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A fuzzy system to support the configuration of baggage screening devices at an airport

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ABSTRACT

An airport is a complex engineering system; it is composed of many elements interconnected with numerous internal relations with a strongly pronounced role of the human factor. One of the specific tasks carried out by the airport managing entity (AME) is to configure the airport security system (ApSS) so that to attain the expected level of confidence in the airport safety and security. This task consists in selection of infrastructure, technical equipment, allocation of personnel and financial means that are necessary to perform all functions of the ApSS. One of the aspects of the configuration of the ApSS is the allocation of available X-ray baggage screening devices searching for items prohibited for transportation. To make this allocation, we need to know how effective these devices are (in terms of detecting prohibited items). This assessment is dependent on several factors which are treated as linguistic variables and are input to fuzzy inference system: the ability to detect explosives, the number of detection lines, the effectiveness of the TIP (Threat Image Projection) system and the age of the machine. Some of these elements are difficult to objective assessment, as they are heavily dependent on the human factor or the information is uncertain or incomplete. So fuzzy ApSS analysis is proposed. The output from the fuzzy inference system is linguistic variable *Device evaluation*. The meaning of this variable is the ability to protect the aircraft against prohibited items. The proposed new method of assessing the airport baggage screening system involves the construction of a hierarchical fuzzy inference system. The usefulness of the method is exemplified for Katowice–Pyrzowice International Airport, for which an assessment of devices has been performed. The results show that not only allocation of specific devices for specific control points is important for the security of passengers. Also important are the locally accepted principles of their work, which so far are not specified by international regulations. This applies for instance to the selection of the number and frequency of TIP images. Experiments show that the proposed approach can be effective as part of an expert system for supporting the airport operator in configuring ApSS.

1. Introduction

Airport is a public use facility used for commercial flights. It is a dedicated area on land, water or other surface, partly or entirely devoted for take-offs, landings and ground or water traffic of aircrafts, with the permanent buildings and facilities, entered into the airports register (Aviation Law, 2002). An airport consists of numerous elements which are linked with various internal relations with a strong impact of the human factor. It is therefore a complicated socio-technical system. Operational availability of an airport may be defined as an exploitation state, where (Kozłowski, Skorupski, & Stelmach, 2008):

– it is possible to continue approach to landing and landing,
– aircraft ground handling is possible including pre take-off handling of an aircraft, passenger service related to accepting passengers on board of an aircraft, as well as disembarking after landing and accepting and receipt of baggage,
– it is possible to execute the departure procedure after finishing the ground handling in accordance with a plan, procedures and air traffic provisions.

The correct operation of an airport requires providing the appropriate level of security by the airport managing entity (AME). One of the aspects involved in providing security is protection against the acts of unlawful interference (ICAO, 2010).

1.1. Literature review

The consequences of admitting the baggage with prohibited content to transport (as a result of misjudgement or carelessness of

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security personnel) can be catastrophic (Pettersen & Bjornskau, 2015; Price & Forrest, 2013). Security of civil aviation can be analysed with the standard risk assessment methods (Tamasi & Demichela, 2011; Wong & Brooks, 2015). However, the probabilities are difficult to assess quantitatively, so these considerations are usually conducted at a high level of generality. In our paper we suggest a different approach. We resign from defining the probabilities to the benefit of assessing the efficiency of screening devices with the use of expert judgements. Among papers that are strictly related to the problems of airport security it is worth to note the works of Gkritza, Niemeier, and Mannering (2006) and Alards-Tomalin et al. (2014), which indicate the need to provide the proper security level at an airport but at the same time minimize the nuisance caused by the security control process to the passengers. The new way of meeting the requirements for security control were suggested by de Lange, Samoilovich, and van der Rhee (2013), where considerable savings were found by using the "virtual queues". However, in the work of Liou, Tang, Yeh, and Tsai (2011) it has been proposed to use dominance-based rough set approach to an airport service survey. The basis for the prepared model is the set of decision-making rules in the "if … then …" form. Similar rules but in the form of fuzzy conditional sentences has been used in this article.

In this work we show that the airport security (protection) system is an element of preventive actions intended for preventing a situation, where the airport will not be able to realise its function. It is therefore, an important area of an effective strategy for keeping the airport system in operation. As there would be no purpose in the attempts of optimisation of the strategy for keeping the technical part of the system in order, if there are unlawful actions from the side of the passengers or terrorists - the airport will not be able to fulfil its functions. In our work we assume that it is not possible to fully evaluate the operational readiness of the system without the prior evaluation of the protection system (airport security system). In (Wells & Bradley, 2012) the relationship between the screening efficiency, and both the human factor and the X-ray equipment were mentioned. However, these two elements were analysed separately. In our paper we extend the analysis by looking at the X-ray devices from the human (operator) perspective. The issue of the security screener's capability to properly interpret the image generated by X-ray devices was taken up by Michel, Mendes, de Ruiter, Koomen, and Schwaninger (2014). In the work of Akgun, Kandakoglu, and Ozok (2010) an interesting model has been presented allowing for multi-criteria evaluation of vulnerability of critical system (such as airports) to a terrorist attack. In (Nie, 2011) a method for baggage risk assessment was presented and sequences of using the particular X-ray scanners were suggested. This work refers to three main areas of research on the issue of improving the efficiency of the baggage security control system: discrete optimisation techniques, simulation methods and cost-effectiveness analyses. In our work we suggest a different approach consisting in considering the human factors in the assessment of screening devices. Our paper suggests an evaluation of an airport security system based on a hierarchical model of fuzzy reasoning. The layers in a hierarchical security system will not always combine as straightforwardly as our intuition would suggest, making the evaluation of a layered security effort difficult (Jackson & LaTourrette, 2015). This results from the fact that the tested system is heavily influenced by the human factor and other elements, which are not subject to unequivocal and precise description. It is impossible to detect the functional relationships between the various factors which influence the effectiveness of the security system and an evaluation of the security level. In such cases it is required to use expert opinions. As we have to deal with expert opinions, it is a known fact that very often they are formulated in a descriptive and an imprecise way. We must therefore view the decision making problem in context of uncertainty related to decision making (Dubois & Prade, 1992). All this locates the decision making problem in an area described by e.g. the theory of fuzzy sets or rough sets (Greco, Matarazzo, & Slowinski, 2001). In (Wu & Mengersen 2013) the necessity to analyse the airport security system in terms of two criteria (capacity and efficiency of control) was suggested. The former can be expressed as numerical values and the latter as linguistic values. The present paper constitutes an attempt to deliver a tool to determine the latter. The issue of making decisions in similar conditions by many decision-makers is presented in (Chen, 2013; Park, Cho, & Kwun, 2011; Skorupski, 2014).

1.2. Design of the paper

This paper focuses on fuzzy reasoning. A similar approach, although related to the evaluation of an aircrew status, was presented in the work by Skorupski and Wiktorowski (2015). This paper is a follow up to the work (Skorupski & Uchroński, 2015a), where the general structure of interaction model in the airport security system is discussed. The extension involves the specification of effectiveness of the whole set of X-ray equipment used, together with their configuration on each security check points. We also present the analysis of equipment age and number of installed TIP images influence on the decision making regarding the possible replacement or change of devices configuration. The analysis of the efficiency of the alternative equipment configuration has been made. The subject of security screening assessment is continued in (Skorupski & Uchroński, 2015b, 2015c) where the efficiency of cabin and hold baggage screening is determined.

