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A SIMULATION-BASED ARCHITECTURE FOR SUPPORTING STRATEGIC AND TACTICAL DECISIONS IN THE APRON OF ROME-FIUMICINO AIRPORT

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ABSTRACT

In this paper we describe an architecture for the evaluation and optimization of aircraft ground movements in apron taxiways. The paper aims at providing an effective methodology for supporting the decision-makers involved in both the apron design and management phases. The purpose deriving from the utilization of the proposed approach consists in obtaining substantial improvements in the level of service with a reduction in congestion and ground delays within airports while considering safety aspects like aircraft separation. The methodology relies on a modular architecture. A simulation-based architecture, in which an optimization module is included, has been developed; an information feedback between simulation and optimization modules is enabled. The validation has been performed through the data of the apron of Rome-Fiumicino Airport. The computational results show a reduction in aircraft flowtime and a relevant decrease in aircraft ground flows. Interesting issues related to strategic modification of system configuration are presented.

1 INTRODUCTION

The increasing trend of demand for air transport over the last years has led airports worldwide to make large investments in order to increase capacity, improve the efficiency, control congestion (Stamatopoulos, Zografos, and Odoni 2004). Expansion planning usually involves a long term perspective. In response to this trend, the use of Decision Support Systems (DSS) has been steadily growing (Andreatta et al. 1998). More in particular these DSS models usually include analytical models and simulation models. However, they often suffer from lack of integration or limitations in flexibility and usability (Andreatta et al. 1998). Moreover, many existing models (analytical and simulation models) are characterized by an inadequate level-of-detail in comparison with the decision levels that are required.

Design and implementation of DSSs require the continuous investigation of new architectures in order to enable the decision-makers to operate effectively and efficiently for complex service systems (e.g. airports). According to Glover, Kelly, and Laguna 1999, new approaches, in which an integration between simulation and optimization is provided, have been created with the objective of "handling decision-making problems in business and industry that could not be adequately approached in the past".

In this paper we describe a simulation-based architecture which is composed by a simulation model and an optimization module. The architecture has been developed in order to enable the evaluation and optimization, under a strategic viewpoint, of aircraft ground movements in apron taxiways at Rome-Fiumicino Airport. According to ICAO-Annex14 and ICAO-A-SMGCS, the apron is "a defined area on a land aerodrome, intended to accommodate aircraft for purposes of loading or unloading passengers, mail or cargo, fuelling, parking or maintenance" (EUROCONTROL 2003).

Rome-Fiumicino Airport is one of the busiest in Europe: in 2004 more than 28 millions of passengers, about 310.000 aircraft movements and more than 175.000 tons of handled freight have been recorded (Assaeroporti 2004).

The remainder of this paper is organized as follows: in Section 2 we first present the problem description and a brief state of the art of existing models and tools. In Section 3 we then describe our integrated optimization-simulation approach focusing on methodology; system description, simulation model and optimization module are presented in Section 4 and 5. Section 6 is devoted to computational results and performance evaluation, Section 7 to implementation issues. Conclusions follow.

2 PROBLEM DESCRIPTION AND EXISTING TOOLS

An airport is composed by two parts: the *airside* and the *landside*. The *airside* includes runways, taxiways, aircraft stands, apron gate areas, etc. (Andreatta et al. 1998; Cheng 1998). The apron is "a defined area on a land aerodrome, intended to accommodate aircraft for purposes of loading or unloading passengers, mail or cargo, fuelling, parking or maintenance" (ICAO-Annex 14, ICAO-A-SMGCS, Eurocontrol 2003). The *landside* includes gates, terminals and other airport facilities.

According to Cheng (1998) we can identify the aircraft delays in two main categories: air delays and ground delays. The first category includes holding and vectoring delays by approach fix and runways. The second one is related to taxi-in, taxi-out delays and, in general, apron-gate delays. The apron therefore is an element of the *airside*, whose related delays significantly impact on level of service (e.g. aircraft flowtime across the apron area), efficiency, operating procedures, such as other *airside* elements.

Moreover, another aspect has to be considered: aircraft ground movements in apron taxiways are subjected to regulations and constraints related to safety like aircraft separation, cross points occupancy, procedural constraints (see also Capozzi 2003). Therefore these issues must be taken into account while facing problems related to possible traffic congestion in apron taxiways.

