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Optimization of Passenger Screening Operations in Air Terminals

Carl Rizk[a], Félix Mora-Camino[b], Hadj Batatia[c] *

[a]Labo ENAC,ENAC, Toulouse
[b]Labo ENAC,ENAC, Toulouse
[c]IRIT-INPT & ENSEEIHT, Toulouse

Abstract

Airports today play an important economic role. As intermodal transport terminals, they have to channel important flows of passengers and goods. In recent decades, they have been the target of terrorist attacks and the place where all types of traffic pass. Consequently, they are faced with the dual objective of maximization of security system as well as maintenance of consistent quality and insurance of fluid traffic flow passengers coupled with the minimization of the expected amount of time a passenger spends in this system.

In this article, we are interested in the evaluation of the system of control of passenger flows at boarding, whatever their subsequent path, through a probabilistic approach.
The general purpose is to:

a) Better organize the flow of passengers at boarding, taking into account the performance of the control system as a whole or the performance of the elements that make it up, including staff.
b) Contribute to new knowledge about increasing efficiency and productivity at airports with regards to security system, by measuring and simulating the operations at an airport, and developing a strategy for improved resource utilization to improve productivity.

After the establishment of a global evaluation model based on an undifferentiated serial treatment of passengers, we are interested in a two-stage control structure that highlights the interest of pre-filtering and organizing passengers in separate groups. This then leads to the formulation of optimization problems to improve the performance of the control system."

Keywords: Airport Security; Modelization; Optimization.

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* Corresponding author.
E-mail addresses: carlrizk@gmail.com (C. Rizk), felix.mora@enac.fr (F. Mora-Camino), Hadj.batatia@irit.fr (H. Batatia).

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1. Introduction

Security is the assurance granted by the company to each of its members for the preservation of its person, rights and property.

In the aeronautical field, security is aimed at the prevention of any intentional malicious act in the airport, the airplane and their environment.

Annex 17 of the ICAO Chicago Convention on International Civil Aviation defines it as “a combination of measures and human, material means to protect civil aviation against acts of unlawful interference” and adds “Security focuses on the areas of prevention and protection against willful and malicious acts, it is a component of safety dedicated to the prevention of a specific risk: acts of malevolence”. (1)

Security measures include “legal and/or regulatory arrangements for organizing, coordinating, implementing, evaluating and controlling the human and material resources necessary to protect civil aviation against acts of unlawful interference”.

Annex 17 of the ICAO Chicago Convention says as well that each Contracting State shall take measures to prevent weapons, explosives or any other dangerous devices to be used to commit an illegal act. Therefore States must ensure that the carriers develop and implement effective complementary security programs compatible with those of the airports out of which they operate. (1)

Securing air transport means giving it immunity against accident, sabotage, assault, aggression, hijack, but also giving it immunity from being exploited to commit a terrorist act. The problems of the airport security cost and its management are present today. The main objective of this study is to bring a methodological contribution to this issue.

Despite the fact that the passengers acknowledge the need for increased security, yet, delayed boarding, cancelled flights, long waiting time have created an environment of passenger dissatisfaction. Passengers noticed the negative impact of increased security requirements and they are increasingly dissatisfied with some of the inconveniences associated with air travel, which led them to seek alternatives such as high-speed rail.

2. Passengers flows in an airport

Any person or dangerous object necessarily takes the flows of people and goods implemented in the airport. A flow is a movement of people or objects along a well-defined path to get from one point to another. There is a wide variety of flows in an airport: passenger flows, aircraft flows, baggage flows, personnel flows, service vehicle flows and others. They can interact with each other or not. The general security rules impose constraints in terms of non-mixing of certain flows while maintaining some facilitation (processing capacity, system flexibility, and passenger comfort).

Measuring passenger flow can help an airport increase operational efficiencies, maximize retail revenues, improve passenger experience and increase security effectiveness…

The main rules generally adopted in airport flow management are: (2)

- No mixing of flows at the departure.
- No mixing of flows on arrival (tolerable if both flights have the same regime).
- No flow crossing.
- Existence of alternative routes in the event of a degraded situation.
- Minimizing distances.
- Signaling corresponding to these rules.

