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# A model to optimize the airport terminal departure operations

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**Abstract**

The rapid increase in passenger traffic on the one hand and the slow expansion of airport capacity on the other have over the years limited the airport's capability to maintain satisfactory service to the customer. The main objectives of airport operators are the cost effectiveness and the customer satisfaction. These two indicators are related to the first two phases of an airport terminal departure operations that involve the check-in controls and the security controls. This paper proposes an optimization model that, given a certain layout and a passengers flow, decides the number of check-in desks and security control checkpoints to minimize a cost function. The cost function considers the costs of check-in and security control checkpoints and an estimate of the passenger dissatisfaction. The model develops an optimization algorithm that integrates a simulation module. The optimization algorithm is based on the surrogate method that minimizes the cost function that does not have a closed-form expression. To this reason, the simulation module reproduces the real scenario of the terminal operations and the passengers behaviour and calculates the value of the cost function. Tests have been conducted considering the real case study of Napoli-Capodichino (IT) airport.


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*Keywords:* airport land side; simulation; optimization; surrogate method;

## 1. Introduction

The land side area of an airport involves different type of resources whose operations influence the airport staff and the airline companies performances. Performances can be measured in terms of effective costs and customers satisfaction. In fact, the problem of deciding what mix of resources, processes and technologies will give the best combination in providing a satisfactory service to the customer is quite complicated. Hence the airport management is interested in adopting decision support systems able to optimize the use of resources and maximize customer satisfaction (9), (7), (10). Due to the complexity of the problems concerning the land side optimization, many authors use simulation tools to predict the passengers behaviour in a highly dynamic environment such as the airport (5), (11).

Our paper concerns the study of issues related to the land side capacity management which tries to maximize the number of passengers served per unit of time, minimizing the costs. In this direction, many studies have already

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focused on the customers satisfaction (12), (4), (13). The problem we address considers the trade-off between the minimization of the discomfort of the passengers and the costs for the companies and airport management, in the first phases of an airport terminal departure operations. In particular, passengers prefer minimizing the waiting times, companies want to minimize the costs of opening the check-in desks and airport management aim to minimize the costs for the security area.

We consider the problem of managing the check-in desks and the security control areas by determining the number of check-in desks and security control checkpoints to be activated to satisfy the demand of the passengers. The check-in is the activity through which the passenger chooses his seat on the airplane and delivers (or not) the luggage.

After the check-in operations, passengers proceed to the security area, where passengers and hand-luggage are controlled.

Our aim is to minimize an objective function which contains the operating costs associated with the activation of the check-in desks and security control checkpoints and the costs related to the discomfort for the users waiting at the queues.

The paper is organized as follows: in Section 2 we describe the problem and we provide a problem formulation. In Section 3 the optimization algorithm is described. In Section 4 some primarily results are reported. Conclusions are reported in Section 5.

## 2. Problem description

We optimize the management of check-in desks and security control check-points representing the resources implied in the first two phases of the airport terminal departure operations.

In this paper we study the Naples International airport (NAP in the international IATA code). The land-side of *NAP* consists of two terminals, Terminal 1 (T1) and Terminal 2 (T2). Since the Terminal 2 is operating only in spring/summer season, and almost exclusively for charter flights, we consider passenger traffic on the only Terminal 1. The path related to passengers departing from Terminal 1 develops on two floors: on the ground floor we have the check-in desks, and on the first floor, accessible by different escalators, the security control facilities and some shops and food services are located. On the other side of the ground floor besides the path related to arriving passengers there are the ticket office, the two currency exchange offices, several car rentals, and so forth. We focus on check-in desks of Alitalia company that is the airline company currently operating a large number of flights per day at Naples International airport (61% vs 39% for the others).

We consider three types of passengers: *business*, that travels alone and has at most one baggage; *tourist* that can travel alone or in groups of at most 4 people and can carry from 0 to 4 luggage; and *smart* that skip the check-in operations and directly go to the security control checkpoints. We also consider two types of check-in desks: *common* to the flights of the same airline company or *dedicated* to a specific flight of an airline company. Note that the problem we solve in this paper considers the optimization of the check-in desks management of a single airline company, but it can be extended to many different airline companies.