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

The basic benefit from using the proposed solution is the ability to obtain a quick and effective answer regarding the use of the given device at a specific baggage control checkpoint, taking into consideration the fact that it is only a tool used by the operator. Alternatively, the proposed expert system may aid the ongoing directing of passenger streams to security checkpoints with specific equipment. The use of the fuzzy inference system in conjunction with access to expert knowledge in the form of a fuzzy rules set allows obtaining a strong practical tool. What is particularly important, most of the input variables of the fuzzy inference system come from measurements, which eliminates the subjectivity of this system component.

The paper presents the basis for building a decision support system which can draw conclusions and make decisions consisting in indicating a solution (screening devices' configuration) with the highest degree of accuracy. This system uses a knowledge base provided by experts who express it in the form of fuzzy rules. Such expert systems are extremely necessary in practice, especially when final evaluations are not known precisely, and there are no known functional relations describing them. An example from the field of aviation security belongs to a class of problems for which there is no formal mathematical model of a problem solving algorithm. Parts of the knowledge, necessary to build the knowledge base for the expert system, are available and expressed precisely (from observations and measurements), especially most input variables. Hence, within the

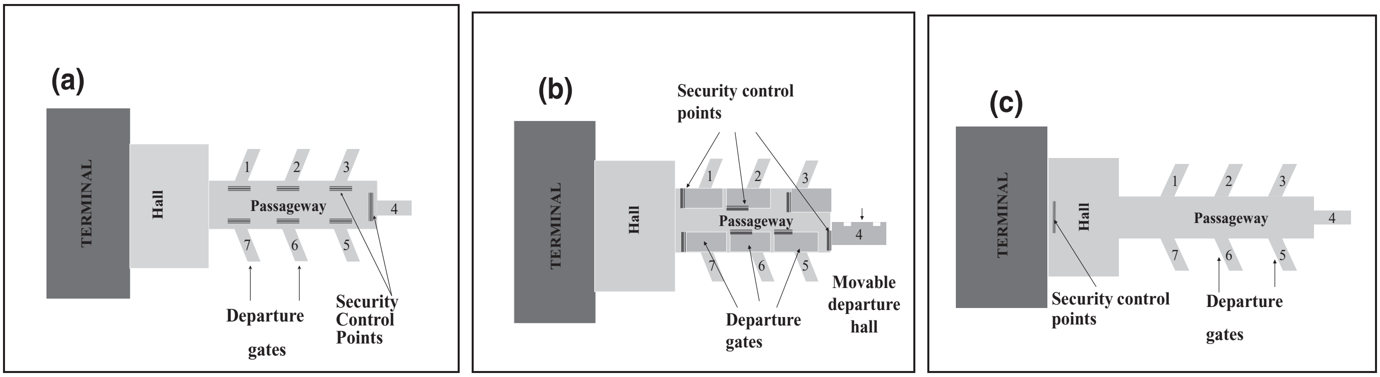

Fig. 1. Security control structures (a - at the departure gate, b - decentralised system, c - centralised system).

proposed model for inference engine resulting evaluations are more reliable. However, some knowledge is uncertain and subjective, especially the conclusions. A computer tool, the Screening Devices Evaluator (SDE), has been built based on the presented theoretical concept, which is a practical implementation of the expert system supporting the management of an airport security system.

The article structure is as follows. In Section 1 the entity and importance of an Airport Security System (ApSS) has been presented in the context of ability to carry out the airport functions. In Section 2 the ApSS structure has been discussed as well as the elements being the part of the system. Section 3 includes short description of the general ApSS model and Section 4 its particularisation and formalisation with the use of fuzzy sets theory. Section 5 contains the main part of the work. Fuzzy model of the X-ray devices for the luggage control has been presented, as well as forms of the linguistic membership functions for the input and output variables, examples of the fuzzy rules for block of inference. This has been the basis for the evaluation of the equipment used in Katowice–Pyrzowice International Airport as well as model validation. Section 6 shows the simulation tests results made with computational tool SDE created in the SciLab environment. The aim of those experiments was to present the possibilities of using of the created approach as an expert system for the decision making support in the scope of choice of configuration and technology for the work of the airport luggage control equipment. The work ends with Section 7 including the summary and final conclusions.

2. Airport security system

An airport security system (ApSS) is used to prevent acts of unlawful interference. This notion is defined in (ICAO, 2010) as an unlawful and purposeful act consisting of:

- using force against a person present on board of the aircraft during its flight, if this act may endanger the aircraft safety,
- destruction of an aircraft or causing its damage that makes the flight impossible or may cause danger to the aircraft's safety,
- placing on board of an aircraft an object, equipment or substance that may be a threat to health or life of passengers or personnel or destroy the aircraft or cause its damage that may prevent its flight or cause danger to the aircraft's safety during flight,
- hijacking of an aircraft with personnel and passengers on board or without them, also with the purpose of using the aircraft as a tool of an air terroristic attack,
- destruction or damage to the airport equipment or onboard equipment, interference of their operation or using force against the personnel operating them, when it causes a significant interference of the air traffic or causes danger to civil aviation safety,
- passing untrue information that causes a threat to people or property in the aviation communication.

A practical method of achieving the goals of the ApSS is to perform a security control of the persons and their baggage before they are boarded on an aircraft. On the other hand it also involves the so called perimeter security i.e. the prevention of unlawful access to the security restricted area or its critical parts (European Commission, 2008).

In reference to the safety control different structures can be observed. They have been described in more detail in (Uchroński, 2011):

- in the departure gate before boarding on the aircraft (lack of departure hall) – Fig. 1a.
- before entering the departure hall (decentralised system) – Fig. 1b.
- before entering the hall leading to the departure gates (centralised system) – Fig. 1c.

International Air Transport Association IATA specified the passenger service level standard in a security control point (SCP). It is recommended that average capacity of one point should be 120 passengers per hour with a maximum waiting time of 7 min (recommended 3 min). One control line should have approx. 130 m^2 area and should be operated by 3–5 employees.

The security control is a complex process that involves numerous devices whose effectiveness and pace of operation has a big impact on the ability of the ApSS to perform its functions (Hainen, Remias, Bullock, & Mannering, 2013). The following devices are used:

- walk through metal detectors (WTMD),
- hand-held metal detectors (HHMD),
- X-ray baggage screening equipment used for detecting explosives and other prohibited items (Wetter, 2013),
- radioactive material detectors,
- explosive trace detectors (ETD).

In reference to peripheral security most commonly used are fences that should inhibit or prevent the access to the airport. In case of forcing the entrance or entering the restricted area in another way, an aid in detecting the intruders may be:

- man or car patrols,
- underground sensoric cable,
- fence sensoric cable,
- CCTV cameras,
- motion detectors,
- radars,
- microwave barriers.

This paper analyses the effectiveness of equipment (X-ray devices) used to detect prohibited items in registered and hand baggage.

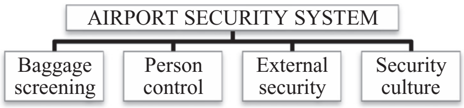

Fig. 2. Diagram of a fuzzy model of main factors influencing the security level at an airport.