2.1 Problem Description

The problem we face is to identify, for each aircraft in a generic instant of the time horizon, an optimal path from its gate to a given runway entrance for take-off or from its runway exit to its gate position, while respecting a determined safety distance (separation).

The safety distance depends on aircraft type.

A similar problem statement is presented in Gotteland et al. (2001).

Our study is bounded to the apron area: we don't consider issues related to runway capacity or runway delay, ground holding out of the apron, gate assignment. We only focus on optimization and balancing of aircraft ground flows in apron taxiways and taxilanes.

The objective is twofold: gaining a reduction in (*i*) apron traffic congestion and (*ii*) aircraft flowtime (i.e. the time spent between a runway entrance/exit and a gate or aircraft stand). So doing we also expect to observe a better balancing in the utilization of apron taxiways which could have a positive impact on safety.

Some of the main difficulties that could arise are related to:

- exact time for departure/arrival
- procedural constraints
- safety aspects
- access restrictions
- intersecting apron taxiways
- airline priorities
- aircraft speed uncertainty.

2.2 Existing Models and Tools

A large number of models and tools are available to face problems related to design and management of airports *airside/lanside*. We refer to Odoni et al. (1997), and to THENA Consortium (2002) for a very exhaustive review of available tools and models with related features. Most of them are simulation-based and/or analytical model-based.

Among these, it is interesting to point out that SIMMOD, TAAM, The Airport Machine (ASI) and MACAD are advanced tools which include apron in their operating scope. In particular, SIMMOD and The Airport Machine provide a very high level-of-detail of *airside* models while covering, through node-link structures, a complete range of aircraft operations and physical aspects. However, even if they represent very useful tools for quantitative evaluations of airport efficiency (Andersson et al. 2000), they also require well-trained and expert users due to a steep learning curve (Stamatopoulos, Zografos, and Odoni 2004); moreover they need a very significant effort for the calibration and validation of airport model (Andersson et al. 2000).

MACAD is a DSS which aims at supporting strategic planning. It considers *airside* models under a macroscopic point of view in order to provide approximate estimates related to capacity and delays of airfield components (Stamatopoulos, Zografos, and Odoni 2004; Andreatta et al. 1998). Essentially, it relies on analytical models except for the apron model which is a macroscopic discrete-event simulation model. MACAD has been positively evaluated at Rome-Fiumicino Airport and in six European airports (Stamatopoulos, Zografos, and Odoni 2004).

In comparison with MACAD our simulation-based architecture for decision support is focused only on the apron area of Rome-Fiumicino airport (i.e. it doesn't concern other components of the *airside*) for supporting strategic decisions with a medium level-of-detail: we exploit a discrete event simulation model of Rome-Fiumicino apron while capturing detailed data only for meaningful indicators related to global routing of airplanes across the system. A system-view could be obtained in terms of apron capacity and Level of Service (LoS) in order to identify critical sub-areas of the apron while observing aircraft ground circulation. Moreover, the proposed simulation-based DSS has been designed and implemented for enabling, if desired, a deep understanding of particular elements or parameters of the system: in fact many other input data and indicators could be easily introduced or modified whether tactical decisions are required. We refer to more detailed features and attributes related to model entities (i.e. aircraft type, aircraft speed, etc.) and infrastructure (i.e. availability of facilities, push-in or push-out conflicts generated by safety rules in the taxifield, etc.). Many of these attributes are already taken into account for an adequate level-of-detail suited for the strategic objectives of our study. The simulation model is characterized by a network-based structure representing the real system configuration; hence bottlenecks and congested apron taxiways or taxilanes could be identified. A detailed description of the architecture of our simulation-based DSS (from now on DSS model) is provided in the following Sections.

3 SIMULATION-BASED ARCHITECTURE: METHODOLOGY AND TOOLS

3.1 Methodology

The proposed approach relies on a modular architecture based on a discrete event simulation model. The simulation model also includes an optimization module. An information feedback between simulation and optimization is enabled during each simulation run.

The objective we pursued in designing the proposed architecture consists in providing a verified and validated methodological approach. In a complex environment we would support decision-making processes that could include system design, hence strategic aspects, as well as system management considering tactical issues.

Figure 1 illustrates our integrated optimization-simulation approach included in the architecture of the DSS model. Each element of the DSS model is described in Section 5.

The simulation model represents the real system configuration (i.e. Rome-Fiumicino apron) and it considers all the necessary constraints, even those related to aircraft circulation.