### 2.1. Problem Formulation

In this subsection we briefly define and describe the variables and the parameters that we use to formulate the problem in general.

The meaning of the parameters used in this formulation is the following:

- $N_C$ the number of airline companies;
- $N_t$ the maximum length of the queue that a passenger can tolerate;
- $f$ passenger flow which includes their arrival time and their typology;
- $NmQueue_T$ the mean number of passengers of type $T$ for a queue, where $T \in \{sc, ded, comm, dedB, commB\}$.

Due the complexity of the problem and the randomness of the passengers behaviour, we compute the parameters value and the objective function by a discrete event system simulator. In particular, the value of $NmQueue_T$ is calculated by simulation given the other three parameters.

Variables of the formulation are:

- $comm_i$: number of common check-in desks open for the i-th airline company;
- $ded_i$: number of dedicated check-in desks open for the i-th airline company;
- $commB_i$: number of common check-in desks open for the i-th airline company for business passengers;
- $dedB_i$: number of dedicated check-in desks open for the i-th airline company for business passengers;
- $sc$: number of security control checkpoints;

Our objective function is:

$$OF = \sum_{i=1}^{N_C} C_1(comm_i + ded_i + commB_i + dedB_i) + C_2 sc + +C_3 \max(NmQueue_{sc} - N_t, 0)+$$
$$+ C_4 \max(NmQueue_{commB} - N_t, 0) + C_5 \max(NmQueue_{dedB} - N_t, 0)+$$
$$+ C_6 \max(NmQueue_{comm} - N_t, 0) + C_7 \max(NmQueue_{ded} - N_t, 0)$$

Costs are related to: ($C_1$) the opening of a chech-in desk; ($C_2$) the opening of a security control point; ($C_3$) the inconvenience for the passenger at the security control queue; ($C_4$) the inconvenience of a business passenger at the check-in desk queue and ($C_5$) the inconvenience of a tourist passenger at the check-in desk queue ((10), (6)).

Subject to:

$$\begin{aligned} min_{comm_i} \leq & \quad comm_i & \leq Max_{comm_i} \\ min_{ded_i} \leq & \quad ded_i & \leq Max_{ded_i} \\ min_{commB_i} \leq & \quad commB_i & \leq Max_{commB_i} \\ min_{dedB_i} \leq & \quad dedB_i & \leq Max_{dedB_i} \\ min_{sc} \leq & \quad sc & \leq Max_{sc} \\ sc & \leq Max_{sc} & \end{aligned} \tag{1}$$

$$\sum_{i=1}^{N_C} comm_i + commB_i + ded_i + dedB_i \leq Max_{ck-in} \tag{2}$$

The set of constraints 1 limit the variables in a fixed interval. Constraint 2 states that the number of check-in desks is subject to physical space capacity.

We denote by $X$ and $Y$ the sets of integer decision variables such that $X = \{comm_i,\ ded_i,\ commB_i,\ dedB_i\}$ is the set of variables related to the check-in desks and $Y = \{sc\}$ is the set of variables related to the security control points.

Our problem can be formulated as the problem of finding out the values of the components of the vector $(X, Y)$ that minimize the objective function $OF$, which expresses the total cost for the system.

Note that a closed form of the objective function is not available, hence we calculate its value by simulation.

The analysis of the objective function can be done by considering its trend when one of the decision variable varies and the others are constant. The trend of the objective function with respect to the security control checkpoint ($Y$) is convex, while its trend, as a function of the check-in desks variables ($X$), presents many valleys and then many local minima. Fig.3 reports on such trend of the objective function when only one airline company is considered.