The passenger (incl. cabin luggage) pattern at airport terminal can be represented as follow: (3)

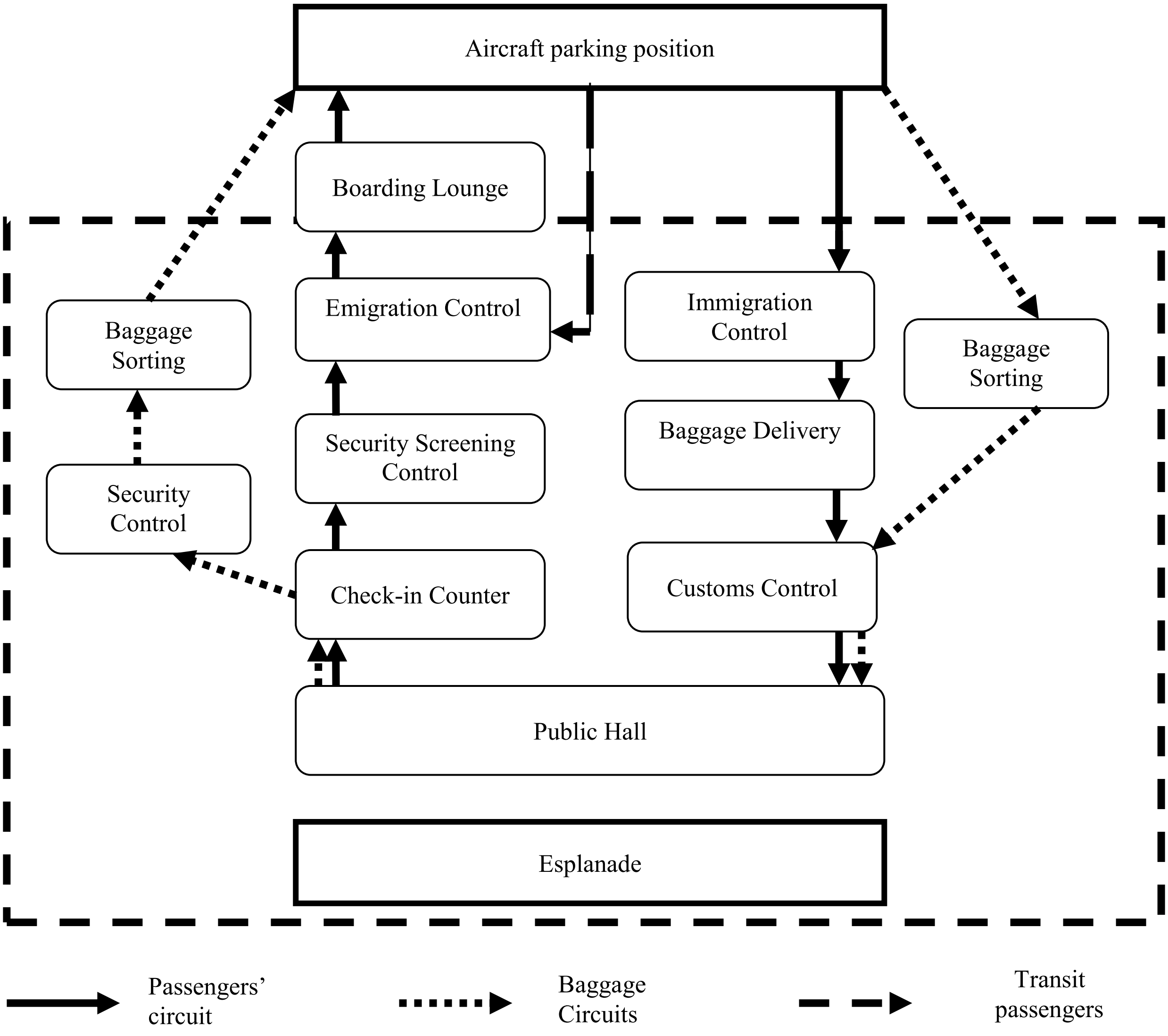

Fig. 1 Organization scheme of a passenger terminal

The composition of the screening checkpoint recommended by ICAO Doc 8973 is as follows:

- An upstream officer to check travel documents, boarding passes; ensure baggage handling, management of electronic devices and small items;
- A downstream officer for the management of alarms, palpation (a woman / a man).
- A downstream officer to monitor images and interpret them.
- An officer for the downstream baggage search.
- Explosives trace detector.

- A supervisor who must perform no other duties than risk assessment and problem management.

3. Literature Review

Many researchers have faced issues concerning the optimization of an airport terminal. The model optimization, by using simulations, is based on different systems. In order to better understand the context and to be aware of all the underlying issues, we worked on a Literature Review of the work done on different simulations as follow:

- Total cost minimization. The costs considered include the cost of space, the operating costs and the cost of uneasiness endured by passengers when the waiting time exceeded the tolerable limit.
- The simulation of passengers flow within an airport terminal allows the detection of any critical issues that could arise in the real flow management taking into account some key factors such as traffic passenger volume and the type of passengers themselves. All passengers behave differently at the airport, and the development of a simulation model therefore helps to infer and predict, taking into account the available capacity and the fact that the volume of passengers depends on day time and the week day and the passenger behavior.

For this reason, we were led to deal with optimization problems. Such problems are common in many disciplines and various domains. In optimization problems, we have to find solutions which are optimal or near-optimal with respect to some goals.

4. Probabilistic Modeling of the checkpoints

The path of a passenger presenting a threat can be modeled by the diagram below, where A stands for “check-in counter”, S for “passenger screening checkpoints” and G for “boarding lounge

