A SET OF APPROXIMATE AND COMPATIBLE MODELS FOR AIRPORT STRATEGIC PLANNING ON AIRSIDE AND ON LANDSIDE

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Abstract

The use of models as decision-support tools for the development of airport infrastructure has been steadily growing. However, existing models still suffer from lack of integration and from severe limitations in their flexibility and usability. In this paper we propose two models for airport strategic planning on airside and landside, and discuss their connectivity. The models proposed are macroscopic in nature, and provide estimates of the capacity and performance of the airport quickly and with little effort. With the use of a common database, these models can be integrated and share the same set of data. It has been illustrated that in this way the, sometimes significant, interactions between airside and landside operations can be captured.

Introduction

The modeling of airport operations has advanced significantly over the past 15 years and the use of models as decision-support tools has been steadily growing. However, existing models still suffer from lack of integration and from severe limitations in their flexibility and usability. For example, there is a sharp separation between models of "landside" elements of the airport (passenger terminal, baggage handling, and ground access) and of "airside" elements (runways, taxiways, aprons, aircraft stands, etc.). This makes it difficult to adopt a system-wide viewpoint of airport operations and efficiency. It is not uncommon for one group of airport planners to recommend changes in one part of the airport (i.e., on airside only or on landside only) without understanding the implications of these changes for the other part (i.e., for landside or for airside, respectively). Existing models for airside or for landside (e.g., SIMMOD, TAAM, The Airport Machine, ARCTERM, etc.) are also primarily "microscopic" in nature, incorporating a high level of detail in data and in system specification. Such models are inappropriate for use in many types of studies that require only approximate answers while examining a wide range of hypotheses and scenarios about future conditions at an airport.

In research projects initiated in January 1996 with support from the European Union and from the Milan Airport Authority, the authors have tried to address such deficiencies by providing an integrated set of very fast, flexible and easy-to-use models for performing strategic planning. They have developed two new models that span all the principal parts of an airport, one covering all elements of the airfield and the other all elements of the passenger terminal. Moreover these models can be operated with a common database, so they can be used in tandem. This paper will present the two models and their technical characteristics, as well as their connectivity.

The new airside model, MACAD, developed at the Athens University of Economics and Business, is aimed at assisting airport operators and managers in planning strategically for optimizing airfield capacity given (1) any particular level of (existing or predicted) demand and (2) a desired level of service. This airfield (airside) level of service is specified in terms of the amount of delay experienced by the aircraft using an airport. The emphasis of MACAD is therefore on capacity analysis and on estimation of delays associated with each level of capacity. In this way, the benefits of alternative capital investment strategies, innovative ATM technologies and procedures, and airport (airside) access policies can be quantified in terms of their implications on airfield delays and airfield level of service. MACAD models the airfield as a service network that consists of a series of components, each of which is used sequentially by aircraft operators. These components are: the arrival runway system, the arrival taxiway system, the gate/apron area, the departure taxiway system and the departure runway system. The model is primarily analytical (not a simulation), probabilistic and dynamic in that it accepts time varying demand and capacity profiles. It also incorporates an approximate airport weather model, which can be used to "simulate" the variability of local weather conditions and attendant change in airport configurations. MACAD includes a GUI that facilitates the data preparation process and the interpretation of the model's results. It is currently being tested at Rome's Fiumicino Airport, one of the busiest in Europe and is scheduled to undergo detailed evaluation during the next six months.

The lack of a satisfactory strategic model of landside operations motivated the creation of SLAM (Simple Landside Aggregate Model) at the University of Padova, in close co-operation with the Milan Airport Authority (SEA). SLAM is an analytical (not a simulation), aggregate model for estimating capacity and delays in airport passenger terminals. SLAM is designed to answer "what if" questions about alternative configurations of the various processing and holding facilities in a terminal. It consists of a network of modules, one for each facility of the terminal. These modules are based on a set of quite simple mathematical formulas: their objective is not to provide a thorough analysis of a given facility, but to be used for the estimation of the capacity of each facility (in terms of passengers per hour) and the level of service (LOS) associated with it. LOS is quantified both in terms of (1) "space available per facility occupant" and (2) waiting time for being processed. This is consistent with the recommendations of IATA and ACI. The required LOS standards are user-specified inputs, but default values can be provided. SLAM is equipped with an interactive GUI and provides, among its outputs, color-coded displays of

LOS achieved at each landside facility over any specified period of time.