The optimization module is embedded in the simulation model. The optimization module is devoted to solve the problem described in Section 2.1. The problem has been modeled as a Shortest Path Problem (SPP) over a weighted undirected graph *G (V, E)* which corresponds to the apron network. The weight w_{ij}, for all $i,j \in V$, associated to a generic edge $(i,j) \in E$ reflects the measure we take into account for minimizing traffic congestion. In particular a well-known solving algorithm for SPP has been implemented in the optimization module. This choice has been made in order to have very simple components of the architecture to be analyzed under the viewpoint of functionality. As a consequence, verification and validation of each element of the architecture, then of the overall architecture, have been made possible. It could be possible to introduce in the existing architecture new problem formulations and more advanced solving algorithms over the graph *G*.

The inclusion of discrete event simulation is related to the indisputable advantages deriving from an essential tool able to support decision-makers in testing and validating their choices before realizations (see also Gotteland et al. 2001). Besides, the airport apron is very suitable for the adoption of a simulation-based approach. The real challenge is to perform a satisfying model validation that is an essential goal of each simulation project. In our study, as expected, the model validation phase represented a very important milestone. Our approach required an high-fidelity representation of system behavior because we would reproduce actual output in response to actual input while respecting the known system performance. The data related to input, output, main performance about Rome-Fiumicino apron were available to operate a complete comparison between the real system and the simulation model.

The optimization module has been introduced in the prototype of the DSS model after the validation of the simulation model. The optimization module is devoted to the shortest path computation for each aircraft in a generic step of simulation run (see Section 5.3). In this process a selection of preferential taxiing paths and alternative paths is performed in order to determine an optimal path to be assigned.

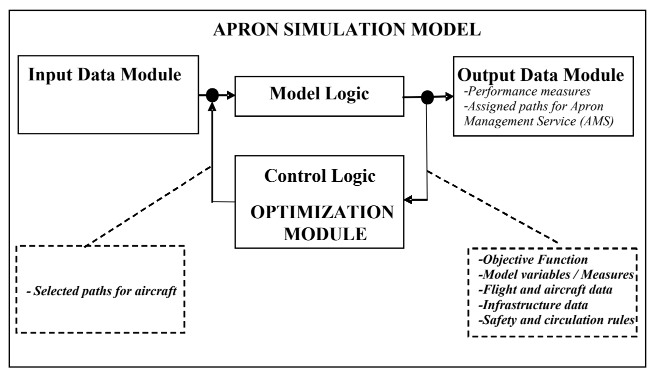

Figure 1: Architecture of the DSS Model

Concerning the main objective of minimizing the congestion, the optimization module operates a balancing of aircraft flows across the apron.

The optimization module "knows" how the model state evolves because, for each computation, its input derive from current "system" state: the optimization module drives the "system" evolving process.

In our architecture the introduction of optimization techniques deriving from Operations Research aims at strengthening the benefits that, in general, simulation involves. Within an high fidelity model of the real system we would embed the intelligence that could effectively drive options and alternatives of decision-makers; as a consequence, macroscopic and significant, more detailed, aspects have to be observable whether required.

The advantage of incorporating optimization methods in validated simulation models via their integration, when possible, could be appreciable in the following senses:

- testing impacts of solutions of analytical models in the dynamic behavior of a system. We refer to the iterative application of an optimization technique while the model state evolves during a simulation run
- selection of the most suitable optimization logic among different strategies contained in a proper set. The optimization strategy selected could depend on the model state observed during several intervals of the time horizon. We could design and/or adopt different objective functions for each class of possible system states
- possibility to verify the feasibility of solutions coming from the simulation model logic. An optimization module could be a filter able to prevent unfeasibility conditions fixed by constraints in the problem formulation.

Very interesting approaches face the problem of combining simulation and optimization. Some effective tools associated with these structured approaches, namely *Simulation Optimization*, have been developed (e.g. OptQuest, etc.). It could be stated that the merging of optimization and simulation has rapidly grown in recent years (April et al. 2003). Faster computers enabled this growth (Law and Mc Comas 2000). A rapid search over the simulation literature confirms this important and promising trend. It is important to point out that, according to Swisher et al. (2000), *Simulation Optimization* aims at determining "optimal input parameter values, where optimal is measured by a function of output (steady states or transient) associated with a simulation model". *Simulation Optimization* is well-suited for strategic studies also; it often relies on metaheuristic techniques. Recently, alternative approaches have been developed also (Dalal, Groel, and Prieditis 2003).