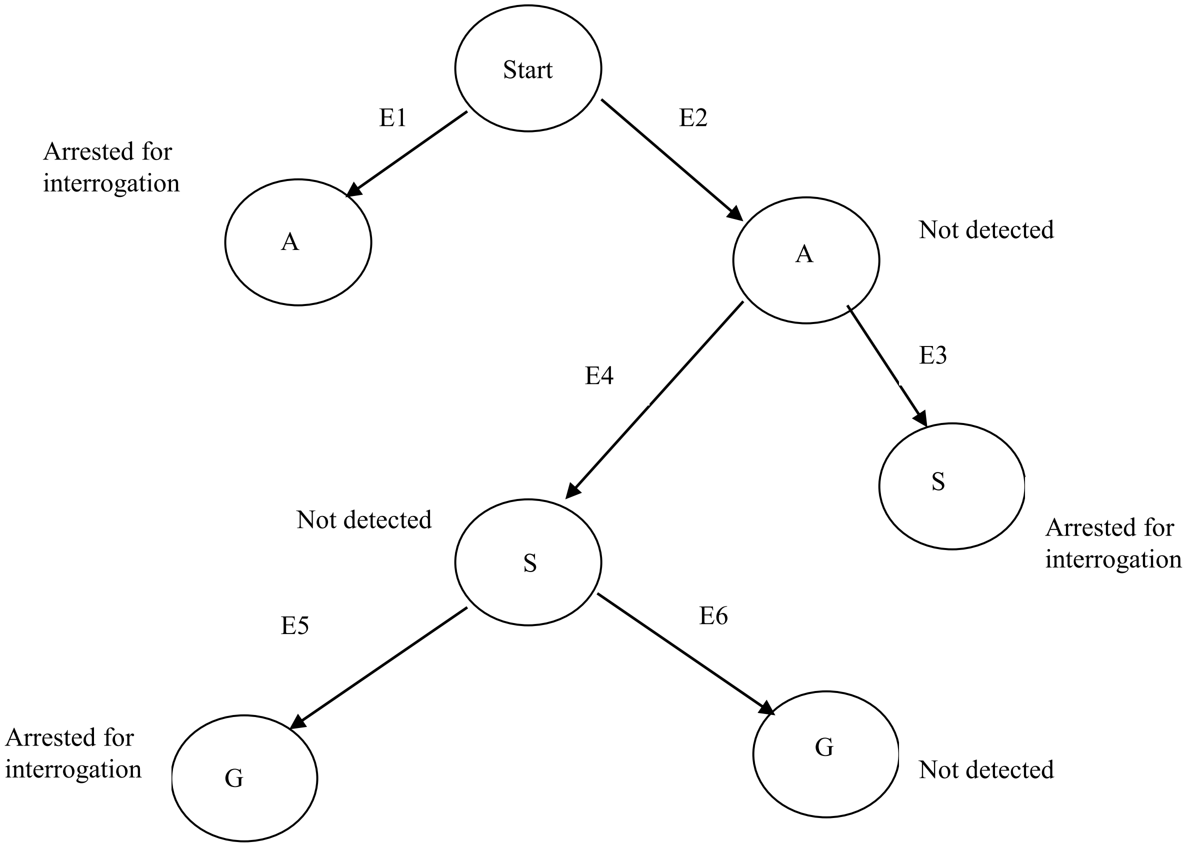

Fig. 2 Security system treatment process

With regards to the threat situations, the events taken into account in this diagram are:

- E1: “potential threat detected at the check-in counter”,
- E2: “potential threat not detected at check-in counter”,
- E3: “potential threat detected at security checkpoint”,
- E4: “potential threat not detected at security checkpoint”,
- E5: “potential threat detected at the boarding lounge”,
- E6: “potential threat not detected at the boarding lounge”.

The probabilities that characterize the system's performance against a threat are:

- P_{cic} : Probability of detecting the terrorist at the check-in counter.
- P_{scp} : Probability of detecting the terrorist at security checkpoint.
- P_{bl} : Probability of detecting the terrorist at the boarding lounge.

The probabilities that characterize the system's performance in a normal situation are:

- P_{FA}^{cic} : Probability of false alarm at the check-in counter.
- P_{FA}^{scp} : Probability of false alarm at security checkpoint.
- P_{FA}^{bl} : Probability of false alarm at the boarding lounge.

The probability of successfully detecting a terrorist is:

$$P_{sd} = P_{cic} + (1\text{-}p_{cic}).\ P_{scp} + (1\text{-}p_{cic}).\ (1\text{-}P_{scp}).\ P_{bl}$$

The probability (success) of non-detection of a passenger who is not a threat is:

$$P_{pax} = (1 - P_{FA}^{cic})\ (1 - P_{FA}^{scp})\ (1 - P_{FA}^{bl})$$

5. Probabilistic Evaluation of a Control System with Pre-Filtering

First, two types of checkpoints are considered:

- Those that are mandatory (named C1).
- Those that reinforce these controls in certain circumstances (named C2).

All these checkpoints are considered capable of detecting different types of threats $M = \{m_1, m_2, ..., m_\mu\}$ and if there is a threat, the probability that it is of type "i" is π_i.

