complex environment (Wu et al., 2014). Gkritza et al. (2006) have analysed the impact of the type and intensity of screening activities on subjective passenger comfort. Similar research has been conducted by Alards-Tomalin et al. (2014). Their conclusions indicate that the type of steps taken by SSO has a major impact on subjective perception of the level of security at a given airport. It also partially depends on the level of awareness of threats concerning aviation and on religious and cultural background (Rusiłowicz, 2011). In general, the results of research in this area point to a fact which is quite obvious: the higher the desired efficiency of screening, the lower passenger comfort and satisfaction will be. The results we obtained in the course of our research move the analysis to a higher level. It is so because they make it possible to choose such configuration parameters for the security screening system at the airport as to minimise onerousness of the system felt by passengers, thus increasing their level of satisfaction, while at the same time adhering to a certain level of security. An example of such a choice is presented in Sections 3.3 and 3.4 in which we discuss a similar problem but in a situation of increased risk of a terrorist attack which could result in further interference with passenger baggage.

Analysing literature regarding cabin baggage screening indicates that there is no method of comprehensively assessing the efficiency of the screening system. By “comprehensive” we mean a solution which would take both technological considerations (the roentgen device for scanning the contents of baggage) and the human factor. Manataki and Zografos (2009) suggest that existing models and tools for airport terminal analysis and performance assessment are too specific or too aggregate. In our study, the human factor is taken into account in two aspects. This is done by means of, on the one hand, considering errors made by SSO with regard to interpreting the contents of scanned baggage and, on the other hand, taking the human factor in the course of manual hand baggage inspection into account. We have concluded that research regarding the matter at hand lacks solutions of the knowledge-based system type which would make it possible to eliminate the human factor from the current decision-making process while at the same time making use of expert knowledge and experience. Our study is an attempt at bridging that gap.

1.3. Concept of the study

The main research objective of this study is to find an answer to the question of what hand baggage screening efficiency is and, consequently, what the level of safety of flights is. Answering this question is not easy because the human factor plays a very important part in many aspects of hand baggage screening system. What is more, input data are mostly subjective, uncertain, and not specific. This applies particularly to manual inspection but not only to it, as baggage screening with the use of X-ray devices is also based to a considerable extent on the subjective opinion of the image observed by SSO.

Taking the significant number of sources of information, the necessity to sum them up, as well as their subjective character and lack of specificity, and taking the subjective character of the reasoning regarding the efficiency of hand baggage screening, we have decided to resort to the fuzzy logic theory, particularly the fuzzy reasoning theory (Siler and Buckley, 2005).

This study develops our earlier analyses further (Skorupski and Uchoński, 2014, 2015a,b). In the present study, we have created a fuzzy model for evaluating cabin baggage screening, taking the issue of manual hand baggage inspection into account and extending it. It is precisely in this area that all problems in ensuring aviation transport security related to the human factor converge. We have paid particular attention to the number and efficiency of manual inspections carried out for various reasons, considering the psychological aspect of SSO work to a certain extent. We have also examined the possibility of influencing the efficiency of hand baggage screening – this could be of vital significance in the context of national security and combating terrorism.

The structure of the study is as follows. In Section 1, the issue of cabin baggage screening is presented in general terms, an overview of literature on the subject is presented, and the objective of the research is stated. Section 2 contains a discussion of the general structure of the Hand Baggage fuzzy model, including all input and output variables and the fuzzy reasoning rules used. Because one of the input variables in this model is at the same an output variable in the Manual Inspection local fuzzy model, Section 2 also contains a description of the latter model. An important passage regarding the validation of the model thus created can be found in Section 2.10. Section 3 contains a presentation of selected experiments carried out using a computer tool under the name of COBAFAS (Caryy-On Baggage Fuzzy ASsessment). In Section 3.1, the manual screening at four security checkpoints (SC) at the Katowice-Pyrzowice airport is assessed. Section 3.2 presents the results of an assessment of a hand baggage screening system which, in addition to considering manual inspection, also takes the equipment used and the training and skills of SSOs into account. Section 3.3, in turn, deals with the possibility of choosing system parameters and the consequences of this, i.e. an increase of the system’s efficiency. The following types of activity have been taken into account: introduction of mandatory inspections, replacement of the X-ray device, changing SSOs, additional training, and influence on the awareness of security in air transport which in turn results in changing the approach of SSOs to the work they perform. Section 3.4 contains the results of analyses regarding the possibility of influencing the efficiency of
security screening by means of declaring a state of high risk of an act of unlawful interference. Section 4 contains a summary and final conclusions.

2. Fuzzy model for assessing hand baggage screening system

In practice, in the course of their activity, staff managing the organisation of security screening at airports often have to take decision under uncertain circumstances which is mostly caused by the impossibility to describe the phenomena and processes taking place in quantitative terms. In a situation like that, one usually bases their actions on simple and obvious qualitative relations such as: large quantity of manually checked baggage means high efficiency of detection of prohibited articles while at the same time lowering the terminal’s capacity. However, we are not able to precisely define neither “large quantity of baggage” nor “high efficiency of screening.” It is also often not possible to determine whether or not results thus obtained are sufficient to justify the reduced passenger comfort or reduced capacity, sometimes even losses sustained by aviation carriers or passengers, which are associated with them. In many cases, the problem with taking the right decision becomes even more serious due to the presence of a large number of vaguely defined input variables which could have an impact on the output. This is also the case with the issue being considered here, i.e. hand baggage screening.

The above-indicated factors and considerations suggest that one should look for solutions in an area of knowledge related to taking decisions under uncertain circumstances. It is under such circumstances that we resort to the experience of specialists, creating a relevant knowledge base. We try to shape final decision according to the collective knowledge of a group of specialists in the field of analysis (Skorupski, 2014). The development of such a knowledge base is a long-term process, therefore creating computerised knowledge-based systems making it possible to solve decision-making issues automatically on the basis of the already existing database under slightly different external circumstances, with slightly differing limitations, etc. is reasonable. Our study is an attempt at creating such a system employing fuzzy reasoning methodology.

### 2.1. Fuzzy inference systems

The internal relationships in the cabin screening system belong to a category of issues impossible to be objectively assessed in quantity. However, there is a possibility to describe the relationships in a subjective and approximate way. Those statements were the basis for using the fuzzy inference systems for solving problems which arose in this work (Siler and Buckley, 2005; Tay and Lim, 2008a, 2008b).