SLAM has already been applied to the airports of Linate and Malpensa in Italy. An important application examined two scenarios for the large Malpensa 2000 terminal, scheduled to open in October 1998, one scenario assuming that Malpensa will become a "hub" for the Italian national air carrier and the other that it will not. A few other applications are currently being tested with potential users.

The MACAD Decision Support System

Objectives

The objective of the MACAD Decision Support System is to provide an integrated environment for assisting airport operators and managers in planning strategically for optimizing airside capacity. Planning at the strategic level requires the ability to examine approximately the implications on the level of service at the airport of a wide range of different scenarios and hypotheses about future conditions. MACAD provides the means to perform this type of "what if" analysis quickly and easily in a user friendly environment

System Outline

Scope of MACAD

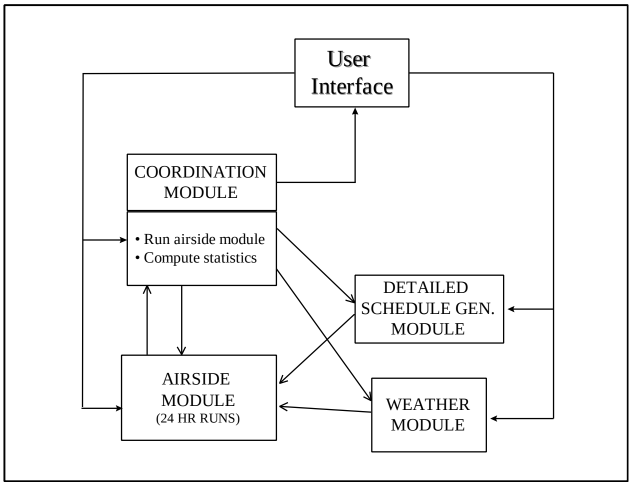
The scope of the MACAD DSS comprises the entire airport airside. The models it consists of are sensitive to the parameters which have a significant effect on airside capacity and level of service and are typically of interest to airfield strategic planning studies. These include: (1) airside demand characteristics such as total demand, temporal distribution of demand, presence of "hubbing", mix of aircraft types and mix of arrival and departure operations (2) airport geometry and operational characteristics such as number of runways simultaneously in use, configuration of the runway system, number of apron stands and gates and taxiing time from runways to apron/gates and vice versa (3) characteristics of the local air traffic control system, such as separation requirements between operations on the same or on different runways, quality of positional information available for arriving and departing aircraft, spacing accuracy achievable between runway operations (4) operational characteristics of the airfield such as aircraft processing ("turn-around") times in the apron/gate area, time required between successive occupancies of an aircraft stand by an aircraft, communication delays between tower and aircraft on the airfield and (5) alteration of weather conditions (in a statistical sense), to the extent that they affect the capacity of the airfield.

The components of the airside that pose capacity constraints and cause congestion, and are therefore of interest in studies at the strategic level are the runway complex system and the apron area. The capacity of the runway complex system is subject to the configuration (set of active runways for landings and takeoffs) and ATC procedures used that depend on the weather conditions and other constraints such as noise. This makes the capacity of the runway system dynamic with significant changes throughout the course of a day. Furthermore, the capacity of the runway complex needs to be shared between landings and takeoffs. For this reason, the capacity of the runway complex, for each different configuration is expressed as *the runway capacity envelope* that indicates the tradeoff between the maximum (under saturation) number of landings and takeoffs that can be achieved.

The capacity of the apron area depends on the number of stands, the types of aircraft each stand can accept, the mix of aircraft types that use the airport, the minimum handling time and the actual turnaround times dictated by the airline schedules. Since this capacity heavily depends not only upon the facilities of the airport and operational characteristics but also upon the particular schedule of flights (turnaround times) it is difficult to express it in a single number, rather it is more interesting to estimate the delays and utilization of the apron area under a variety of traffic scenarios.

System Architecture

The MACAD DSS is a synthesis of macroscopic - fast and easy to use - models for the analysis of the different elements of the airside. The integration has been designed in such a way that the, sometimes significant, interactions among the different components of the airfield, and the propagation of delays among them are captured.



The MACAD Decision Support System

As it is illustrated in the above Figure, the proposed system consists of five modules. A brief description of each one of them follows:

The "Airside" module is the most important module of the system. In this module, an estimate of the capacity, utilization and delays of the airside, given the (dynamic) configuration of the airside, the operational characteristics, and the demand for a 24-hour period, are computed. This module is discussed further in the next Section.