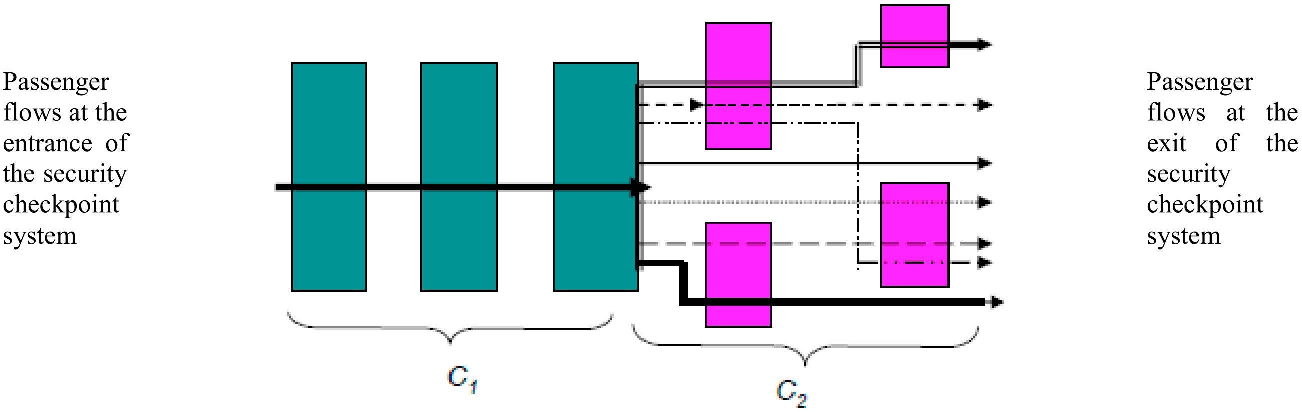

Fig. 3 Example of a security control structure

Let G_n be the n^{th} group of passengers to which is associated a set of security checkpoints $C^n_2 \subset C_2$ and let x_n the proportion of passengers assigned to G_n

The proper functioning of a checkpoint "j" can be described by:

- The probability of detecting a real threat of type k at checkpoint “j” is p_{kj}.
- The probability of not generating a false alarm at checkpoint “j” is q_j.
- The proportion of passengers passing through the checkpoint “j” is given by:

$$y_j = 1 \text{ if } j \in C_1,\; y_j = \sum_{i=1,\, j\in C_2^i}^{N} x_i \text{ if } j \in C_2$$

If τ is the probability that a random passenger is a threat, the probability of having an alarm at checkpoint “j” is given by:

$$P_A^j = \tau \left(\sum_{k=1}^{\mu} p_{kj}\; \pi_k\right) + (1-\tau)\,(1-q_j))\; y_j$$

6. Optimizing the assignment of passengers to screening checkpoints

The aim here is to minimize the probability of non-detection of a threat while trying to guarantee a maximum level of false alarms and taking into account the average availability of the checkpoints.

$$Min \left(\sum_{i=1}^{N} \left(\sum_{m=1}^{\mu} \pi_m \prod_{j\in C_2^i} (1-p_{mj}) \right) x_i \right)$$

Under the constraints:

$$(1-\tau_A)\sum_{i=1}^{N}((1-\prod_{j\in C_2^i} q_j)\, x_i) \le P_{FA}^{\max} \qquad \sum_{i=1,\, j\in C_2^i}^{N} x_i \le y_j^{\max} \qquad j \in C_2$$

$$\sum_{i=1}^{N} x_i = 1 \qquad 0 \le x_i \le 1 \qquad i = 1,\cdots,N$$

7. Example

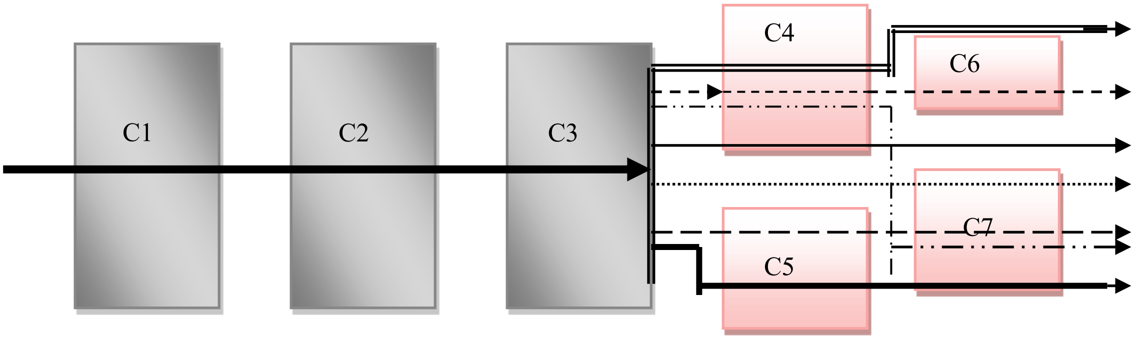

Fig. 4 Example application

In the above picture we consider that there are only four types of threats. The following table gives the probabilities of detection associated with the checkpoints by threat type, the probabilities by threat type and the probabilities of false alarms by checkpoint.