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

For the input of the fuzzification block we give unfuzzy values $X$ 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 $\tilde{X}$ 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 $y$. 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.

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

### 2.2. General structure of the Hand Baggage fuzzy model

Hand baggage screening has two aspects. The first one of them is screening baggage with X-rays devices 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 (Fig. 2) is concerned, three input variables correspond to those two aspects. Two of them – Device evaluation ($y_d$) and Type A Errors ($X_{ea}$) – are related to the X-ray scanning of cabin baggage. Equipment used for such scanning at different security checkpoints (SC) may differ considerably in terms of materials it is capable of detecting, its sensitivity, its precision, the quality of image on the display of the operator, etc. 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. 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.

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. On the other hand, the quality 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 SC 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. Particular input variables and the way in which they are used in practice are described in Sections 2.3, 2.4, 2.6–2.8.

The model presented is a fuzzy hierarchical structure, as outputs from one reasoning system lead to and become inputs to other fuzzy reasoning systems. For example: variable \( (y_p) \) is an output from the Employee Evaluation fuzzy reasoning system and, at the same time, an input to the Manual Inspection fuzzy reasoning system. Similarly, variable \( (y_m) \) is an output from the Manual Inspection fuzzy reasoning system and, at the same time, an input to the Hand Baggage fuzzy reasoning system.

2.3. The Device evaluation input variable

Let us first consider the Device evaluation linguistic variable. As was already mentioned above, X-ray devices for screening baggage which are available on the market and used at airports differ in terms of their technological advancement and functional features. Due to this, the efficiency of baggage screening effected using different devices varies. 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. The Device evaluation output value, defined by the four parameters indicated above, is subjective and not exact. When all this is taken into account, the conclusion is that the Device evaluation variable needs to be defined using methods assuming presence of uncertain data. In the course of our research, we have created an appropriate fuzzy reasoning system, described in more detail in (Skorupski and Uchoński, 2015a). Its application yielded results for every X-ray device – an assessment in linguistic form expressed as one of the five possible values (very high, high, average, low, very low). Particular values of the Device evaluation linguistic variable correspond to fuzzy sets whose membership functions are presented in Fig. 3.

In numerical examples presented in subsequent sections of our study, numerical evaluation of particular devices obtained from the model described in Skorupski and Uchoński (2015a) will be used for evaluating the efficiency of cabin baggage screening.

2.4. The Type A Errors input variable

Research and measurements carried out at the Katowice-Pyrzowice International Airport (International Civil Aviation Organisation Code: EPKT) from January to April 2014 made it possible to conclude that SSOs make the following types of errors (Skorupski and Uchoński, 2014):
They fail to indicate (fail to notice) the virtual prohibited article interposed on the image of the scanned baggage. We called this “type A error”. It is worrying situation. If SSO failed to notice a virtual prohibited article, it may be assumed that he/she could also fail to notice a real prohibited article with the same likelihood. A large number of errors of this type would mean that the efficiency of the entire security system of a given airport is to rated low, as the main objective for which baggage is screened in the first place, i.e. detecting prohibited articles, is not achieved.

They designate baggage which contains neither actual nor virtual prohibited articles as dangerous. We called this “type B error”. A situation like that can be interpreted in two ways. We may assume that the screener had (having analysed the image seen on the display of the X-ray device) reasonable doubts and suspicions as to the contents of a given baggage, i.e. the operator was alert which is doubtlessly a positive characteristic. However, it is also possible that the operator designated a considerable number of bags as dangerous in order to receive a positive evaluation, doing so without thinking, automatically, and out of habit.

The first type of error forms the basis for defining the Type A Errors input linguistic variable. The point of screening carried out by humans with the use of X-ray devices is the ability to recognise prohibited articles inside baggage. The Type A Errors variable is a measure of this ability and will therefore be considered important in fuzzy reasoning rules.

The membership functions of the Type A Errors linguistic variable have been defined on the basis of measurements we mentioned above. For each SSO the personal data and device ID have been recorded as well as the number of pieces of luggage inspected during a shift, number of displayed TIP images, number of correctly interpreted images, number of undetected images (type A errors) and number of false alarms (type B errors). A part of summarised results is presented in Table 1.

The value which we used as the basis for determining the membership function of the Type A Errors variable is the share of unrecognised TIP, expressed as a percentile value, described using the following formula:

$$x_{\text{et}} = \frac{N_m}{N_{\text{TIP}}} \times 100\%$$

where:

- $N_m$ – number of A-type errors (number of missed TIPs),
- $N_{\text{TIP}}$ – number of displayed TIP images.

On the basis of our measurements, we assumed particular values of the said variable in line with Fig. 4.

Trapezoidal shapes were assumed for the membership functions. For example for 17–21% error value all experts agreed that they may be qualified as average value of the linguistic variable Type A errors. Therefore their level of membership in this set was assumed as equal to 1. For error values from 14% to 17% and from 21% to 24% the experts did not agree and some included them in the low or high values accordingly. Therefore the membership level of these values in the average fuzzy set are lower than 1. At the same time, they also belong to the low and high sets to a certain degree. Additionally, when establishing the criteria and division thresholds also the international regulations, which specify, among others, the maximum error level above which the SSO should be removed from the post and receive additional training, were taken into consideration.