3. General idea of the airport security system model

In Section 2 different operation methods and technical means constituting ApSS have been presented. The aim of this work is to propose a method allowing for quantitative evaluation of ApSS efficiency depending on used equipment, personnel qualifications, efficiency of the security management system, procedures etc. Four basic factors which influence the airport security level may be defined. These are: the baggage screening system, the passenger control system, external security and security culture. A general schema of relations between these factors is presented in Fig. 2.

Each of the elements (rectangles) presented in Fig. 2 is a complex structure. The internal relations are highly dependent on the human factor and other factors which are not subject to precise description. As a result, they will be treated as representations of fuzzy hierarchical local models with numerous inputs. Establishing the values of linguistic variables *Baggage Screening, Person Control, External Security* and *Security Culture* requires a further development of the diagram. Due to the limited volume of the paper it is impossible to present the entire diagram structure. In order to illustrate the essence of the method, Section 5 discusses a local model used for the evaluation of devices used for registered and hand baggage screening.

4. Concept for the evaluation of an airport security system

Airport managing entity (AME) is responsible for keeping the airport in operation availability. One of the specific tasks performed by the AME is configuring the airport security system so that the required level of trustworthiness regarding its security is reached (Kirschenbaum, Mariani, Van Gulijk, Rapaport, & Lubasz, 2012). This task requires the selection of infrastructure, technical equipment and personnel allocation (Soukour, Devendeville, Lucet, & Moukrim, 2013) and assigning the financial means required for the implementation of all ApSS functions. Configuring the ApSS in a rational manner requires the knowledge on how the different elements of the complicated structure affect the final security level of an airport (Gerstenfeld & Berger, 2011).

Review of literature indicates that there are no effective methods for the evaluation of airport security. With this in mind, we suggest a mathematical model based on the theory of fuzzy reasoning whose output would be an evaluation of the airport security system as a factor for providing the continuity of operation of an airport. This evaluation will be expressed as linguistic variable value and the method used to obtain it will involve all the required factors related to airport security: screening baggage, control of passengers, perimeter security and security culture. It will also include the impact of the environment in the form of the organisational and operational characteristics. In this work we present the idea of evaluation the entire ApSS, however, we will concentrate on more detailed description of the local model for evaluating of the X-ray equipment used for screening of the checked and hand luggage. The developed model, together with its computerised implementation in the SciLab environment may be treated as an expert system supporting the decision making process for persons who are in practice responsible for selecting infrastructure components, technical equipment and personnel required by the airport security system.

A fuzzy set will denote a set of

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

where μ_A is the membership function of this set.

A linguistic variable is a variable whose values are words or sentences in a natural or artificial language. These words or sentences will be called the linguistic values of a linguistic variable.

Our models will most often assume that the membership functions of linguistic variable values have a trapezoidal shape and reach values *very low* (*vl*), *low* (*l*), *medium* (*m*), *high* (*h*) and *very high* (*vh*). For *very low* value trapezoidal membership function with (*a,b,c,d*) parameters is as follows:

$$\mu_{vl}(x; a, b, c, d) = \begin{cases} 0, & x < a = b \\ 1, & b \le x \le c \\ \dfrac{d-x}{d-c}, & c < x \le d \\ 0, & x > d \end{cases} \tag{2}$$

For values *low, medium* and *high*:

$$\mu_i(x; a, b, c, d) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & a < x \le b \\ 1, & b < x \le c \\ \dfrac{d-x}{d-c}, & c < x \le d \\ 0, & x > d \end{cases} \tag{3}$$

where $i \in \{l, m, h\}$

For *very high* value the function is specified with a formula:

$$\mu_{vh}(x; a, b, c, d) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & a < x \le b \\ 1, & b < x \le c \\ 0, & x > c = d \end{cases} \tag{4}$$

Within the scope of the reasoning process we will use the input value fuzzification block, reasoning block using a number of rules and the defuzzification block. The rule sets will be created using experts' opinions, in particular those presented by persons responsible for organising a security management systems (SeMS) at airports. Such set may contain classic non-fuzzy implications as well as fuzzy implications. In the second case we will use the so called compositional method of reasoning introduced by Zadeh (1973) which uses a generalised "modus ponens" fuzzy reasoning rule. This results in the following reasoning scheme (Kacprzyk, 1986)

$$\begin{aligned} I &: P \Rightarrow Q \\ P &: P' \\ C &: P' \circ (P \Rightarrow Q) \end{aligned} \tag{5}$$

where I denotes implication, P - premise, C - conclusion, while "$\circ$" is a max–min composition whose result for fuzzy relations $A \subset X \times Y$ and $B \subset Y \times Z$ is a fuzzy relation $A \circ B \subset X \times Z$ with a membership function:

$$\mu_{A \circ B}(x, z) = \bigvee_{y \in Y} (\mu_A(x, y) \wedge \mu_B(y, z)),\ \forall x \in X,\ \forall y \in Y \tag{6}$$

We will use implications in the form of fuzzy conditional sentences (rules) i.e.

$$\text{IF } P \text{ THEN } Q \text{ ELSE } S \tag{7}$$

The conditional sentence is equal to a certain fuzzy relation $R \subset X \times Y$; we will use the max–min rule that was selected from the numerous definitions of such fuzzy relations found in the literature

$$R = (P \times Q) + (\sim P \times S) \tag{8}$$

which is expressed in the form of the following membership function

$$\mu_R(x,y) = (\mu_P(x) \wedge \mu_Q(y)) \vee ((1-\mu_P(x)) \wedge \mu_S(y)),\quad \forall x \in X,\ \forall y \in Y \tag{9}$$

If we write down the reasoning scheme (5) in the form of a fuzzy reasoning system we will reach the following form

$$\begin{aligned} &I : IF\ P\ THEN\ Q \\ &\quad P : x\ IS\ P' \\ &\quad C : y\ IS\ Q' \end{aligned} \tag{10}$$

where $P, P' \subset X,\ Q, Q' \subset Y$

The result of reasoning Q' is specified according to the compositional rule of inference as

$$\mu_{Q'}(y) = \bigvee_{x \in X} (\mu_{P'}(x) \wedge \mu_R(x,y)),\ \forall y \in Y \tag{11}$$

where $R \subset X \times Y$ is a fuzzy relation specified by the formulas (8–9). In such cases the membership function of the result has the final form of

$$\mu_{Q'}(y) = \bigvee_{x \in X} (\mu_{P'}(x) \wedge (\mu_P(x) \wedge \mu_Q(y)) \vee (1-\mu_P(x))),\ \forall y \in Y \tag{12}$$

A fuzzy reasoning system implemented in the SciLab package SDE (Screening Devices Evaluator) and applied in Section 5 uses the above inference reasoning method specified in formulas (8–10).

5. A fuzzy model for the evaluation of X-ray baggage screening devices at an airport

5.1. *General structure of the fuzzy model* Device evaluation

Fig. 2 presents a general diagram of interactions in the *Airport Security System* fuzzy model. As mentioned before it is a complex hierarchical structure. One of its elements is the *Baggage screening* local model. It consists of two local sub-models: *Hand baggage* and *Hold baggage*. Each of these is further composed of local models: *Device evaluation, Operator's assessment* (Skorupski & Uchroński, 2015d) and *Security control option*.