In a *Simulation Optimization* approach the performance optimization is based on decision variables and performance measures; optimization is pursued through the computation of simulation experiments often applying metaheuristics outside the simulation model.

However, our approach is intended to merge simulation and optimization in a different sense.

We embed an optimization logic in a simulation model. In order to investigate and test an optimizing control logic through the simulation model we enable an information feedback between them.

Through our DSS model we can also obtain strategic directions about model parameters (these issues are presented in Section 6). The main objective of our study is to reduce possible congestion effects on the existing system as well as obtaining a satisfying LoS. So doing we gain also strategic suggestions about system capacity without neglecting data of each simulation run.

Concluding this brief discussion, in our DSS model the performance optimization is pursued internally, over a given system configuration we modeled in the simulation environment. We can conclude that it could be interesting to investigate the application of *Simulation Optimization* to our DSS model.

3.2 Tools

The selected tools for testing our integrated optimization-simulation approach are listed below:

- Simulation: Arena 8.0 Professional
- Optimization: Visual Basic for Application (VBA)
- Data Import/Export: Microsoft Excel/Microsoft Access and VBA
- Output Analysis: Microsoft Excel.

The simulation model embodies the optimization module exploiting a particular feature of Arena and VBA (see Bapat and Sturrock 2003).

The model is flexible for the introduction or modification of parameters, variables, attributes, and particular performance indicators. It could be integrated with simulation/analytical models related to other elements of airport *airside*, for instance by sharing a common database (Andreatta et al. 1998). An approach which includes optimization and simulation is presented in Yan, Shieh, and Chen 2002, and it is related to face the gate assignments problem whose solutions, in general, are considered as input of our DSS model.

4 SYSTEM DESCRIPTION AND MODELING ISSUES

Rome-Fiumicino International Airport has got a leading role in Italian air traffic scenario. It is a 3 runways aerodrome and it is the most important Italian airport considering the aircraft movements and the number of passengers per year.

Traffic data mentioned in Section 1 highlight the complexity and difficulty in decision problems related to this complex service system due to the huge variety of decisions and actors involved in an airport environment; coordination activities have to be effectively managed.

The first step in modeling Rome-Fiumicino apron consisted in finding a flexible mathematical instrument for analyzing aircraft ground movements; furthermore it was important to manage a well-known instrument by which could be tested well-known optimization techniques and algorithms.

The instrument we decided to adopt is a graph *G(V,E)* (Figure 2) as presented in Section 3.1. It fits our requirements of flexibility and implementation of classical optimization methods.

The identification of two correlated sets was then required: vertices and edges of the graph. For this purpose we identified all the possible positions within the apron. In this area we identified the positions where one of the following three conditions can occur:

- starting position
- final position
- possibility for aircraft of routing towards more than one direction (there's more than one eligible direction).

The adoption of this approach has led to identify 215 vertices; on the ground of the three above mentioned conditions, we identified three sub-sets of vertices:

1. External vertices: they represent the conjunction of manoeuvring area to apron area, i.e. the starting position of a path associated to an aircraft that enters the system, otherwise they represent a final position associated to an aircraft that leaves the system. We identified 10 external vertices
2. Parking (stand) vertices: they represent parking stands in apron area, i.e. the starting position of a path associated to an aircraft that leaves the system, otherwise they represent the final position associated to an aircraft that enters the system. Parking vertices are equal to 101
3. Internal vertices: they represent positions where aircraft can select different directions. They cannot be starting or final positions in a path associated to an aircraft but only intermediate positions in the moving process. Internal vertices are equal to 104.

According to existing maps of apron area, we built the planar undirected graph whose edges represent the topological connections between vertices. Edges of the graph are equal to 236.

Afterwards a network of the apron has been defined through the association to each edge (i,j) of a weight w_{ij}.

For each edge we defined three main characteristics to be taken into account in order to compute current weights and traffic conditions (e.g. transfer times, occupancy rules, etc.):

1. Length
2. Direction
3. Capacity.

We also identified 842 preferential taxiing paths.

We then defined the following performance measures which could well-fit our objectives in order to evaluate LoS and congestion issues:

- Mean Flow Time
- Maximum Flow Time
- Mean Time in Queue
- Maximum Time in Queue
- Average Number in Queue
- Maximum Number in Queue
- Mean Apron Network Occupancy.