## 3. Solution approach: the Surrogate Method

We propose a solution approach that consists of on an optimization algorithm based on the Surrogate Method ((8), (1), (2), (3)). It was initially developed for resource allocation problems of the form:

$$\min_{x \in A_d} J_d(x)\ A_d = \{x : x = [x_1, \ldots, x_N]', \sum_{i=1}^{N} x_i = K, x_i \in \mathbb{Z}^+\} \tag{3}$$

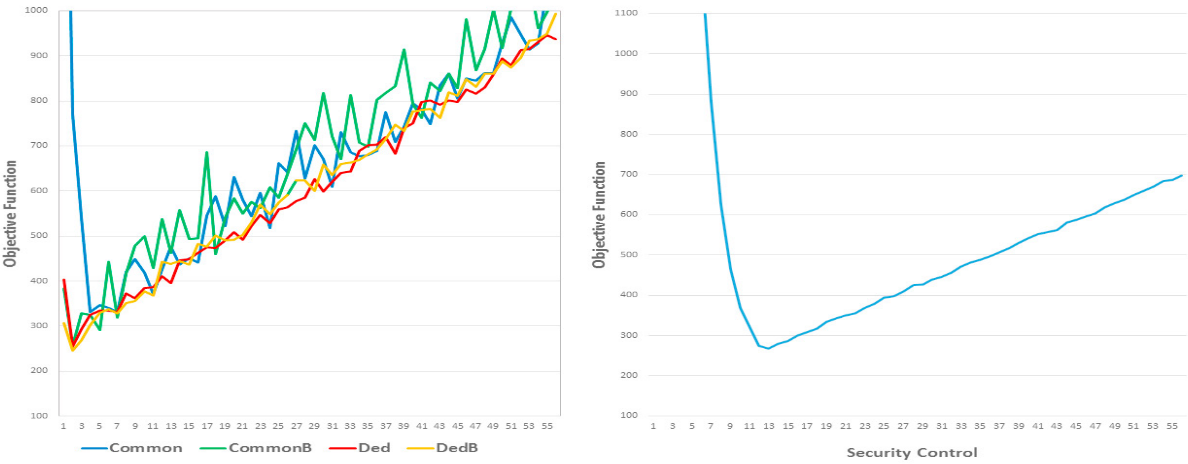


Figure 1. Trend of the objective function respect to the Check-in desks variables and security check point for only one company.

where $x$ is an $N$-dimensional decision vector with $x_i$ denoting the number of resources that user $i$ is assigned, subject to a capacity constraint and $J_d(x)$ is the cost incurred when the state is $x$. The integer capacity constraint is relaxed and a resulting surrogate problem is given by:

$$\min_{\rho \in A_c} J_c(\rho)\ A_c = \{\rho : \rho = [\rho_1, \ldots, \rho_N], \sum_{i=1}^{N} \rho_i = K, \rho_i \in \mathbb{R}^+\} \tag{4}$$

The basic idea of this method is to solve the continuous optimization problem above with standard stochastic approximation methods and establish the fact that when (and if) a solution $\rho^*$ is obtained it can be mapped into a discrete point $x = f(\rho^*) \in A_d$ which is in fact the solution of (**??**). The steps sequence is reported in Fig.3.

Note however, that the sequence $\{\rho_k\}$, $k = 1, 2, \ldots$ generated by an iterative scheme for solving (**??**) consists of real-valued allocations which are unfeasible, since the actual system involves only discrete resources. Thus, a key feature of our algorithm is that at every step $k$ of the iteration scheme involved in solving (**??**) the discrete state is updated through $x_k = f_k(\rho_k)$ as $\rho_k$ is updated. This has two advantages:

- the cost of the original system is continuously adjusted (in contrast to an adjustment that would only be possible at the end of the surrogate optimization process);
- it allows us to make use of information typically employed to obtain cost sensitivities from the *actual* operating system at every step of the process.

Note that there is an additional operation: the $\{x_k\}$ corresponds to feasible states based on which one can evaluate estimates $\nabla L_c(\rho_k)$, calculated on actual system $x_k$ (not the surrogate state $\rho_k$, see step 3). We can therefore see that this scheme is intended to combine the advantages of stochastic approximation type of algorithm with the ability to obtain sensitivity estimates with respect to discrete decision variables.