The subject of analysis in this section is the *Device evaluation* fuzzy model. Its diagram is presented in Fig. 3. The output of the fuzzy reasoning system (y_d) associated with this fuzzy model is dependent on four input variables: *Detectability* (x_{md}), *TIP evaluation* (y_t), *Number of detection lines* (x_g), *Device age* (x_a). These variables are described below.

5.1.1. Detectability *input variable*

The *Detectability* linguistic variable characterises the technical parameters of the X-ray devices which determine the effectiveness of the entire security control process. This category encompasses the conventional RTG devices and EDS (Explosive Detection System) devices. The latter are more advanced as they are able to detect explosives on their own. In case of conventional RTG devices the effectiveness of security control rests in the most part on the abilities of the Security Operator (SO) usually called screener. EDS devices, apart from the parameters of conventional equipment, also allow:

- detecting explosive materials located in the baggage or other parcels irrespective of their shape, location and position and signalling their presence using an alarm,
- sending an alarm signal also when baggage contains an object that is used to prevent the detection of explosive materials or the contents of the baggage is too dense.

Additionally, in case of an alarm, the EDS device indicates the cause and the location of the item which triggered the alarm within the piece of baggage or parcel. In the recent years automatic systems for forbidden items detection have been developed. Their effectiveness is related strongly to the quality of the method used for image recognition. An interesting example related to baggage screening has been presented in (Maloof & Michalski, 1997).

The values assumed by the *Detectability* linguistic variable are: *very low, low, medium, high* and *very high*. It is assumed that the membership functions of given fuzzy sets will have a trapezoidal shape. To establish them we will use a standard procedure for the evaluation of the device that is performed during every start-up. This calls for using a standard test sample that help verify if the device meets the minimum values related to set requirements (European Commission, 2010):

1. resolution of a single wire,
2. useable penetration,
3. spatial resolution,
4. singular penetration (thin material),
5. singular penetration (dense material),
6. differentiating materials,
7. detection of explosive material and signalling,
8. signalling the detection of an item preventing the detection of explosive materials,
9. signalling if the contents of the baggage or parcel are too dense to control,
10. indicating the location of the item that triggered the alarm.

The end result of the test is a filled record form which specifies the number of requirements being met. For a standard, fully functional RTG device this number is 6 (requirements 1–6) and for an EDS class device - 10 (additional requirements 7–10). Other values are possible for devices which are partially damaged during operation which is not noticed by the technical personnel. Such device will operate at lower effectiveness of detection of prohibited items until another test is performed which usually occurs at the next start-up. The representation of the *Detectability* linguistic variable is shown in Fig. 4.

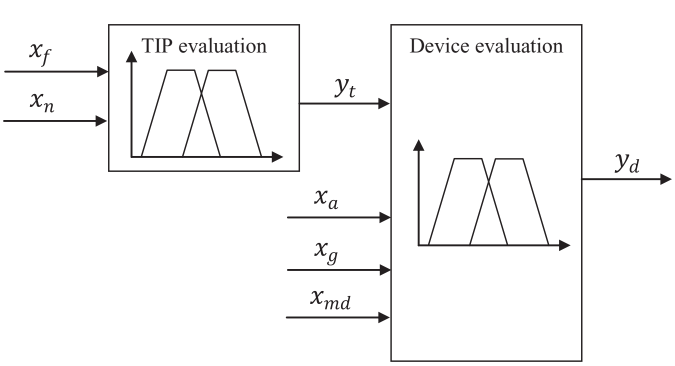

Fig. 3. Diagram of the *Device evaluation* fuzzy model.

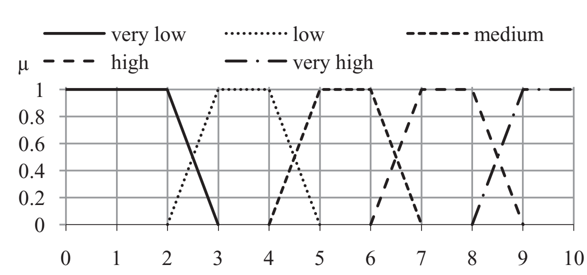

Fig. 4. Membership functions of the *Detectability* linguistic variable values.

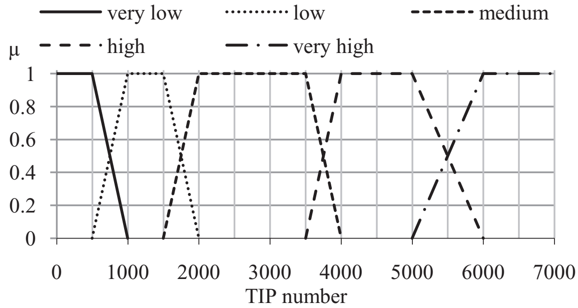

Fig. 5. Membership functions of the *TIP Number* linguistic variable.

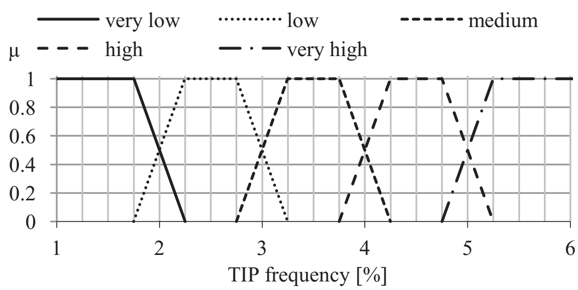

Fig. 6. Membership functions of the *TIP Frequency* linguistic variable.

5.1.2. TIP Evaluation *local model*

The second input variable in the *Device evaluation* model is the variable specifying the TIP (Threat Image Projection) system effectiveness. In fact this variable is an output of another local model with *TIP number* (x_n) and *TIP frequency* (x_f) being the fuzzy input variables. The TIP system used for projection of virtual threat images is one of the tools which allow for constant improvement of the operator's skill. Its idea is to project a virtual prohibited item on the image of the piece of baggage being screened. The task of the operator is to detect the virtual object in the image and confirm this fact by pressing the button on the RTG device's console. This increases the awareness of SO personnel who are forced to search for prohibited items in the baggage image more closely than is the case when the TIP system is not used. The effectiveness of the TIP system depends on two parameters:

– number of dedicated TIP images (number of TIPs), which must be numerous enough to prevent memorising their configuration, shape, type etc.; the greater the number of virtual images available in the device the more effective it is at screening baggage,
– frequency at which the TIP images are projected on the real screen image (TIP frequency); in this case, too high frequency of the TIP images in relation to the number of baggage items being screened may cause automatic indications of suspect baggage without an in-depth analysis of the reviewed baggage image.

TIP frequency is established based on individual practice at every airport and this value is restricted. The *TIP number* and *TIP frequency* input variables assumed for this model are shown in Figs. 5 and 6.

The output variable of the local fuzzy reasoning model for *TIP Evaluation* is presented in Fig. 7. This variable is at the same time the input

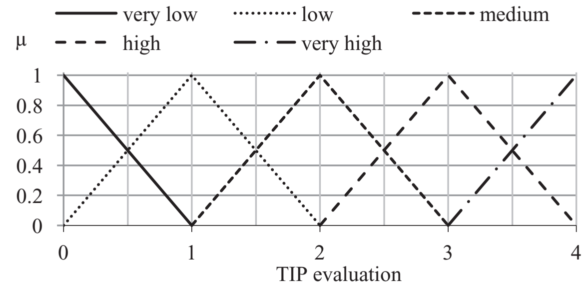

Fig. 7. Membership functions of the *TIP Evaluation* linguistic variable.

variable for the *Device evaluation* model. The example assumed fuzzy reasoning rules that has been specified basing on the expert knowledge and they are shown in Table 1.