Table 1. Adopted probability distributions

-	C4	C5	C6	C7	π
P_{1j}	0.990	0.980	0.850	0.750	0.40
P_{2j}	0.850	0.995	0.965	0.550	0.25
P_{3j}	0.980	0.950	0.580	0.990	0.25
P_{4j}	0.800	0.975	0.995	0.780	0.10
q_j	0.999	0.999	0.998	0.998	-

In Figure 4 we considered seven different treatments in the second phase of the control.

Table 2. Control circuits in phase II

Proportion	***Treatment***
x_1	*Nil*
x_2	*C4*
x_3	*C4 - C6*
x_4	*C4 – C7*
x_5	*C5*
x_6	*C5 - C7*
x_7	*C7*

Normal treatment times and processing times with alarms are shown in the table below:

Table 3. Processing times at checkpoints (in seconds)

-	**C4**	**C5**	**C6**	**C7**
$\bar{t}_j$	10	15	10	15
Δt_j	100	150	100	150

We take T = 10 minutes and initially, a request of 1600 passengers / hour to pass the control. It is assumed here that all the checkpoints consist of 6 identical stations operating simultaneously.

This leads to the formulation of the following linear optimization problem:

$$\min x_1 + 0.0665\, x_2 + 0.00625125\, x_3 + 0.022325\, x_4 + 0.04925\, x_5 + 0.0032375\, x_6 + 0.237\, x_7$$

$$x_2 + 3\, x_3 + 3\, x_4 + x_5 + 3\, x_6 + 2\, x_7 \leq 1002\, P_{FA}^{\max}$$

with the constraints:

$$x_5 + x_6 \leq 0.9625$$

$$x_3 + x_6 \leq 0.9625$$

$$x_4 + x_6 + x_7 \leq 0.9625$$

$$\sum_{i=1}^{7} x_i = 1$$

$$0 \leq x_i \leq 1 \qquad i = 1, \cdots, 7$$

Taking $P_{FA}^{\max}$ = 0.003, the following solution is obtained:

$$x_1 = 0,\ x_2 = 0,\ x_3 = 0.30729,\ x_4 = 0.03751,\ x_5 = 0,\ x_6 = 0.65520,\ \ x_7 = 0$$

It corresponds to a probability of not detecting a threat of 0.00488 for a false alarm probability of 0.00300.

By varying the total demand, we obtain the following table:

Table 4. Solutions for different levels of demand

D	x_1	x_2	x_3	x_4	x_5	x_6	x_7	P_{ND}	P_{FA}
1400	0.0	0.0	0.33672	0.0	0.0	0.66328	0.0	0.00435	0.00300
1600	0.0	0.0	0.30729	0.03751	0.0	0.65520	0.0	0.00448	0.00300
2000	0.0	0.01254	0.29901	0.03232	0.02301	0.61194	0.02321	0.00476	0.00299
2400	0.12388	0.03452	0.25161	0.05223	0.03333	0.32712	0.17731	0.00628	0.00267
3200	0.42331	0.09612	0.08560	0.05726	0.09721	0.14281	0.09770	0.01329	0.00213

Table 5. Solutions for different levels of P_{FA}^{max} (demand = 1600 pax / h)

P_{FA}^{max}	x_1	x_2	x_3	x_4	x_5	x_6	x_7	P_{ND}
0.00285	0.0	0.02105	0.23541	0.13908	0.13307	0.44116	0.01023	0.00482
0.00290	0.0	0.00015	0.24452	0.10043	0.06742	0.58320	0.00428	0.00475
0.00295	0.0	0.0	0.27745	0.06761	0.02381	0.63113	0.0	0.00461
0.00300	0.0	0.0	0.30729	0.03751	0.0	0.65520	0.0	0.00448