2.5. Overall structure of the Manual Inspection fuzzy model

The efficiency of cabin baggage manual inspection depends on two factors. On the one hand, it depends on the skills and involvement of SSO in it and, on the other hand, on the frequency with which such inspections are carried out. If manual inspections are frequent (i.e. a large portion of baggage is subjected to inspection) and thorough (by highly skilled SSO), then the likelihood of a forbidden article being carried on board of an aircraft is low, i.e. the efficiency of manual inspection is high. Its efficiency is lower if the percentage of baggage inspected is low or if the inspection is carried out by an inexperienced SSO or by an SSO who disregards their duty.
The foregoing observations became the basis for developing the structure of a local Manual Inspection fuzzy model whose output is at the same an input to the Hand Baggage fuzzy model (Fig. 2). Its inputs are three linguistic variables. The first one of them is Employee Evaluation, describing the skills and involvement (attitude towards work) of security screening operators. The other two are Number of type B manual inspections and Number of type C manual inspections, describing the percentile share of baggage subjected to manual inspection. Two different variables are used because of the different reasons for which an SSO carries out a manual inspection and, consequently, the differing efficiency of inspection. Type B manual inspections are performed in the following situations:

1. An inspection carried out after the following sequence of events:
   - SSO notices a shape they find alarming in the X-ray image of the screened baggage.
   - SSO presses the button of the TIP system in order to ascertain whether or not this is an image displayed by that system (this stage is absent at SC equipped with X-ray devices without the TIP system).
   - A negative response from the TIP system follows, meaning that no virtual threat image is projected (not applicable to SC equipped with a X-ray device without the TIP system).
   - SSO undertakes manual inspection in order to ascertain the source of the alarming shape observed inside baggage.
2. Inspection carried out after being informed by a passenger that they have in their cabin baggage articles which may be forbidden.
3. Inspection carried out as a result of observing the behaviour of a given passenger. Factors which make such an inspection probable: particular anxiety on the part of the passenger, the passenger making suspicious gestures while preparing their cabin baggage for inspection, the passenger failing to comply with instruction concerning order, etc.
4. Cabin baggage being filled with objects making proper interpretation of its contents on the basis of image created by the X-ray device impossible.

It must be noticed that the case described in item 1 will be recorded by the TIP system as a type B error. As there are also other cases when a type B inspection is performed (described above in items 2 to 4) the number of B type errors is assumed as the lower limit for B type inspection number. This may be described using the following formula:

\[ x_{eq} = \frac{N_f}{N_b} \cdot 100\% \]  

(2)

where:
- \( N_f \) – number of B type errors (number of false alarms),
- \( N_b \) – number of inspected bags.

In our model, we assume that manual inspection of type B is carried out with maximum thoroughness possible, limited only by the skills and knowledge of a given SSO (described using the Employee Evaluation variable). This happens because there are realistic reasons to believe that the luggage contains prohibited items.

Type C manual inspections are performed in the following situations:

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### Table 1
Results of measurements carried out in order to define membership functions of the Type A Errors input variable.

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of bags ( N_b )</th>
<th>Number of TIP ( N_{TIP} )</th>
<th>Type A errors ( N_m )</th>
<th>% of type A errors ( x_{eq} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>9–11.01.2014</td>
<td>16,682</td>
<td>141</td>
<td>31</td>
<td>21.99</td>
</tr>
<tr>
<td>15–17.01.2014</td>
<td>15,055</td>
<td>257</td>
<td>54</td>
<td>21.01</td>
</tr>
<tr>
<td>22–24.01.2014</td>
<td>15,196</td>
<td>381</td>
<td>68</td>
<td>17.85</td>
</tr>
<tr>
<td>3–5.02.2014</td>
<td>16,051</td>
<td>255</td>
<td>48</td>
<td>18.82</td>
</tr>
<tr>
<td>10–12.02.2014</td>
<td>16,449</td>
<td>245</td>
<td>57</td>
<td>23.27</td>
</tr>
<tr>
<td>14–16.02.2014</td>
<td>17,923</td>
<td>175</td>
<td>34</td>
<td>19.43</td>
</tr>
<tr>
<td>20–22.02.2014</td>
<td>15,524</td>
<td>258</td>
<td>56</td>
<td>21.71</td>
</tr>
<tr>
<td>25–27.02.2014</td>
<td>14,473</td>
<td>342</td>
<td>70</td>
<td>20.47</td>
</tr>
</tbody>
</table>

---

**Fig. 4.** The form of membership function of the Type A Errors linguistic variable.
– the security checkpoint is equipped with a X-ray device without the TIP system,
– SSO sees no alarming shapes which could suggest that a given piece of baggage may contain prohibited articles in the image of the piece of baggage being scanned,
– SSO has no suspicions, e.g. suspicions regarding the behaviour of a passenger or information obtained from the passenger,
– SSO nevertheless decides to carry out a manual inspection in view of the formal requirement to inspect a certain percentage share of all baggage imposed by the law (European Commission, 2010b).

A manual inspection carried out under such circumstances should be as thorough as it is in the previously described situation. However, it is obvious that it is likely to be less thorough. SSO, seeing nothing suspicious in the X-ray image of a given piece of baggage, will briefly inspect its contents, unlike in a situation where they are looking for a specific suspicious article. Consequently, type C manual inspections will be assigned lesser importance than type B manual inspections in the Manual Inspection local model because their importance in effectively eliminating prohibited articles is lower.

To sum up the considerations it might be said that type B inspections are used when the SSO has reasons to believe the luggage contains prohibited items. Type C inspections occur when the SSO does not have such suspicions, however he/she performs the inspection due to obligations resulting from regulations. In practice, for example during measurements, we used the following algorithm to determine whether the given inspection belonged to type B or type C.

1. In equipment using the TIP system:
   – if there was no imposed duty to perform a minimum number of manual inspections – all inspections belong to type B,
   – if the TIP system recorded a type B error – the inspection which followed belonged to type B,
   – if the passenger informed (asked) the SSO, whether the given item may be transported – the manual inspection belonged to type B,
   – in case of passengers whose behaviour was suspicious, or in case of overfilling the luggage – the inspection belonged to type B; these cases are more difficult to evaluate, therefore, during the measurements we used the help of an experienced SSO who helped us interpret the behaviour of the observed person,
   – in other cases – inspection type C.
2. In case of devices not equipped with the TIP system the qualification of the inspection to type B or C is a more difficult task and requires the help of an experienced SSO who interprets the situation. It must be note that the use of older types of equipment, without the TIP system, is rare, especially in relation to hand luggage inspection.

2.6. The Employee Evaluation input variable

Determining the efficiency of SSO at detecting prohibited articles is difficult and such an evaluation cannot be expressed in the form of a formal description. This variable is therefore defined on the basis of a fuzzy reasoning system. Factors having an impact on the Employee Evaluation ($y_p$) variable taken into account in the said system are:

– experience, defined on the basis of the number of months for which a given individual has worked as an SSO,
– amount of time since the last comprehensive training, defined on the basis of the number of months since the last comprehensive training,
– amount of time since the last current training, depending on the number of months since the last current training,
– attitude to work performed, expressed as a linguistic variable with three possible values (mild, average, restrictive) and characterising the overall attitude of a given SSO to inspections they carry out.