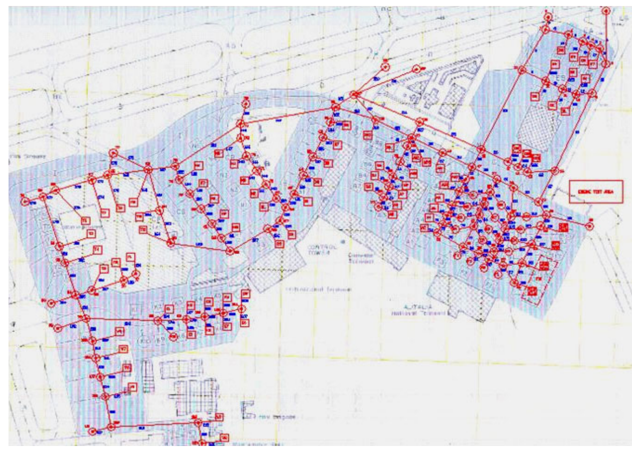

Figure 2: Graph of the Apron

5 ELEMENTS OF THE DSS MODEL

The DSS model is simulation-based. It consists of a simulation model which exploits a module for data import and a module for data export. The simulation model is divided into two parts: the model logic, which represents the physical behavior of aircraft in the system, and the control logic in which the optimization algorithm operates (i.e. optimization module). We implemented the simulation model logic connected to the module devoted to the control logic.

5.1 Data Import/Export Modules

Input data are imported into the model logic through proper routines. All imported data correspond to the actual system.

Imported data could be divided into two categories: topological data and management data.

Topological data are related to physical characteristics of the infrastructure like stands, length and capacity of edges. The utilization of custom-made routines for input data brings advantages in terms of flexibility since even physical modifications of the system can be automatically imported.

Management data are related to external decision-making processes (i.e. stands/gates assignment, arrivals/departures planning, and preferential taxiing paths). The actual outcomes of these processes are input of the simulation model. The model design criteria makes it possible that each external decision-making process could be easily implemented through the manipulation of the related routines which can be connected to our model.

Output data are exported from the model through internal routines. All data are automatically recorded in external spreadsheets facilitating to operate both statistical analysis and evaluation of system performance.

5.2 Simulation Model Logic

In our simulation model logic the entities correspond to airplanes; their ground movements occur through the network described in Section 4.

The input data imported into the model represent the actual traffic data of Rome-Fiumicino airport.

We assigned to each entity several attributes in order to reproduce the real system dynamics. The main attributes are:

- Arrival / Departure time
- Aircraft length: it depends on aircraft type and it impacts on edge capacity
- Aircraft sequence: list of vertices to be included in a generic aircraft path
- Aircraft speed
- Starting vertex
- Final vertex
- Parking (Stand) vertex
- Edge to be seized
- Edge to be left (released)
- Direction
- Distance to be covered.

The assignment of attributes is an essential process for modeling synchronization and other features; edges are considered as resources with a defined capacity and their utilization depends on aircraft length and separation distance (safety rules).

In the simulation model logic five main processes are performed:

1. Entity Creation process: entities are created according to actual system data (Arrival/Departures chart)
2. Entities Disposing process: entities reach their final position (i.e. parking vertex/external vertex)
3. Queuing process
4. Moving process
5. Routing process: to each entity is assigned a taxiing path (preferential or alternative).

The model logic is composed by two main parts:

1. Arrivals and Departures logic
2. Network logic.

In the Arrivals and Departures logic we perform the Entity Creation process and the Entity Disposing process; in the Network Logic the other processes listed above that are ruled by the control logic.

5.3 Optimization and Feedback in the Control Logic

The optimization is implemented in the control logic module.

Optimization is based on the application of a shortest path algorithm over a weighted graph that is updated at each step of the simulation run. In general, preferential taxiing paths are assigned to aircraft. For each path the total cost is computed. An alternative path (different from a preferential taxiing path) is assigned whether a lower total cost is computed. The cost computation is performed taking into account the ground movements recorded in the network in order to obtain a substantial balancing of aircraft flows. So doing we enable an information feedback concerning the values of model variables (i.e. system or user-defined variables that represent the system state); hence the entity path assignment is a dynamic process based on path cost computation performed by the optimization module. The input of the optimization module is represented by all the necessary elements for path assignment (i.e. objective function, topological data, management data, rules and constraints, variables, etc.). The output of the optimization module is then a path to be assigned to an aircraft.