The following figure shows some points of the Pareto border for a demand level of 1600 passengers / hour:

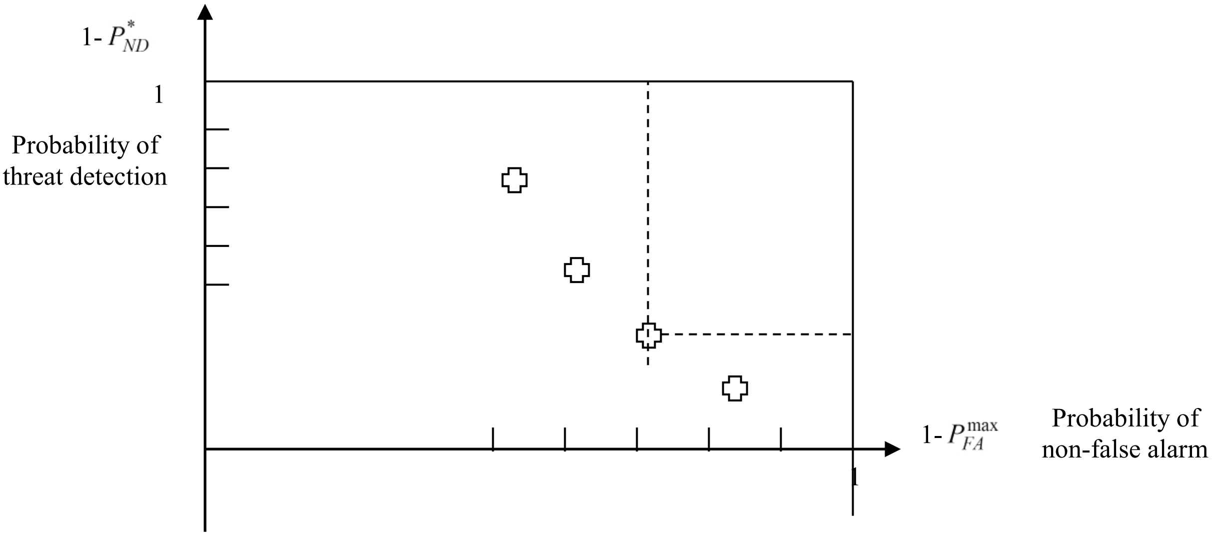

Fig. 5 Pareto border for the efficiency of the system (1600 passengers / hour)

8. Optimization of Passenger Assignment with Pre-Selection

It is assumed here that the sequence of mandatory checks C1 makes it possible to make a first classification of the passengers with respect to the threats that they can represent. It is considered that if at each checkpoint an evaluation is made, the classes of passengers considered will be M = $2^{|C_1|}$. It is assumed here that there is a priori probability $\tau_m, m = 1 \text{ à } M$ that a passenger of class m represents a real threat.

So we have:

$$\sum_{m=1}^{M} z_m = 1 \qquad \text{with} \quad 0 \le z_m \le 1 \quad m = 1 \text{ à } M$$

We introduce the variables x_{im} which represent the proportion of passengers of the threat class m, m = 1 to M, which are assigned to the group i, i = 1 to N. We therefore have:

$$\sum_{i=1}^{N} x_{im} = z_m \qquad m = 1 \text{ to } M$$

$$0 \le x_{im} \le 1 \qquad i = 1 \text{ to } N,\ m = 1 \text{ to } M$$

We can then formulate the problem of minimizing the probability of non-detection of a hazard, under the constraints of a maximum level for the probability of false alarms and the availability of checkpoints.

$$Min \sum_{m=1}^{M} \sum_{i=1}^{N} (\tau_m (\sum_{u=1}^{\mu} \pi_u \prod_{j \in C_2^i} (1 - p_{uj}))\ x_{im})$$

Under the constraints

$$\sum_{i=1}^{N} ((1 - \prod_{j \in C_2^i} q_j) \sum_{m=1}^{M} (1 - \tau_m)\ x_{im}) \le P_{FA}^{\max} \ ,$$

where $P_{FA}^{\max}$ is the maximum level of false alarm probability retained.