All those values are input variables for a local fuzzy model whose output is the Employee Evaluation linguistic variable. Details pertaining to that model can be found in (Skorupski and Uchroński, 2015b). The Employee Evaluation linguistic variable describes the potential of a given employee. We assume that the value of this variable can be expressed at five levels whose membership functions are presented in Fig. 5.

We used a membership function typical for such situation (trapezoidal shaped for limit values and triangular shaped for other values). The employed fuzzy inference mechanism allows for transforming the set of possible input values, first into linguistic values and then, using the defuzzification process, into a set of real numbers $[0, 6]$.

2.7. The Number of type B manual inspections input variable

As we already mentioned in Section 2.5, type B manual inspections take place when the SSO has a reasonable suspicion that there may be prohibited articles in the cabin baggage of a given passenger. SSO then commences with thoroughly inspecting such baggage in order to remove a specific prohibited article.

The lower limit of the Number of type B inspections variable is the number of type B errors, as defined in Section 2.5. On the basis of previous research, we assume in our present study that the average number of type B errors (and type B inspections associated with them) is around 3.5% for an inexperienced SSO and around 0.6% for a highly qualified SSO. The values come from measurements specified in Section 2.4 and were established in accordance with formula (2) in Section 2.5.
The upper limit of the Number of type B manual inspections is the capacity of the security screening system. In the event of an extremely high risk of a terrorist attack, it is even possible for all cabin baggage to be inspected manually. Due to this, for purposes of further analysis, in Section 3 we will consider the Number of type B manual inspections variable a decision variable with the use of which airport authorities could influence the level of efficiency of the airport’s security system. Obviously, this is different from deciding that a certain percent of all baggage is to be subjected to inspection (this is the case with type C manual inspections, described in Section 2.8.). Influencing the level of efficiency of cabin baggage screening is to take place in view of the level of threat with an act of unlawful interference defined by aviation authorities.

In a situation where there is no heightened risk of a terrorist attack and in a situation where that risk is greater than usual alike the actual number of type B manual inspections, which we will use as an input variable for the Manual Inspection fuzzy model, is to be defined experimentally (by measurement). In the course of our work, we have made the relevant measurements at the Katowice-Pyrzowice airport in August 2014 with the threat of an act of unlawful interference was at its standard level. The summary of those measurements is presented in Table 2.

As one can see, the percentile share of type B inspections averages at 9%. The results of measurements conducted constituted the basis for creating a membership function for the Number of type B manual inspections variable. We have assumed that the variable can be expressed at one of the four levels. The membership functions of fuzzy sets corresponding to particular levels are presented in Fig. 6.

Under regular circumstances, it is to be assumed that the value of the Number of type B manual inspections will be at the average level. This is seen in measurements presented in Table 2. It will be at the high level in a situation where the risk of a terrorist attack is greater. If this is the case, one should expect longer queues in front of security checkpoints, especially when passenger traffic is heavier. In spite of this, the airport can function on a fairly regular basis. The very high level of this variable corresponds to an extreme situation and applies only in a particularly high emergency. In such a situation, one should expect that the functioning of the airport will be significantly disrupted, with possible delays regarding flights or flight cancellation. Unfortunately, we were not able to measure the frequency of type B inspections in a situation where the risk of an unlawful interference is greater and, consequently, we have made use of expert opinions of specialist from the field of airport security in defining those functions.

2.8. The Number of type C manual inspections input variable

Type C manual security inspections are carried out if according to the provisions of European Union law (European Commission, 2010b), carrying out manual inspections with regard to a certain pre-defined share of all cabin baggage is mandatory, choosing pieces of baggage to be inspected at random. So type C manual inspections are carried out rather due to an obligation and not due to the SSO believing that the baggage of a given passenger may contain a prohibited article. Such inspections may turn out to be carried out with much less diligence than type B inspections. The attitude of the SSO is also important – they tend to work with greater thoroughness if they believe the inspection they are carrying out is reasonable.

In our further analyses we have assumed that the efficiency of type C manual inspections is lower than the efficiency of type B inspections. There is no set frequency of type C inspections, particularly in a situation where the risk of an act of unlawful interference is greater than usual. Due to this, the Type C Manual Inspection membership functions we propose are only inspired by the said regulation. The form of fuzzy sets corresponding to particular values of the said variable is presented in Fig. 7. If the value of the variable is none then it is a fuzzy singleton corresponding to a situation where cabin baggage screening takes place using a device equipped with the TIP system. In a situation like that, type C inspection is not usually performed.

Increasing the number of type C manual inspections decreases the likelihood of a forbidden article concealed in cabin baggage being brought onto a plane. However, manual inspection of cabin baggage is a time-consuming process and, consequently, increasing the number of such inspections reduced the capacity of SC, just like in the case of type B inspections. The Number of type C manual inspections is at its high or very high level only when there is an increased risk of acts of unlawful interference (terrorist attacks).
2.9. The Manual Inspection output variable

The output variable of the Manual Inspection fuzzy reasoning model may be expressed at five values whose membership functions are presented in Fig. 8.

The fuzzy reasoning system is supplemented with fuzzy reasoning rules. Their source is a group of specialists – experienced SSOs and persons managing the organisation of baggage security screening. As it has already been noted the impact of individual input variables on the output variables cannot be described numerically in a precise way. Therefore, there are used fuzzy rules, which are much easier to formulate for experts. At the same time, they are much more reliable. The fuzzy reasoning system enables to determine relationships between the non-fuzzy input variables and non-fuzzy output evaluations using only the expertise expressed imprecisely, by the fuzzy rules. 100 such rules have been defined and some of them are presented in Table 3.

2.10. Validation of the Manual Inspection model

In this section, we present the validation process for the model. To create it, a statistical estimate of the expected quantity of baggage for which it could be claimed with near-certainty that they contain no prohibited articles was used, taking different values of linguistic variables into account. The results of this estimation were compared with the opinions of specialists.

Baggage for which it could be said that it contains no prohibited articles will be called “safe bag.” The first step of validation consisted of estimating the minimum and maximum number of safe pieces of baggage. Calculations were carried out for a batch of 1000 pieces of baggage.