Given the values of the parameters, considering the trend of the objective function, the set $X$ represents our decision variables for the surrogate method, and the security checkpoint is calculated via enumeration. In fact, the evaluation of the security checkpoint is not a complicate task, but it can significantly increase the computation time of the surrogate method, because the research space has one more component.

Hence, we assume here that the objective function is:

$$\begin{aligned} J_d \quad &= \textstyle\sum_{i=1}^{N_C} C_1(comm_i + ded_i + commB_i + dedB_i) + C_4 \max(NmQueue_{commB} - N_t, 0) + \\ &+ C_5 \max(NmQueue_{dedB} - N_t, 0) + C_6 \max(NmQueue_{comm} - N_t, 0) + C_7 \max(NmQueue_{ded} - N_t, 0) \end{aligned} \tag{5}$$

**Steps of the Surrogate Method SM**

0 Initialize $\rho_0 = x_0$ and perturb $\rho_0$ to have all components non-integer.
For any iteration $k = 0, 1, \ldots$ repeat the following steps
1 Determine the selection set $S(\rho_k)$ using these steps:
Initialize
I= $\{1, ..., N\}$
v = $\rho$ - $\lfloor\rho\rfloor$
Repeat the following steps Until $I \neq \emptyset$
- $i = \arg\min_{j\in I}\left(v_j\right)$
- $y_i = v_i$
- $Wi = \sum_{j\in I} e_j$
- $v = v - y_i Wi$
- $I = I/\{i\}$

$S(\rho_k) = \{Wi - \lfloor\rho\rfloor, i = 0, .., N\}$
2 Select a *transformation function* $f_k$ such that
$x_k = f_k(\rho_k) = \arg\min_{r\in S(\rho_k)} \|x - \rho_k\|$.
3 Evaluate the gradient estimation
$\nabla L_c(\rho_k) = [\nabla_1 L_c(\rho_k), ...., \nabla_N L_c(\rho_k)]^T$,
using the following relationship
$\nabla_j L_c(\rho_k) = L_d(x^j) - L_d(x^k)$, where k satisfies
$x^j - x^k = e_j$ (versor with $j$-th component equal to 1).
4 Update state: $\rho_{k+1} = \pi_{k+1}[\rho_k - \eta_k \nabla L_c(\rho_k)]$.
5 If some stopping condition is not satisfied, repeat steps for $k + 1$. Else set $\rho^*$.

Figure 2. Steps of SM

And the problem formulation is:

$$\min_{X\in A_d} J_d(X, f), \quad A_d = \{X := [X_1, \cdots X_{N_C}]', min_{X_i} \leq X_i \leq Max_{X_i}, x_i \in \mathbb{Z}^+; \textstyle\sum_{N_C}(X_i) = Max_{x_{ck-in}}\} \quad (6)$$

In Figure 3 our solution approach is depicted to clarify the integration of the simulation module into the optimization algorithm. For each updating step of the surrogate state (step 4 of figure 2) we compute $N + 1$ times the objective function value by the simulation module. Hence, it becomes crucial to develop an efficient simulation module which performs an acceptable computation time.

## 4. Test analysis

In this subsection we provide a short description of the probability distribution of the parameters that we consider for the generation of the instances processed by the simulation module.

We consider the simulation time divided into 32 time slots, each of 15 minutes. The distribution of the passengers arrival is depicted in Figure 4. The maximum number of check-in desks that can be opened is 56, while the maximum number of security control check-points is 25.

In each slot the inter-arrival time is uniformly distributed.