It is also necessary to consider the temporal availability constraints of the C_2 checkpoints during the period T:

$$\sum_{i=1,\ j \in C_2^i}^{N} \sum_{m=1}^{M} x_{im} \le y_j^{\max} \qquad j \in C_2$$

with the constraints of proportion:

$$\sum_{i=1}^{N} x_{im} = z_m \qquad m = 1 \text{ to } M$$

$$0 \le x_{mi} \le 1 \qquad i = 1, \cdots, N \quad m = 1, \cdots, M$$

We consider the following prior distributions (for M = 4):

Table 6. Passenger distribution after pre-filtering

m	1	2	3	4
z_m	0.70	0.15	0.10	0.05
τ_m	0.0001	0.001	0.001	0.002

For $P_{FA}^{\max}$ = 0.00300, we obtain the following solution:

$$x_1 = 0,\ x_2 = 0,\ x_3 = 0.30634,\ x_4 = 0.02845,\ x_5 = 0,\ x_6 = 0.66531,\ x_7 = 0$$

which corresponds to a probability of not detecting a threat of 0.00439 for a false alarm probability of 0.00300.

By varying the total demand, we obtain the following table:

Table 7. Solutions with pre-filtering for different levels of demand

D	x_1	x_2	x_3	x_4	x_5	x_6	x_7	P_{ND}	P_{FA}
1400	0.0	0.0	0.32655	0.0	0.0	0.67345	0.0	0.00428	0.00300
1600	0.0	0.0	0.30634	0.02845	0.0	0.66531	0.0	0.00439	0.00300
2000	0.0	0.01167	0.28784	0.03332	0.01983	0.64578	0.02139	0.00458	0.00300
2400	0.12388	0.03452	0.27023	0.04536	0.05452	0.55538	0.09351	0.00527	0.00287
3200	0.42331	0.09612	0.23945	0.04975	0.07843	0.42580	0.11045	0.09829	0.00254

Table 8. Solutions with pre-filtering for different levels of $P_{FA}^{\max}$

$P_{FA}^{\max}$	x_1	x_2	x_3	x_4	x_5	x_6	x_7	P_{ND}
0.00285	0.0	0.01320	0.25231	0.18621	0.14320	0.39067	0.00841	0.00472
0.00290	0.0	0.0	0.24452	0.13429	0.07670	0.54449	0.0	0.00461
0.00295	0.0	0.0	0.28761	0.05462	0.04530	0.61277	0.0	0.00450
0.00300	0.0	0.0	0.30634	0.02845	0.0	0.66531	0.0	0.00439

Thus, we see the beneficial effect of selective pre-filtering which for the same level of false alarms leads to much lower levels of non-detection of threat.

9. Conclusion

The probabilistic approach used in this study has several advantages:

- It allows putting in equation the dilemma (Probability of non-detection X Probability of false alarm).
- It shows the interest of the differentiated treatment of passengers who have all taken a first step.
- It shows the interest of establishing a first filtering before implementing a differentiated treatment that only becomes more efficient.
- It makes it possible to integrate the static dimensioning of the control equipment to be implemented.
- The degree of complexity of the probabilistic models developed remains of medium level and leads to problems of linear programming in small continuous variables.

Nevertheless, this approach also has important limitations:

- It is completely static and cannot provide online decision support.
- It does not take into account the stochastic aspect of the request and the introduction of queuing considerations (average file size, average waiting time) in the developed models and could only be done using simplistic models of a non-linear nature that would lead the optimization problems considered to have admissible non-convex domains, which would make their numerical resolution more difficult.
- The modeling chosen cannot take into account the spatial organization of the passenger terminal and its control system.

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