The number of safe pieces of baggage is at its minimum when the number of type B inspections is at its minimum. In order to estimate it we assumed that the minimum number of type B inspections for the batch indicated above is 20 (2%). This is the middle value for the fuzzy set representing the low value of the membership function of the linguistic variable Number of type B manual inspections (Fig. 6). Another factor is the number of type C inspections. When estimating the minimum number of safe pieces of baggage, we assume this value to equal zero. Lastly, as the third element of our estimate we assumed that the number of safe pieces of baggage will be at its minimum when manual inspection is performed by

<table>
<thead>
<tr>
<th>SC</th>
<th>Terminal</th>
<th>% of type B inspections</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC-1</td>
<td>A</td>
<td>8</td>
</tr>
<tr>
<td>SC-2</td>
<td>A</td>
<td>10</td>
</tr>
<tr>
<td>SC-3</td>
<td>B</td>
<td>11</td>
</tr>
<tr>
<td>SC-4</td>
<td>B</td>
<td>7</td>
</tr>
</tbody>
</table>
an SSO for whom the value of the Employee Evaluation linguistic variable is very low. The number of errors made during a manual inspection by SSO was estimated on the basis of survey-based research whose partial results are presented in Table 4. The four experts whose estimations are presented in Table 4, are representative for certain groups of experts (experts 2 and 4 were screeners with a vast experience and broad expertise, while experts 1 and 3 were people in control, responsible for organising the safety control system). The experts were asked to estimate how many errors in manual control were made by employees described by the individual linguistic variables. Errors referred to in this table consist in non-detecting a prohibited object during the manual Type B control. For example, expert 1 estimated that a person whose evaluation is average made 8% errors during the manual control, expert 2 estimated that the person made 5% of the errors, expert 3 – that he or she made 15% of the errors, and expert 4–6% of errors. In reality, 18 experts took part in the evaluation, the values in the “Average” column are the average of all experts’ opinions, not just those presented in the table.

Lastly, for purposes of developing a worst-case scenario, it was assumed that an employee whose skills are rated as very low makes errors 18% of times while carrying out manual inspection. In general, the formula for estimating the number of safe pieces of baggage could be expressed as follows:

\[
y_m = y_p \left( x_B + e_c \cdot \max(0, x_C - x_B) \right)
\]

where:
- \(y_m\) – expected number of safe pieces of baggage,
- \(y_p\) – efficiency of an employee expressing the likelihood of that employee making no mistake during manual inspection if the Employee evaluation is at \(y_p\),
- \(x_B\) – average number of type B inspections if the Number of type B manual inspections is at \(x_B\),
- \(e_c\) – indicator defining the relation between the efficiency of type C inspections to the efficiency of type B inspections; we have, on the basis of a survey-based research, assumed that the value of this indicator is 0.8,
- \(x_C\) – average number of mandatory type C inspections if the Number of type C manual inspections is at \(x_C\).
- \(\max(0, x_C - x_B)\) – the number of type C inspections actually carried out. If the number of type B inspections is greater than the mandatory number of inspections (\(x_C\)) then type C inspections are not performed because the obligation to screen a certain portion of baggage is fulfilled by means of type B inspections. If it is not so, type C inspections are carried out, their number corresponding to the difference between the mandatory number of inspections (\(x_C\)) and the number of inspections actually performed as type B inspections (\(x_B\)).

In summary, in order to establish the minimum number of safe pieces of luggage, we assumed the following values:

- the inspection is performed by a screener with a very low estimation, we assume: \(y_p = 1 - 0.18 = 0.82\) (Table 4, 1st line)
- the Number of Type B Manual Inspections variable is low, which corresponds to the value of \(x_B = 20\) (Fig. 6),
- the Number of Type C Manual Inspections variable is none, which corresponds to the value of \(x_C = 0\) (Fig. 7),
- the ratio of \(e_c\) was assumed as 0.8.

---

**Table 3**

Principles of fuzzy reasoning for the Manual Inspection local model.

<table>
<thead>
<tr>
<th>Rule</th>
<th>Employee evaluation input variable</th>
<th>Number of type B inspections input variable</th>
<th>Number of type C inspections input variable</th>
<th>Manual inspection output variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Very high</td>
<td>Average</td>
<td>None</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>19</td>
<td>Low</td>
<td>Average</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>26</td>
<td>Average</td>
<td>High</td>
<td>Low</td>
<td>Average</td>
</tr>
<tr>
<td>49</td>
<td>Any</td>
<td>Low</td>
<td>Very high</td>
<td>High</td>
</tr>
<tr>
<td>58</td>
<td>High</td>
<td>Very high</td>
<td>Very high</td>
<td>Very high</td>
</tr>
</tbody>
</table>

---

![Fig. 8. Membership functions of the Manual Inspection linguistic output variable.](image-url)
Using the above-indicated indicators and using formula (3), we receive 16.4 as the lower limit of safe bags in a batch containing 1000 bags:

$$\bar{y}_m = \bar{y}_p (\bar{x}_B + \varepsilon_c \cdot \max(0, \bar{x}_C - \bar{x}_B)) = 0.82(20 + 0.8 \cdot \max(0, -20)) = 0.82(20 + 0.8 \cdot 0) = 16.4$$

By similar reasoning, we establish the upper limit of safe pieces of baggage. The following values of parameters are assumed:

- inspection is performed by an SSO rated very high, we assume $\bar{y}_p = 0.97$ (Table 4, last line),
- the Number of type B manual inspections is at very high which corresponds to $\bar{x}_B = 250$ (Fig. 6),
- the Number of type C manual inspections is at very high which corresponds to $\bar{x}_C = 350$ (Fig. 7), which, in turn, means that the estimated number of type C inspections actually performed will be 100.

Using the formula indicated in (3), we obtain as the result the upper limit of the number of safe pieces of baggage in a batch of 1000 pieces of baggage: 320.

Similarly, the estimates of the safe bags number performed for every possible combination of Employee evaluation, Number of type B inspections and Number of type C inspections variables. With the estimate values we suggest a scale (Table 5) based on normal (Gaussian) distribution. Using this scale results in evenly distributed safe bag values in different intervals (the intervals are almost equivalent).

Next, the number of safe bags for particular rules (obtained from the formula (3)) and the values of the Manual Inspection variable was determined and compared with the scale presented in Table 5. The results of this comparison are presented in Table 6.