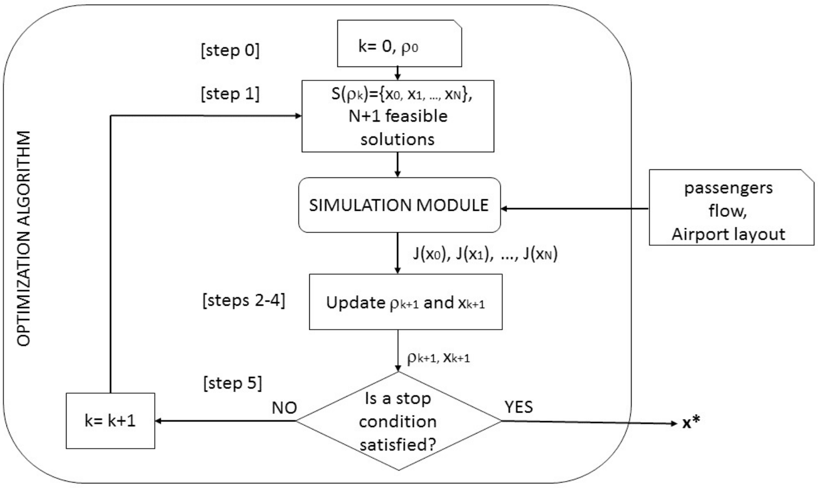


Figure 3. Schema of the solution approach: integration of the Simulation Module in the Surrogate Method.

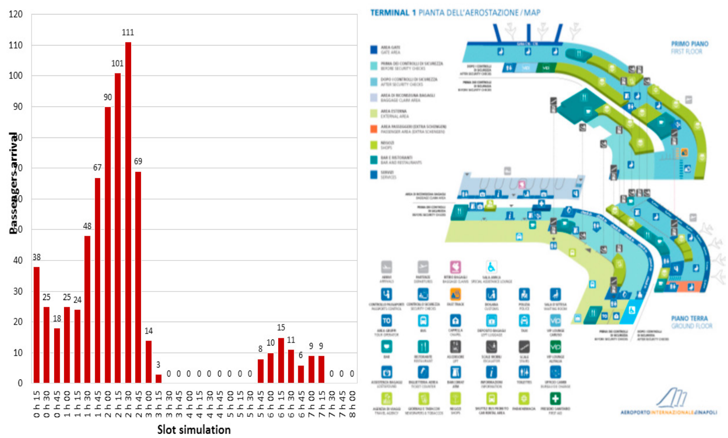


Figure 4. Distribution of the passengers arrival and layout of Napoli-Capodichino airport.

We assume that the 68% of the passengers are passengers, the 7% are business passengers and the remaining 25% smart passengers. Moreover the 60% of the check-in desks are common and the 40% are dedicated. The tolerance threshold for the passengers is set to 15.

Let $N_{group}$ be the number of people of the group each passenger belongs to. Let $N_{bag}$ the number of baggage each passenger has got. The values of $N_{bag}$, which change respect to the value of $N_{group}$ associated to the tourist passenger, are reported in Table 4. The 60% of business passengers have no luggage and the 40% have only one luggage.

| N_bag | N_group 1 | N_group 2 | N_group 3 | N_group 4 |
|---|---|---|---|---|
| 0 | 41 | 15 | 10 | 7 |
| 1 | 43 | 40 | 33 | 14 |
| 2 | 1 | 40 | 30 | 8 |
| 3 | 5 | 4 | 27 | 71 |
| **C_1** | **C_2** | **C_3** | **C_4 = C_5** | **C_6 = C_7** |
| 12.5 | 10 | 20 | 15 | 10 |

Table 1. Distribution (%) of variable $N_{bag}$ (tourist passengers) and unit cost values (euros)