6 COMPUTATIONAL RESULTS AND PERFORMANCE EVALUATION

Main computational results are presented in Table 1. In order to evaluate LoS and congestion issues, we selected mean and maximum values of aircraft flowtime, queue statistics related to internal vertices or intersecting points within the apron, network occupancy. Network occupancy and then the utilization degree of edges support the evaluation of safety aspects also.

Table 1 summarizes the results obtained from simulation runs of the validated model (AS-IS model) which simulates the actual situation; in this model only preferential taxiing paths are assigned to aircraft. In the same table we then present the results referred to decision-making processes through the DSS supported assignment of paths (DSS model); in this model a set composed of preferential taxiing paths and alternative paths are assigned to aircraft. Deviations (percentage) in terms of performance measures between the AS-IS model and the DSS model follow.

Comparing the output of the DSS model with the AS-IS model, we observe an estimated reduction in aircraft mean flowtime equal to 9.97% and, more important, a relevant decrease in maximum flowtime (about 18%). This issue already allows to consider that possible congestion effects in aircraft circulation are reduced. This consideration is confirmed by the evaluation of queue statistics: a strong reduction in terms of maximum time in queue (33,7%) in conjunction with the corresponding mean value reduction (4.6%).

The average number of aircraft in queue is stable in the DSS model also but, even in this case, we observe a substantial decrease in the maximum queue length which has a deviation equal to -14,6%.

We can conclude that, in terms of LoS, the observation of results lefts margins to gain substantial improvements, even considering the deviation which, in general, could affect the performance while comparing the actual system and the related simulation model.

Concerning the statistics over the number of aircraft that seize the network resources (i.e. the network edges), we observe a relevant decrease in mean network occupancy (31,7%). This issue is very important in terms of safety due to the fact that a lower number of aircraft that simultaneously occupy the network reduces the probability of conflicts and severe congestion occurrence. Considering also the edges utilization we observe that a better balancing (see Figure 3) is obtained, confirming that an harmonization of aircraft flows is gained through the exploitation of less loaded edges in the path assignment process.

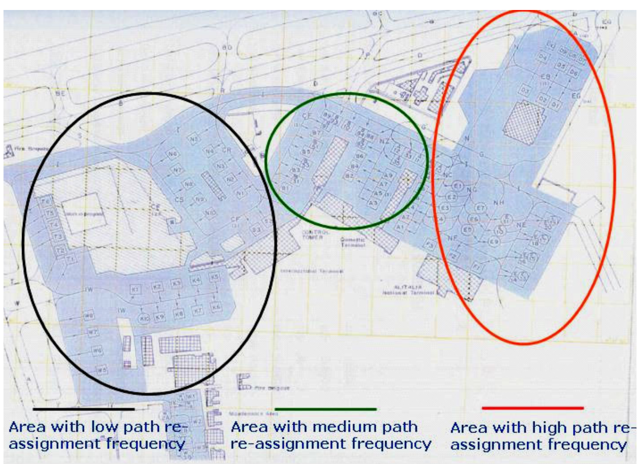

Figure 3: Frequency-based Path Re-assignment Areas

These results are useful in order to have also a macroscopic view of aircraft flows recorded within the network. This system-view suggests other strategic issues: in fact we observed the frequency related to path re-assignment process (i.e. the modification of preferential taxiing paths occurred in each area of the apron). We observe that the East area of the apron is characterized by an high frequency of path re-assignment to aircraft: in general this area is devoted to the stands for domestic flights. Within the East area more congestion effects are expected than in the areas of the apron devoted to stands for international or intercontinental flights (see Figure 3).

Two reasons justify this evaluation: (*i*) the higher percentage of domestic flights in comparison with international or intercontinental flights and (*ii*) the mandatory assignment of some preferential taxiing paths to some international or intercontinental flights.

Therefore, we can conclude that the East area could be the first candidate whether modification in taxiways/taxilanes configuration will be considered within the apron area (e.g. realization of new taxiways/taxilanes or enlargement of existing ones).