In Table 6, we make a validation of results from the fuzzy reasoning model with an estimation based on statistical calculations. It only applies to manual controls, which are performed only in case of some of the bags. Regardless of what type of inspection we have (B or C), the term of an “error” in this case means the same thing: the screener manually searched the baggage, did not see a prohibited object and allowed it to be transported. This is the same error as the Type A error made in the case of a control using X-ray devices. Depending on the type of inspection and the evaluation of the employee, the likelihood of such mistake is different. However, it is generally smaller than in the case of controls performed using X-ray equipment. By specifying the number of manual inspections and the probability of an error, we determine the number of “safe bags”. The bigger it is, the more effective the manual inspection.

Due to spatial limitations of the study, the results for rules 21–44 were omitted. As can be seen in the table presented above, values in the Manual Inspection column (based on rules created by experts) and values in the Rating according to the scale column (based on a statistical estimate) are consistent. There were instances when values based on the statistical estimate were between values defined as part of the scale presented in Table 5 but in every such instance the value based on expert opinions corresponds to the results of calculations. This proves that the model created is valid.

### 2.11. The Hand Baggage output variable

The Hand Baggage output variable of the fuzzy reasoning model depends on three inputs (Fig. 1): Device Evaluation ($y_{d}$), Type A Errors ($x_{eA}$) and the already discussed Manual Inspection ($y_{m}$). Membership functions of those linguistic variables are discussed in Sections 2.3, 2.4, and 2.9, while membership functions of fuzzy sets corresponding to particular values of the Hand Baggage output variable are presented in Fig. 9.

Similarly as in other cases, a subjective five-point scale has been used for the evaluation of output variables of trapezoidal shaped membership functions for limit values and triangular membership functions in case of other values. The fuzzy reasoning is supplemented with fuzzy reasoning rules developed by a group of specialists, who manage the process of baggage security screening. This way it was possible to qualify every combination of input variables to corresponding output linguistic variables, of course with a specified membership level. 75 fuzzy inference rules have been defined and some of them are presented in Table 7.
3. Evaluation of the hand baggage screening process at an airport

In order to make it possible to effectively apply theoretical solutions developed in practice, a computer system under the name of COBAFAS (Carry-On Baggage Fuzzy ASsessment) was created to automatically implement the models prepared.
The software has been built using the SciLab 5.4 environment and the Fuzzy Logic Toolbox 0.4.6 package. Thanks to this tool, it is possible to conduct numerous experiments using such models. Three of such experiments are presented in this section. They involved changing the configuration of the selected security control components and specifying the effectiveness of the hand luggage inspection system. The first experiment was used to evaluate the effects of making the decision on introducing the obligation to perform a set minimum number of manual inspections. The second experiment was used to evaluate the parameters such as replacing the equipment, change of SSO at the inspection station, additional training, changing attitude towards work. The third experiment was used to evaluate the effects of introducing a state of increased unlawful interference threat level.

The tool was developed with a view to facilitate the work of authorities managing the security of an airport, particularly the screening of hand baggage. It makes it possible to evaluate the impact of technical equipment and the composition of SSOs working at the same time on the efficiency of the entire hand baggage screening process. It should be pointed out that the models developed enable to comprehensively evaluate the role which the human factor and the technical factor play in hand baggage inspection.

### 3.1. Example of evaluation of hand baggage manual inspection efficiency at the Katowice-Pyrzowice airport

Evaluation of hand baggage manual inspection efficiency was carried out for four security checkpoints located at Terminal A and Terminal B of the Katowice-Pyrzowice airport. In the basic variant, we assumed that the situation is as it was in August 2014, i.e. we assume that the risk of an act of unlawful intervention is as usual. Consequently, we have assumed that the number of type B manual inspections is consistent with the measurements presented in Table 2 and, at the same time, assumed that type C inspections are not carried out. SSOs are evaluated in line with the results presented in (Skorupski and Uchronski, 2015a). Results of the evaluation of hand baggage manual inspection efficiency for particular security checkpoints, obtained from the COBAFAS system, are presented in Table 8 (variable $y_{op}$ corresponds to an evaluation of SSO group and replaced $y_{p}$ variable in the model).

It is clear from the table above that the evaluation of the efficiency hand baggage manual inspection is satisfactory at all security checkpoints subjected to the research in a situation where the risk of an act of terrorism is standard. This was to be expected and it is as it should be. If inspection is rated as satisfactory it means that all formal requirements have been met without any special and additional measures being taken, ensuring high capacity of the security checkpoint. As can be seen on the basis of Table 8, the evaluation of a group of SSOs varies from average to very high. It should be noted that SSOs with the highest rating worked where the fewest manual inspections were carried out and that SSOs with the lowest rating (average) worked where the greatest number of type B manual inspections were performed. Thanks to this, the overall level of manual inspection was the same in almost every case.

### 3.2. Example assessment of hand baggage screening system at the Katowice-Pyrzowice International Airport

As a second stage of our analysis, we have evaluated the efficiency of the hand baggage screening system at the Katowice-Pyrzowice International Airport. Terminals of this airport are equipped with different X-ray devices for screening baggage. Table 9 presents specification details of those devices, including their evaluation included in (Skorupski and Uchronski, 2015a).

Results of the efficiency of hand baggage screening assessment are presented in Table 10. The number of type A errors for particular groups of SSOs was defined on the basis of measurements which are discussed in greater detail in Section 2.4.

The results obtained demonstrate that there are differences between the levels of efficiency of hand baggage screening at particular security checkpoints.

SC-1 is equipped with a standard X-ray device which is rated low and which is already 10 years old. In spite of the good quality of work performed by SSOs and in spite of them making relatively few type A errors, the final rating of hand baggage screening efficiency at SC-1 is at a level slightly above low.

SC-2 is equipped with a relatively advanced device, with a function for detecting explosives (EDS) – this results in the device being rated very high. However, taking the fact that SSO working at that checkpoint make an average number of type A errors, the final evaluation of hand baggage screening there is average.

SC-3 is also equipped with an old X-ray device, without EDS. What is more, the SSOs working there have made a high number of type A errors which results in the final assessment of hand baggage screening at that point being very low. An analysis of all parameters regarding the functioning of SC-3 indicates that all standards and regulations are observed there. Its very low rating should trigger a response from the authorities managing the functioning of the security screening system. In addition to suggesting what is obvious, i.e. conducting further training and providing SSOs with practice to reduce the number of errors they make, we recommend organisational and technical solutions. Such suggestions are presented in Section 3.3.