As previously mentioned for establishing of the output value of the linguistic variable *TIP Evaluation*, the compositional inference rule max–min type described in formulas (8–10) will be used. It should be noticed that in this case predecessor of P implication is actually a product of two linguistic variables *TIP Number* and *TIP Frequency*. We will mark those linguistic variables N_{TIP} and F_{TIP} accordingly. So the inference scheme for this local model is as follows

$$\begin{aligned} I &: IF\ N_{TIP}\ \ AND\ F_{TIP}\ THEN\ Q \\ P &: x_n\ IS\ N'_{TIP}\ AND\ x_f\ IS\ F'_{TIP} \\ &\quad C : y\ IS\ Q' \end{aligned} \tag{13}$$

where $N_{TIP}, N'_{TIP} \subset X_N,\ F_{TIP}, F'_{TIP} \subset X_F, Q, Q' \subset Y$

Inference result Q' is described in accordance with the compositional inference rule as

$$\mu_{Q'}(y) = \bigvee_{(x_n,x_f)\in X_N\times X_F} \left(\mu_{N'_{TIP}}(x_n) \wedge \mu_{F'_{TIP}}(x_f) \wedge \mu_R(x_n, x_f, y)\right),\ \forall y \in Y \tag{14}$$

where $R \subset X_N \times X_F \times Y$ is a fuzzy relation described as follows:

$$R = (N_{TIP} \times F_{TIP} \times Q) + (\sim (N_{TIP} \times F_{TIP}) \times S) \tag{15}$$

Membership function of a fuzzy relation R may be expressed in the following form

$$\begin{aligned} \mu_R(x_n, x_f, y) &= \left(\mu_{N_{TIP}}(x_n) \wedge \mu_{F_{TIP}}(x_f) \wedge \mu_Q(y)\right) \\ &\quad \vee \left(\left(1 - \mu_{N_{TIP}}(x_n) \wedge \mu_{F_{TIP}}(x_f)\right) \wedge \mu_S(y)\right), \\ \forall (x_n, x_f) &\in X_N \times X_F,\ \forall y \in Y \end{aligned} \tag{16}$$

Since in the inference scheme (8) used for establishing the value of linguistic variable *TIP Evaluation* set S does not exist, the membership function has the final form

$$\begin{aligned} \mu_{Q'}(y) = \bigvee_{(x_n,x_f)\in X_N\times X_F} &\left(\mu_{N'_{TIP}}(x_n) \wedge \mu_{F'_{TIP}}(x_f) \wedge \left(\mu_{N_{TIP}}(x_n) \wedge \mu_{F_{TIP}}(x_f)\right.\right. \\ &\left.\left. \wedge\, \mu_Q(y)\right) \vee \left(1 - \mu_{N_{TIP}}(x_n) \wedge \mu_{F_{TIP}}(x_f)\right)\right),\ \forall y \in Y \end{aligned} \tag{17}$$

A fuzzy inference system has been implemented in the SciLab package for the estimation of the linguistic variable *TIP Evaluation* and based on the above inference scheme and compositional inference rule described in the formulas (13–17).

Table 1
Fuzzy reasoning rules for the *TIP Evaluation* local model.

Rule	Premise	Conclusion
R1	TIP_Number IS very_low AND TIP_Frequency IS very_high	TIP_Evaluation IS very_low
R2	TIP_Number IS low AND TIP_Frequency IS high	TIP_Evaluation IS low
R3	TIP_Number IS medium AND TIP_Frequency IS medium	TIP_Evaluation IS medium
R4	TIP_Number IS high AND TIP_Frequency IS low	TIP_Evaluation IS high
R5	TIP_Number IS very_high AND TIP_Frequency IS very_low	TIP_Evaluation IS very_high

Table 2
Fuzzy reasoning rules for the *Device evaluation* local model.

Rule	Premise	Conclusion
R1	Detectability IS very_low	Device_evaluation IS very_low
R32	Detectability IS low AND TIP_Evaluation IS medium AND Number_of_detection_lines IS low AND Device_age IS very_low	Device_evaluation IS low
R102	Detectability IS medium AND TIP_Evaluation IS low AND Number_of_detection_lines IS high AND Device_age IS very_low	Device_evaluation IS medium
R193	Detectability IS high AND TIP_Evaluation IS medium AND Number_of_detection_lines IS high AND Device_age IS low	Device_evaluation IS high
R292	Detectability IS very_high AND TIP_Evaluation IS very_high AND Number_of_detection_lines IS medium AND Device_age IS very_low	Device_evaluation IS high

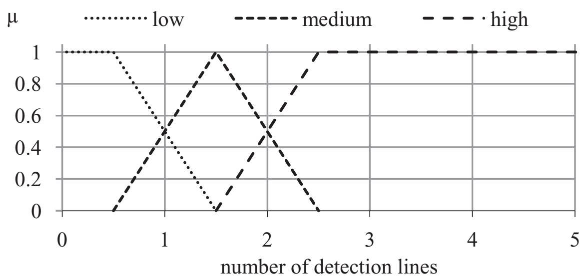

Fig. 8. Membership functions for the *Number of detection lines* linguistic variable.

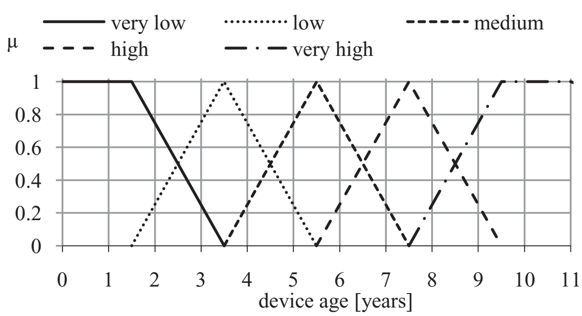

Fig. 9. Membership functions of the *Device age* linguistic variable.

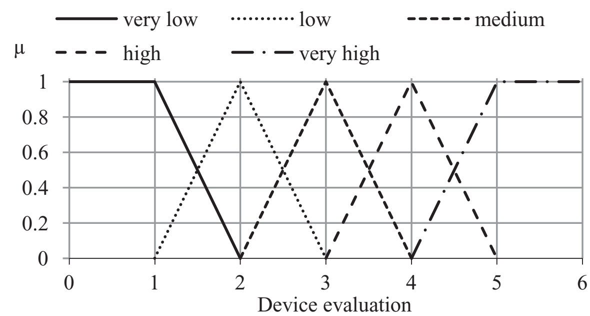

Fig. 10. Membership functions of the *Device evaluation* output variable.

Table 3
List of baggage X-ray devices at the Katowice–Pyrzowice International Airport.