Table 1: Values of Performance Measures for the Validated Simulation Model (AS-IS Model) and the Optimization-Simulation Approach (DSS Model)

Performance Measures	Units	AS-IS model	DSS model	Deviation (%)
Mean Flow Time	Minutes	10.63	9.57	-9.97
Max Flow Time	Minutes	14.72	12.00	-18.47
Mean Time in Queue	Minutes	1.08	1.03	-4.62
Max Time in Queue	Minutes	2.97	1.97	-33,67
Avg Number in Queue	Number of Aircraft	5.78	5.69	-1.55
Max Number in Queue	Number of Aircraft	9.02	7.70	-14.63
Mean Apron Network Occupancy	Number of Aircraft	8.43	5.76	-31.67

7 IMPLEMENTATION ISSUES

At operational level, the aircraft path (re-)assignment is a complex process which requires an integration with other equipments to be effectively performed in real-time while obeying safety rules and standards. A tower/ground controller must monitor the surface operations exploiting the automatic assistance provided by an Advanced Surface Movement Guidance and Control System (A-SMGCS) supported also by a Surface Movement Radar (SMR). In fact a real-time aircraft path (re-)assignment process must meet all the safety requirements. Within an aerodrome, continuous check, evaluation, and control of the real-time traffic situation, and related constraints for safety rules, are needed. Any case, under these conditions, warnings and emergency situations must be manageable in real-time by the controllers in order to prevent potential risks and therefore modify their instructions while enabling a simple and fast interaction between themselves and the module of the SMGCS devoted to Route Planning (RP). RP (i.e. the process of planning paths to be assigned to aircraft) is one of the service included in a A-SMGCS; the other, prioritized, services are: Surveillance, Control, and Guidance (EUROCONTROL 2003). Hence, in the event of any paths modification needed, a re-planning process in this service should be easily coordinated and enabled.

At the moment, the proposed DSS model is intended to be a basis for possible, more advanced, applications related to surface movements of aircraft. It could be useful for managing strategic and tactical aspects through an off-line use by air navigation services or airport authorities. A real-time operational use of the proposed DSS model should need investments on proper technologies and further investigations. Nevertheless, under these conditions, it could be integrated and implemented it in an A-SMGCS.

In the solutions provided by the DSS supported path re-assignment process, we observed that, in comparison with the base case (i.e. the AS IS model), a decrease in the number of way-points virtually given to pilots for reaching the final position (i.e. graph's vertex representing a runway entrance or a gate position) is obtained. The estimated decrease is approximately equal to 10%. This result is probably due to the configuration of many preferential taxiing paths originally assigned to domestic flights. These paths often consist of a large number of internal vertices. The re-planned paths, generated by the DSS Model, are shorter than the preferential taxiing paths while respecting the circulation constraints of the apron. We also underline that a constraint in the SPP formulation consists in excluding any loop for aircraft over the graph $G(V,E)$.

From a safety perspective, the reduced apron occupancy seems not to impact on the modification of preferential taxiing paths (virtually) communicated to pilots; in any case the pilots of aircraft are always addressed by traffic controllers while they're moving in the aerodrome. So doing the real traffic situation should be under control avoiding risks about prohibited taxiway/taxilane or possible collisions.

8 CONCLUSIONS

This paper is focused on highlighting the utility deriving from the exploitation of discrete event simulation in conjunction with optimization techniques for solving problems related to the design phase as well as management phase of elements included in complex service systems like airports.

In our study we investigated a simulation-based architecture for a DSS model which aims at supporting the path assignment process to aircraft while they're moving in the apron area of Rome-Fiumicino Airport. So doing we would predict and reduce congestion effects, improve LoS, and gain strategic directions also.

The prototype of the DSS model that has been implemented would be general: it has been designed in order to be flexible in case of structural modifications of the aerodrome and in terms of reusability; moreover our DSS model lefts the possibility of varying the weights of the network edges (i.e. apron taxiways/taxilanes) with alternative criteria in order to take into account other issues, alternative policies or requirements depending on particular needs. Other problem formulations over the graph representing the apron could be introduced and, consequently, more advanced solving algorithms also.

Future research tasks will concern the possibility to adopt *Simulation Optimization* approaches for our DSS model, which embodies an optimizer too, for considering other strategic issues useful for the optimal input parameters sizing. Our aim is to strengthen the advantages of combining and merging simulation and optimization techniques in several senses.

Computational results show that through the adoption of a very simple algorithm for the SPP, good performance estimates in terms of LoS for the aircraft ground movements are obtained.

The proposed approach suggests also strategic directions about possible investments in structural modification of the aerodrome.

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