The "Weather" module generates weather conditions, on an hourly basis, for the duration of the run. This module can be very useful for the creation of realistic alterations of weather conditions that affect the use (and capacity) of the runway system. If the data are provided in a statistical way, the model uses a Markov chain model and a random number generator to determine the weather of each hour, taking into account the weather of the previous hour and the transition probabilities among the weather categories. Users of the system also have the option to provide the weather pattern for each hour for the duration of the run, and use, for example, data from a "typical" year in the past. The weather model associates each weather condition with a use of the runway system, in a deterministic or probabilistic way.

The "Detailed Schedule Generation" module generates detailed aircraft schedules based on aggregate descriptions of the demand, provided on an hourly base for the purpose of assisting users in the creation of a wide range of alternative demand scenarios as easily as possible. It assumes that arrivals are randomly distributed within each hour (following the pattern of the uniform random distribution) and it uses a random number generator to generate a detailed aircraft schedule. This is done for every hour and every aircraft type. Also, for each arrival, it generates a scheduled departure time, again using a pseudo random number generator given the statistics provided on the amount of time between the scheduled arrival and scheduled departure of aircraft, always allowing at least the average handling time. The fraction of airlines and domestic versus international flights are also taken into account in generating a schedule.

The "Coordination" module determines the sequence of operations and flow of data, calls the different modules of the system, and manages the statistics for the output.

Finally, the "User Interface" facilitates the data entry process by guiding users to provide the required information in a structured manner. Also, it illustrates the results graphically and textually such that users can readily obtain the information that is of interest to them. The user interface is windows based, and it includes the standard options of the windows based programs.

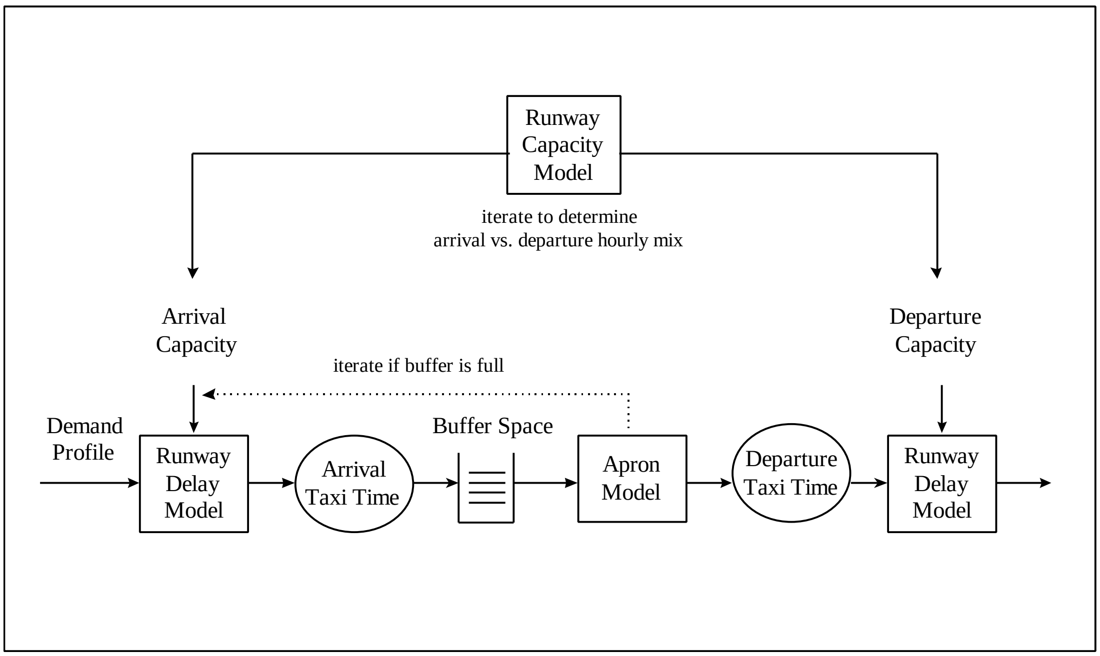
The Airside Module

The "Airside" module consists of three models having different scope and combined in such a way that an overall picture of the capacity and level of service of the airfield is obtained by taking into account the complex interactions among the runway system and the apron area. The three models are the following:

A Runway System Capacity Model – A generalized stochastic analytical model for the estimation of the capacity envelope of the runway complex, for a wide variety of runway configurations has been developed [Zografos et al, 1997]. This model consists of: (1) a single-runway capacity model; (2) a generalized two-runway model that extends the single-runway capacity model, and (3) algorithms for the evaluation of the potential capacity benefits from sequencing arriving aircraft. This model computes the runway capacity envelope that identifies the capacity limits for all mixes of arrivals versus departures, and explicitly takes into account the stochastic nature of aircraft operations.