No	Manufacturer/Model	x_n	x_f[%]	x_{md}	x_g	x_a	y_d
1	Heimann 6040 aTiX	6000	2.8	10	4	6	5.2
2	Heimann 6046 si	6000	2.8	6	1	7–8	2.8–3.1
3	Heimann 6040 i	6000	2.8	6	1	9–10	2.1–2.5
4	Heimann 100100 T	0	0	6	1	7	1.4
5	Smiths 10080 EDX-2is	904	2.8	10	2	8	4.4
6	Smiths 100100 T-2is	599	2.8	6	2	4	3.5
7	Smiths 100100 V-2is	0	0	6	2	3	2.7

5.1.3. Number of detection lines *input variable*

The X-ray devices differ with the number of generators creating the image. Each generator creates one detection line which allows for creating an image seen from one direction (angle). In a multiple generator variant, the screened baggage (as it passes through the device's tunnel) is inspected by several beams of Roentgen radiation which generates signals in multiple detectors installed in the device at various angles. This allows us to obtain images as seen from different directions. Therefore, the probability of detecting a prohibited item hidden in the baggage is much greater if a device with several radiation generators is used during security control. The membership functions for the *Number of detection lines* linguistic variable are shown in Fig. 8.

5.1.4. Device age *linguistic variable*

The fourth factor taken into account in the analysis is the device age. It influences the probability of failure of the device during operation. Due to frequent reliability checks of the device (at every start-up) the possible time of operation at less the full operational capability is relatively limited. It happens because the equipment that does not fulfil all requirements is not admitted for operation. Thus, the age of the device will also be considered a minor factor in the evaluation.

The assumed membership functions for different values of the *Device age* linguistic variable are shown in Fig. 9.

5.1.5. Output variable of the Device evaluation *local model*

The *Device evaluation* local model assumes a five-level scale of linguistic variable values. This is shown in Fig. 10. The fuzzy reasoning system is completed by 301 fuzzy rules defined by expert practitioners; some examples are shown in Table 2.

Inference scheme and compositional inference rule presented above and described with formulas (13-17) has been used for the establishing of linguistic variable *Device evaluation*.

5.2. Example of device evaluation for Katowice–Pyrzowice International Airport

The Katowice–Pyrzowice International Airport (ICAO code: EPKT, IATA code: KTW) has almost 2.5 million passengers per year with 1.7 million passenger in scheduled traffic and about 0.8 million in charter. In the years 2011–2013 about 30 thousand air operations per year were performed (GTL, 2014a). The Upper Silesian Aviation Group, the entity managing the airport has developed and implemented its own security policy. One of its elements is to perform effective and proactive corrective actions in order to minimise the risk (GTL, 2014b). One of the elements of such actions may be the evaluation of X-ray devices presented below.

At the Katowice–Pyrzowice International Airport, baggage screening is performed using standard commercially available equipment listed in Table 3. Using the hierarchical fuzzy model described above and a calculation tool SDE created using the SciLab package, utilising the max–min compositional inference rule based on relations (8–10),

Table 4
Evaluation of baggage X-ray devices made by experts.

No	Manufacturer/Model	Expert 1	Expert 2	Expert 3	Expert 4	Average
1	Heimann 6040 aTiX	6	6	5	5	5.5
2	Heimann 6046 si	4	4	3	3	3.5
3	Heimann 6040 i	4	3	3	3	3.25
4	Heimann 100100 T	2	2	1	2	1.75
5	Smiths 10080 EDX-2is	5	5	4	4	4.5
6	Smiths 100100 T-2is	3	4	2	3	3
7	Smiths 100100 V-2is	2	4	1	2	2.25

the following results were achieved which are specified in the last column of Table 3.

Analysis of the results shows that the devices operating in the EDS standard ($x_{md} = 10$) are evaluated as *very high* or *high* (see Fig. 10). The evaluation of the device without the EDS function ($x_{md} = 6$) depends mostly on the number of detection lines. In case of devices with two lines the evaluation results are close to *medium* even though these devices have very few TIP images or do not have such function at all (no. 6–7). Devices with a single detection line are rated in the scope from *very low* for an X-ray without TIP image function (no. 4), through *low* for older device (no. 3), to *medium* for newer devices of this class (no. 2).

5.3. Method validation and verification

The evaluation of each device made with a tool created in SciLab system, thanks to the formed fuzzy model, may be the basis for checking the correctness of received results. In order to do that, a test with experts has been carried out - people with many years of experience in security and safety management. The experts have been provided with the list of X-ray devices including the equipment configuration consisting of:

- TIP number x_n,
- TIP frequency x_f,
- device type description (EDS/conventional) x_{md},
- number of detection lines x_g,
- device age x_a

and made an evaluation of the devices in the 0–6 scale, the same scale that has been used for output variable *Device evaluation*, taking as a criteria the device efficiency in the baggage security control process. Results of the evaluation have been presented in Table 4.

The comparison of the evaluation made by the experts with the evaluation resulting from the model shows their high conformity. It refers both to evaluation value (average experts' evaluation and evaluation after defuzzification from the model) and evaluation expressed in linguistic variable. The comparison has been shown in Table 5.

There is high analogy between the extreme evaluations - the best and the worst. There are slight discrepancies for interim evaluations. The explanations of the evaluation given by the experts show that they took in greater extent into consideration the age of the device. They considered it more as an important parameter of the device usability for the enterprise than as a parameter influencing the efficiency of detecting forbidden objects.

In our case, validation of the model together with verification of the created calculation tool shows their correctness and usability.

5.4. Evaluation of the efficiency of the chosen devices configuration

Evaluation of each device may be the basis for the evaluation of efficiency of a certain devices configuration. This constitutes of number and degree of device exploitation for each type of the device. Presented below is the way of evaluating of the joined configuration of the devices in use. We make it separately for hand and checked baggage scanners. It should also be taken into consideration that a certain time span t has to be specified, for which the analysis will be made.

We determine the set of available hand luggage control devices

$$DH = \{dh_i\},\ i = 1, \ldots,\ dh \tag{18}$$

Received from fuzzy inference system efficiency evaluations for each device will be identified with function values

$$y_{dh} : DH \to \mathbb{N} \tag{19}$$

where $y_{dh}(dh_i)$ - means defuzzified evaluation of ith device for the hand luggage control received from local fuzzy model *Device evaluation*.

The number of baggage items screened in time t is described by the function

$$bh : DH \to \mathbb{N} \tag{20}$$

where $bh(dh_i)$ means the number of hand luggage pieces scanned by the ith device. This number is the basis to establish the evaluation weight for ith device in the total evaluation of devices configuration. We will determine therefore the weight function wh

$$wh : DH \to [0, 1] \tag{21}$$

where $wh(dh_i)$ - weight of ith device is described as follows

$$wh(dh_i) = \frac{bh(dh_i)}{\sum_{i=1}^{dh} bh(dh_i)} \tag{22}$$

So the final evaluation of the configuration of hand luggage control devices is given in the formula

$$y_{DH} = \sum_{i=1}^{dh} wh(dh_i) \cdot y_{dh}(dh_i) \tag{23}$$

In our example, using the same symbols and taking into account November 2013 as time span t we can make the evaluation of the configuration used in Katowice International Airport for the hand luggage control. Results have been presented in Table 6.

In an analogical way we will determine the set of the devices for control of the checked luggage

$$DC = \{dc_i\},\ j = 1, \ldots,\ dc \tag{24}$$

Table 5
Comparison of the experts' and model evaluation.