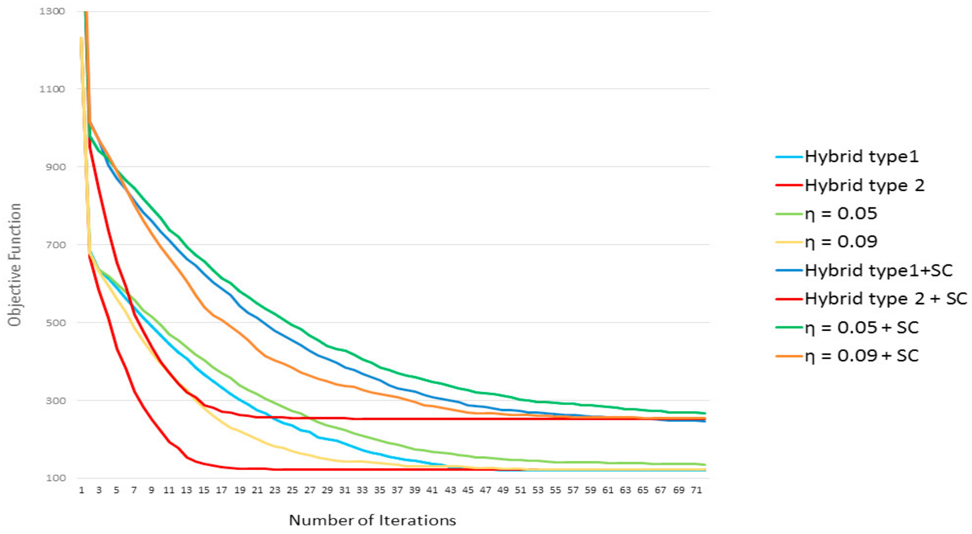


Figure 5. Rate of convergence for different step size with or without SC.

The results we report in the following are the mean values calculated on 20 different run with the same probability distribution of the simulation parameters.

The speed of convergence of the Surrogate Method depends not only on the characteristics of the objective function but also on the choice of the step size ($\eta_k$ in Figure 2). For this reason we have tested different step sizes and two different procedures: one is static (just one value for $\eta_k$) and one is hybrid ($\eta_k$ changes considering the gradient's value). In Figure 4 we report on the Type1 where $\eta_k \in \{0.0070.06\}$ and Type2 where $\eta_k \in \{0.0050.02\}$.

The Surrogate Method for the check-in management problem is very fast, but it is faster with a hybrid step (it needs 32 iterations instead of 44 for a particular realization of one company). Each interaction of the Surrogate Method needs more objective function evaluation. For this reason we consider:

- *number of iterations*: the number of the iterations to obtain the optimal/sub-optimal solution
- *number of simulation*: the number of simulation to compute the value of the objective function before computing the optimal/sub-optimal solution

In Figure 4 the rate of convergence is reported. It is evident that the surrogate method applied both at the check-in and to the security control needs more iterations to converge to the optimal solution (or near to optimal). Obviously the value of the objective function becomes larger when also the security control is performed, since the cost of the security control is considered in the objective function calculated from the surrogate method. In Table 2 the computation time (in seconds) for the surrogate method with and without the security control check-points variable is reported. Given the values of the decision vector, the simulator takes one hundredth of a second to give the objective function value. Also in this simple case the calculation of *sc* by enumeration is more convenient (consider the sum of the first and the third columns respect to the value of the second column). Obviously, if we consider a set of companies the problem becomes more complex: the dimension of decision vector becomes bigger and the objective function presents an higher number of local minima. Hence the surrogate method needs more iterations to find the optimal solution, therefore the surrogate method should be applied only to the check-in variables.

Moreover, as regard to the discomfort costs, the results related to the test instance give that the queues at the check-in desks, for all the check-in types, always satisfy the tolerance threshold $N_t$; on the contrary we have an additional discomfort cost for the security control check-points.

| $\eta$ Type | Check-in desks | Check-in + SC | SC |
|---|---|---|---|
| Type 1 | 2.6 | 4.7 | 0.8 |
| Type 2 | 1.7 | 3,4 | 0.8 |
| $\eta$ = 0.05 | 2.9 | 5.8 | 0.8 |
| $\eta$ = 0.09 | 3.3 | 6.1 | 0.8 |

Table 2. Computation time (sec) with or without Security Control

## 5. Conclusions

In this paper we present an efficient algorithm for determining the number of critical resources at the airport terminal departure operations. This optimization algorithm, based on the Surrogate Method that integrates a simulation module, minimizes a generalized cost function that takes into account not only the cost, but also the passengers' satisfaction. This is a preliminary study, in fact we apply the solution approach to only one airline company. Nevertheless the problem is already hard since the objective function presents many local minima. In future research we aim to apply the procedure to a set of companies and compare it with other optimization algorithms. The results of such further step could be useful both to optimize an airport departure area and to design the size of a departure area for a new airport.

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