SC-4 is rated the highest as far as the efficiency of screening is concerned – its score is high. Such a high score results from the good rating of the X-ray device (very high) (like in the case of SC-2) and the low number of type A errors made.
3.3. Choosing functional parameters for the hand baggage screening system

As was remarked in the introduction to this study, the fuzzy reasoning system in question could be very useful in planning organisational and investment-related activity connected with baggage screening or, on a higher level, to the security system of an airport. It is so because it makes it possible to assess the consequences of activities in the context of improving the detection efficiency of prohibited articles in hand baggage and, consequently, enhancing the safety of air traffic.

One of the fields in which the method could be used is choosing the number of mandatory cabin baggage inspections (type C inspections) to be carried out at a security checkpoint. This is, in truth, a manifold task. To make the right decision, one has to take into account, on the one hand, the expected intensity of air traffic and the capacity of SC when a certain number of manual inspection is carried out and, on the other hand, the expected increase of air traffic safety, expressed as the efficiency with which prohibited articles are detected. While the former criterion is well-defined and relatively easy to determine, the latter is much more difficult to define due to the vagueness and subjectivity associated even with formulating the issue at hand and due to the lack of measurement capabilities and, consequently, the incompleteness of data available. The model developed and the COBAFAS system enhance public security in this respect.

Fig. 10 presents changes of the efficiency of hand baggage screening system depending on the number of type C manual inspections introduced, with all other input variables unchanged. As a result of an evaluation of the efficiency of security screening described in Section 3.2 (Table 10), SC number 3 was chosen as the one ranked the lowest and requiring remedial steps. Even though there is a roentgen device equipped with the TIP system at this checkpoint (i.e. no type C inspections are carried out there), it may be possible to increase the efficiency of that checkpoint by means of introducing this type of inspection.

The results presented (Fig. 10) indicate that the maximum possible level of efficiency is average – this requires introducing an obligation to carry out around 36% of type C manual inspections. This level is achievable in practice but the capacity of the security checkpoint would then be very limited. The exact extent of this limitation would require separate research. Introducing an obligation to carry out type C inspections for 16% of baggage would make it possible to raise the efficiency of SC-3 to low.

As can be seen from the foregoing, simply introducing the obligation to carry out manual inspections results in only a limited increase of efficiency. Table 11 presents the results of analyses performed using the model, ones in which we consider other possible lines of action to be taken, presenting the changes to the relevant input parameters of the model.

It is clear that improving the efficiency of security screening at SC-3 is possible by means of taking relatively simple organisational steps and also by means of making investments in more technologically advanced equipment or training. However, the potential improvement is relatively low if only one measure is implemented: the efficiency of screening rises to low or to a level between low and average. A more significant change would follow only if several solutions were to be implemented concurrently.

### Table 8
Results of manual inspection efficiency evaluation (EPKT, August 2014).

<table>
<thead>
<tr>
<th>SC</th>
<th>Terminal</th>
<th>$y_{DF}$</th>
<th>$x_B$ (%)</th>
<th>$x_C$ (%)</th>
<th>Manual inspection $y_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC-1</td>
<td>A</td>
<td>4.92</td>
<td>8</td>
<td>0</td>
<td>2.0</td>
</tr>
<tr>
<td>SC-2</td>
<td>A</td>
<td>4</td>
<td>10</td>
<td>0</td>
<td>2.0</td>
</tr>
<tr>
<td>SC-3</td>
<td>B</td>
<td>3</td>
<td>11</td>
<td>0</td>
<td>2.0</td>
</tr>
<tr>
<td>SC-4</td>
<td>B</td>
<td>4.46</td>
<td>7</td>
<td>0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### Table 9
X-ray devices for screening hand baggage at EPKT.

<table>
<thead>
<tr>
<th>SC</th>
<th>Terminal</th>
<th>Device</th>
<th>$y_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC-1</td>
<td>A</td>
<td>Heimann 6040i</td>
<td>2.1</td>
</tr>
<tr>
<td>SC-2</td>
<td>A</td>
<td>Heimann 6040aTIX</td>
<td>5.2</td>
</tr>
<tr>
<td>SC-3</td>
<td>B</td>
<td>Heimann 6040i</td>
<td>2.5</td>
</tr>
<tr>
<td>SC-4</td>
<td>B</td>
<td>Heimann 6040aTIX</td>
<td>5.2</td>
</tr>
</tbody>
</table>

### Table 10
Results of the evaluation of hand baggage screening efficiency (EPKT, August 2014).

<table>
<thead>
<tr>
<th>SC</th>
<th>Terminal</th>
<th>$y_d$</th>
<th>$x_B$ (%)</th>
<th>$y_m$</th>
<th>Hand baggage $z_B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC-1</td>
<td>A</td>
<td>2.1</td>
<td>12</td>
<td>2.0</td>
<td>2.1</td>
</tr>
<tr>
<td>SC-2</td>
<td>A</td>
<td>5.2</td>
<td>19</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>SC-3</td>
<td>B</td>
<td>2.5</td>
<td>26</td>
<td>2.0</td>
<td>0.76</td>
</tr>
<tr>
<td>SC-4</td>
<td>B</td>
<td>5.2</td>
<td>13.55</td>
<td>2.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>
We have also analysed the impact of the organisational and technical changes indicated in Table 11 on the efficiency of other security checkpoints. The results are presented in Table 12.

A quantitative evaluation of the results of different decisions indicates that their impact depends on the initial evaluation level of security screening to a considerable extent. In the case of SCs whose base evaluation was low, the most effective solutions are investments into better equipment and training or exchanging SSOs for SSOs more skilled at recognising virtual threat images. As far as SCs with good technological equipment and high initial rating are concerned, the most beneficial solution would be to try and influence the attitude of SSOs towards their work and to make them aware that it is necessary to act on all suspicions, no matter how insignificant those might seem. It is possible to achieve a similar effect by means of declaring a state of heightened risk of an act of unlawful interference.