No	Manufacturer/Model	y_d		Linguistic	
		Model	Expert	Model	Expert
1	Heimann 6040 aTiX	5.2	5.5	*Very high*	*Very high*
2	Heimann 6046 si	2.8–3.1	3.5	*Medium*	*Medium/high*
3	Heimann 6040 i	2.1–2.5	3.25	*Low/medium*	*Medium*
4	Heimann 100100 T	1.4	1.75	*Very low/low*	*Very low/low*
5	Smiths 10080 EDX-2is	4.4	4.5	*High/very high*	*High/very high*
6	Smiths 100100 T-2is	3.5	3	*Medium/high*	*Medium*
7	Smiths 100100 V-2is	2.7	2.25	*Low/medium*	*Low*

Table 6
Joined evaluation of the hand luggage control devices in Katowice International Airport.

i	dh_i	$y_{dh}(dh_i)$	$bh(dh_i)$	$wh(dh_i)$	$wh(dh_i)\cdot y_{dh}(dh_i)$
1	29828	2.1	515	0.003	0.01
2	64090	2.5	30894	0.201	0.5
3	69497	2.8	27273	0.178	0.5
4	74722	3.1	10107	0.066	0.2
5	74723	3.1	16590	0.108	0.33
6	75776	3.1	6567	0.043	0.13
7	75777	3.1	2846	0.018	0.06
8	79985	5.2	26358	0.172	0.89
9	79986	5.2	32426	0.211	1.1
y_{DH}					**3.7**

The efficiency evaluations of each device received from the fuzzy inference system we will identify with function values

$$y_{dc} : DC \to \mathbb{N} \tag{25}$$

where $y_{dc}(dc_j)$ - means defuzzified evaluation of jth device for the control of checked luggage received from the fuzzy local model *Device evaluation*.

Number of checked baggage scanned in time t is determined by function

$$bc : DC \to \mathbb{N} \tag{26}$$

where $bc(dc_j)$ means the number of checked baggage scanned with jth device. This number is the basis for establishing the weight of the jth device evaluation in the total evaluation of the devices configuration. We will determine therefore the weight function wc

$$wc : DC \to [0, 1] \tag{27}$$

where $wc(dc_j)$ - weight of the j-th device is determined as follows

$$wc(dc_j) = \frac{bc(dc_j)}{\sum_{j=1}^{dc} bc(dc_j)} \tag{28}$$

So the final evaluation of the checked baggage control devices configuration is specified in the formula

$$y_{DC} = \sum_{j=1}^{dc} wc(dc_j)\cdot y_{dc}(dc_j) \tag{29}$$

6. Method for selecting equipment and work technology for X-ray devices at an airport

6.1. Choice of the TIP frequency

It is obvious that the most beneficial solution would involve using only new, modern EDS devices with numerous detection lines and equipped with many TIPs. However, this is a very costly solution, which is often hardly justified by the volume of air traffic (Gillen & Morrison, 2015).

The presented method for the evaluation of an X-ray device allows us to present an interesting solution in the field of work technology. This solution is a result of analysis of impact of increasing the frequency of TIPs. A relation between the *Device evaluation* output variable and *TIP Frequency* input variable has been analysed by changing the x_f value in the scope between 0 and 6%. Fig. 11 shows the results for an EDS standard device but with a small number of TIPs using the Smiths Detection 10080 EDX-2is as an example.

As we can see the X-ray device's evaluation result depends on the frequency of TIP images. The borderline values which guarantee the highest evaluation values for the device reaching 4.4, which is the intermediate zone between the *high* and *very high* result, are values

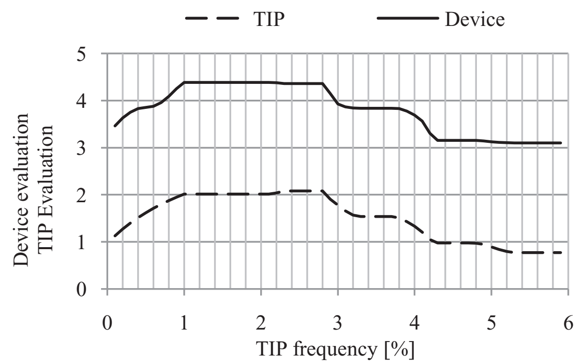

Fig. 11. Relation between the *TIP Evaluation* and *Device Evaluation* variables and the *TIP Frequency* variable for the Smiths Detection 10080 EDX-2is.

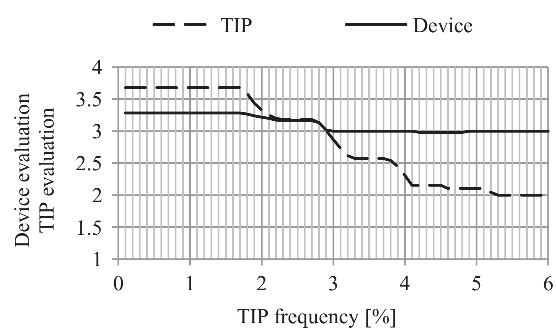

Fig. 12. Relation between the *TIP Evaluation* and *Device Evaluation* variables and the *TIP Frequency* variable for the Heimann Smiths 6046 si device.

1% and 2.8%. Exceeding those values would result in lowering the effectiveness of the baggage screening system to as low as level 3.1 i.e. *medium* value. The decrease of the result is explained by the low number of TIPs available in the X-ray machine. High frequency of images not only lowers the alertness of the SO but also allows him/her to memorise the TIPs, thus decreasing the effectiveness of the control.

In case of a standard RTG device, the selection of the correct TIP frequency may also result in increased work effectiveness (Fig. 12).

As we can see the evaluation result for this device is not affected very much by the TIP display frequency. This is understandable as they are very numerous and the SO is unable to memorise them. Yet, the remark made in the section describing input variables still applies - too high TIP frequency lowers the alertness of the operator. Assuming a work technology which displays more than 3% of TIPs results in an evaluation result of about 3.0, which is equal to the *medium* value. Lowering the TIP frequency to about 1.6–1.8% allows slightly improve the effectiveness of the system (to 3.3).

Taking into consideration the borderline frequencies for device with a low number of TIPs and for devices with a high number of TIP we suggest assuming the *TIP Frequency* parameter value at about 1.8% as a simple and cost-free method of improving the effectiveness of baggage screening system at the airport.

6.2. Evaluation of the TIP number and the device age on its efficiency

Frequency of TIP display is subject in big extend to the decision made by the security service of the airport. It must take into account the possibility of making the correct evaluation by SO fulfilling their task using the X-ray devices, which will allow for taking further actions increasing the efficiency of detecting the forbidden objects. Since the efficiency of SO actions is to big extent the indication of the security level of the airport, the correct evaluation of the working quality of this group of personnel is very important in the design and

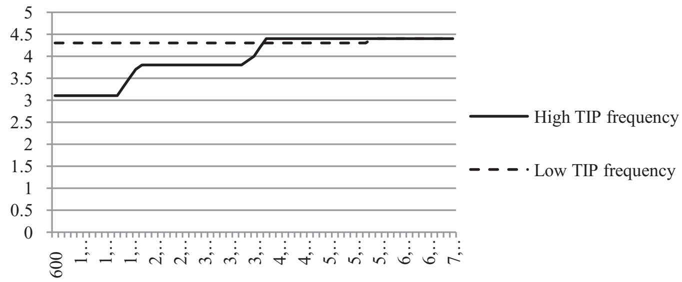

Fig. 13. Dependence of the *Device evaluation* from TIP images number.

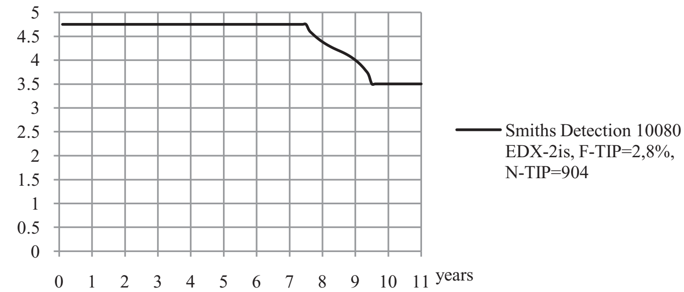

Fig. 14. Dependence of the *Device evaluation* from its age.

control process of an airport security system. The created method of the devices evaluation can be used for the analysis of the sensitivity to the change of input parameters. Such analysis may help the decision maker to make a decision regarding a possible device replacement or establish its further use. Such actions have got preventive character. They minimise the risk of using defective devices during the control or devices not fulfilling the standard requirements, and therefore, allow for the risk management regarding the occurrence of the above mentioned situations. The example of such parameter is the quantity of the available TIP images or the age of the device that influences the devices evaluation and their configuration as a whole.

6.2.1. *TIP number evaluation*

Evaluation of the available TIP images on the efficiency of a device have been made for the Smiths Detection 10080 EDX-2is type device used for checked baggage control. It is a good quality device EDS class with two detection lines. The analysed device was eight years old. Two cases have been taken into account. First - the device is working in the high TIP images display frequency, second - when the TIP frequency is low. Results have been presented in Fig. 13.

As we can see, when the TIP display frequency is high (tested for $x_f = 5.8\%$) the bigger number of TIP images available in the device, the higher evaluation. It is in compliance with the expectations, as for low number of TIP images (on the level of 600–1000) displayed with high frequency, SO is able to memorise them easily and therefore, their vigilance and at the same time efficiency of the baggage control process drops.

On the other hand when the frequency of TIP display is low (tested for $x_f = 1\%$) the number of available TIP images does not influence the evaluation. It derives from the opposite situation than the one described before. Even with the low number of images SO is not able to memorise them as they are displayed rarely.

6.2.2. *The evaluation of the device age*

As mentioned before, the device age does not play a significant role in the efficiency evaluation of the luggage scanner. Of course old and exploited devices may fail often eliminating them from work and therefore, cause problems for the services responsible for ApSS operation. However, during everyday work the influence is small, if the devices are often tested, which makes the possibility of undetected failure (decreasing the possibility of forbidden objects detection) less probable. Negative influence of this parameter has been checked as before for the Smiths Detection 10080 EDX-2is type scanner used for checked luggage control. During the test it was accepted that the devise has got $x_n = 904$ TIP images and that their frequency equals $x_f = 2.8\%$. The result has been presented in Fig. 14.

Evaluation of the device dependent from its age has got maximum values (between *high* and *very high*) for the relatively big scope of input variable. Only in case of a device seven years old and older the evaluation drops and reaches the values between *average* and *high* in case of the devices nine years old or more.

Table 7
Joined evaluation of the hand luggage control devices in Katowice International Airport.

i	dh_i	$y_{dh}(dh_i)$	$bh(dh_i)$	$wh(dh_i)$	$wh(dh_i) \cdot y_{dh}(dh_i)$
1	29828	2.1	515	0.003	0.01
2	64090	5.2	30894	0.201	1.05
3	69497	5.2	27273	0.178	0.93
4	74722	3.1	10107	0.066	0.2
5	74723	3.1	16590	0.108	0.33
6	75776	3.1	6567	0.043	0.13
7	75777	3.1	2846	0.018	0.06
8	79985	5.2	26358	0.172	0.89
9	79986	5.2	32426	0.211	1.1
y_{DH}					**4.7**

6.3. *Replacement of devices*

It is of course clear that the proposed method may be also used for the estimation of the effectiveness of the other than existing devices configuration, e.g. in case of purchase plans. The example may be a plan or replacement of the existing device for a new one or a device of a new type. Taking into account big costs of such purchase, it is good to know the advantages for the security level the replacement will bring. For example, Table 7 shows the efficiency calculations for hand luggage control devices in case of a replacement of the devices marked as dh_2 and dh_3, that is accordingly nine year old Heimann 6040 and seven year old Heimann 6046 si, with new devices Heimann 6040 aTiX.

Table shows that with the remaining parameters unchanged (quantity and equipment as well as usage of each security check point) the system efficiency evaluation y_{DH} changes (compare Table 6) from 3.7 (between *average* and *high*) to 4.7 (between *high* and *very high*). Such an analysis may help the decision maker in rational allocation of resources allowing for informed planning of the equipment purchase that will guarantee expected baggage control security level.

7. Summary and conclusions

The method for the evaluation of effectiveness of X-ray devices at an airport suggested in this paper allows for simple evaluation of individual devices as well as all existing equipment, including the configuration on each security check point. The latest is made with the use of weights, taking into account the exploitation level for each device. The developed *Device Evaluation* fuzzy model is part of a bigger model constructed in order to improve the effectiveness of the airport's entire security system.

The evaluation of effectiveness, although important, needs not to be a goal by itself. The suggested approach allows for researching the possible changes in equipment and work technology in order to find solutions that are better than those currently in use. The presented practical example of the Katowice–Pyrzowice International Airport shows what growth in the general evaluation of all devices may be achieved by replacing specific device. It has also been shown what change appears in case of change of work technology, that is a change of frequency of TIP images display or installation of bigger number of TIP images in a device.

The implementation of an efficient method for assessing the effectiveness of baggage screening devices allows for a better management of 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 equipment with different characteristics. Moreover, there may appear the necessity to adjust the level of control to the current needs resulting from the 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 individuals directly responsible for airport security with the necessary knowledge about the effectiveness of devices used for 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.

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

The intention of the study was to provide airport managers and airport security system designers with the most objective information possible on the effectiveness of the solutions they use. Contrary to what one might expect, the results are not obvious. Introducing advanced security control devices is not the only solution to increase the quality of screening. A security system relies heavily on variables that cannot be reliably evaluated without a detailed analysis and practical studies. The SDE computer system has been developed as a result of conducting empirical studies and experiments, and by using expert knowledge. One of the authors of the paper is directly responsible for the organization and supervision of an airport security control system. The validation of the software in real-life conditions has confirmed its practical usefulness by providing an assessment of the configurations of the existing and planned security control devices. In practice, this enables conscious decision making, in this case on the issue of equipment selection, in order to achieve the required effectiveness level of a security control checkpoint.

Further work related to the development of the created expert system shall continue in three directions. First, we will aim at including new types of devices introduced to the security control systems at airports. Second, we will develop the fuzzy inference system by including the expert evaluation aggregation method, which is required when using expert groups as was the case during the research. At this phase the aim was to achieve consensus among the experts. Third, we will include the expanded version of the method for automatic verification of the knowledge base based on multiple-criteria group evaluation of variants described in (Skorupski, 2015). This will allow for more comprehensive use of both objective and subjective input variables.

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