### 3.4. Analysis of declaring a state of heightened risk of an act of unlawful interference

On the level of a country, various authorities are involved in trying and preventing terrorist attacks. If intelligence services learn that an attack is planned, usually a state of increased readiness is declared, resulting in, among other things, more thorough screening at airports. In the context of this study, that is connected with increased alertness on the part of SSOs who would carry out manual inspection in the case of even the slightest suspicions regarding the contents of a given piece of hand baggage or the behaviour of a passenger. Those would be type B inspections because they are performed due to a reasonable suspicion that a given piece of baggage may contain prohibited articles. The aviation authorities could also declare that the number of mandatory inspections is to be increased.

Using the COBAFAS system, the impact of declaring a state of increased risk on the efficiency with which prohibited articles are detected in hand baggage was determined. It was assumed that, under such circumstances, the security staff would be obliged to inspect 20% of baggage manually (type C inspections), regardless of whether or not the relevant screening devices are equipped with the TIP system. What is more, SSO, being aware that the risk is greater than usual, would inspect baggage more often on their own initiative (type B inspections). Those would be type B inspections because they are performed due to a reasonable suspicion that a given piece of baggage may contain prohibited articles. The aviation authorities could also declare that the number of mandatory inspections is to be increased.

An increase of the number of type B manual inspections which could result from declaring a state of increased risk almost universally results in an increase of the efficiency of hand baggage screening $z_h$ at the SC. In the case of the SC examined, the maximum rating (very high) is achieved with around 18% of type B inspections. In our opinion, no considerable and impossible to counteract drop of the airport’s capacity would result from such a number of type B inspections. This means that declaring that the risk level is greater than usual would, in this case, bring actual positive effects without hindering the functioning of the airport too much.
It is also interesting to compare the number of type B inspections required at a given SC to achieve maximum rating. The results of such a comparison are presented in Table 13. The maximum efficiency rating varies for different SCs and ranges from average to very high. The number of type B inspections needed to achieve the maximum efficiency rating varies. For example, their number does not need to be increased at all for SC-4. This stems from the fact that SSO at that checkpoint make few type A errors, have good equipment at their disposal, and are properly trained. To achieve the highest rating (very high), it is enough, in their case, to impose an obligation to carry out manual inspections for 20% of baggage (type C inspections).

### 4. Summary and conclusions

In our study, we presented fuzzy reasoning models and a computer system (COBAFAS) for implementing them, developed in order to evaluate the efficiency of hand baggage screening at airports. An important innovative feature of the present study is taking both the human factor and the technical factor into account and considering the human factor the more significant one as far as the functioning of airport security is concerned. Due to subjective character of evaluation and due to the impossibility of clearly defining phenomena, an approach based on fuzzy reasoning systems was used. As a result, quantitative ratings of the level of safety were obtained, expressed as the efficiency of the system for detecting prohibited articles in cabin baggage.

Experiment-based research was carried out, using the models developed, and its results indicate that the ratings of particular security checkpoints differ. It was also demonstrated that it is possible to improve the efficiency of SCs with a low rating. This could be done via costly solutions consisting in providing more technologically advanced equipment for the checkpoint or by means of training or by means of organisational activity. An SC located at terminal B of the Katowice-Pyrzowice International Airport served as an example. Until now, research in the relevant field focused on capacity and not on the level of transport security. In general, solutions ensuring high capacity tend to be associated with lower level of prohibited article detection. It was proven that it is actually possible to influence the efficiency of inspection by means of declaring a state of increased risk with an act of unlawful interference. An important aspect of our studies is a quantitative analysis, making it possible to test particular SC on an individual basis. Thanks to this, we are able to achieve maximum

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**Table 12**
The impact of changing working parameters on the efficiency of hand baggage security screening.

<table>
<thead>
<tr>
<th>Action</th>
<th>SC-1</th>
<th>SC-2</th>
<th>SC-3</th>
<th>SC-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>No action (base variant)</td>
<td>2.1</td>
<td>3.0</td>
<td>0.76</td>
<td>4.0</td>
</tr>
<tr>
<td>Introducing mandatory inspections</td>
<td>3.1</td>
<td>4.0</td>
<td>2.0</td>
<td>5.24</td>
</tr>
<tr>
<td>Replacing the roentgen device with Heimann 6040aTIX</td>
<td>4.0</td>
<td>–</td>
<td>2.0</td>
<td>–</td>
</tr>
<tr>
<td>Changing the staff of SC (exchange with SC-4)</td>
<td>–</td>
<td>4.0</td>
<td>2.5</td>
<td>–</td>
</tr>
<tr>
<td>Additional training in recognising threat images</td>
<td>2.1</td>
<td>4.0</td>
<td>2.5</td>
<td>4</td>
</tr>
<tr>
<td>Changing the attitude of employees (improving their alertness)</td>
<td>3.1</td>
<td>5.24</td>
<td>2.0</td>
<td>5.24</td>
</tr>
</tbody>
</table>

**Table 13**
The number of type B manual inspections required to achieve maximum rating for a given SC.

<table>
<thead>
<tr>
<th>Action</th>
<th>SC-1</th>
<th>SC-2</th>
<th>SC-3</th>
<th>SC-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of type B manual inspections (%)</td>
<td>22</td>
<td>18</td>
<td>22</td>
<td>2</td>
</tr>
<tr>
<td>Efficiency of inspection achieved</td>
<td>High</td>
<td>Very high</td>
<td>Average</td>
<td>Very high</td>
</tr>
</tbody>
</table>

**Fig. 11.** The impact of declaring a state of increased risk on the efficiency of hand baggage screening $z_w$. 

It is also interesting to compare the number of type B inspections required at a given SC to achieve maximum rating. The results of such a comparison are presented in Table 13. The maximum efficiency rating varies for different SCs and ranges from average to very high. The number of type B inspections needed to achieve the maximum efficiency rating varies. For example, their number does not need to be increased at all for SC-4. This stems from the fact that SSO at that checkpoint make few type A errors, have good equipment at their disposal, and are properly trained. To achieve the highest rating (very high), it is enough, in their case, to impose an obligation to carry out manual inspections for 20% of baggage (type C inspections).
security standards without at the same time hindering the functioning of the airport too much and reducing the comfort with which passengers travel.

What is more, it was also concluded that the choice of employees performing tasks is of great significance. Thanks to the fuzzy approach used, it was possible to obtain quantitative evaluations which could then be used by airport services to, for example, properly plan the work of SSOs.

References