A Runway Delay Model – An analytical model that utilizes algorithms developed by Kivestu [Kivestu, 1976], to solve the $M(t)/E_r(t)/1$ queue and compute the distribution of delays throughout the time interval of interest given the dynamic capacity and demand.

An Apron/Taxiway Macroscopic Simulation Model – A macroscopic simulation model whose main function is to compute the delays due to the limitation of apron stands, and the utilization of the apron area. This model identifies the stands that are most limiting (depending on the aircraft types, the type of flights, and the handler/airline they serve), and the ones that are underutilized for the configuration and the demand scenarios studied.



The Airside Module

These models are synthesized in the "Airside" module by performing the sequence of computations as shown in the above Figure. The "Airside" module uses the runway capacity model to determine the capacity envelopes for all possible runway configurations. After the determination of the runway capacity envelopes, the system uses the runway delay model to estimate the arrival delays due to runway congestion in the arrival process, taking into consideration the schedule of arrivals, the runway configuration(s) used (provided on an hourly basis), and the mix of arrivals versus departures computed on an hourly basis. Next, the system computes a revised schedule of arrivals at the apron area, using this estimated arrival delay and adding an estimated taxi time. Based on the schedule for arrivals in the apron area, the aircraft are assigned apron stands, provided they are available. When apron stands are not available, aircraft enter the apron buffer space where they stay until a stand becomes available. If the capacity of the apron buffer space is exceeded, the arrival process must be discontinued for some time. In this case, the system re-computes the delays using reduced capacity for arrivals according to the intervals of time the arrival process is blocked. Next, based on the schedule for departures and on the earliest time aircraft will be ready to depart from their stands, the system constructs a revised schedule for departures. With this schedule (after adding an estimated departure taxi time), and given the departures capacity profile, the system estimates the departure delays. Finally, because the mix of arrivals versus departures in the original schedule may not be valid any more, the system repeats the process using a mix computed with the revised schedule.

The SLAM Decision Support System

Objectives

The modeling of airport terminal operations has advanced significantly over the last 15 years. Available models have improved in detail and fidelity, as well as "user friendliness". As a result, their use as decision support aids or design tools in terminal development projects has been steadily increasing.

Some existing models are "strategic" in nature sacrificing level of detail in exchange for speed and flexibility, while others are primarily "tactical" incorporating high levels of detail in data and system definition. The tactical models are simulation (stochastic) models, they require a detailed input based on an operational configuration of the terminal, and they provide a detailed output using a lot of CPU time: they are suited for management purposes.

The strategic models are aggregate (deterministic): since they usually require a simple input it is easy to try alternative configurations; they provide "quick and dirty" output with very low computational requirements and they are made for planning purposes.
The lack of a satisfactory strategic model of landside operations motivated the creation of SLAM.
SLAM is an analytical (not a simulation), aggregate model for estimating capacity and delays in airport passenger terminals. SLAM was created to answer "what if" questions (alternative configurations). The most important SLAM output is the Level of Service provided in each facility.

SLAM consists of a network of modules, one for each facility of the terminal: these modules are based on a set of quite simple mathematical formulas. Their objective is not to provide a thorough analysis of a given facility, but to be used for the estimation of the capacity of the facility (in terms of passengers per hour) and the level of service (LOS) associated with it (compared to internationally accepted standards as those, for example, in the IATA manual (1995)).

SLAM is equipped with an interactive GUI and provides, among its outputs, color-coded displays of LOS achieved at each landside facility over any specified period of time.

Aggregate Models implemented in SLAM

In this section it is presented the aggregate model implemented in SLAM of the processing facilities (check-in, security screening, passport control) of a terminal. The models of this section are intentionally simple: the output produced by an aggregate model must be easy to understand and very fast to obtain.
For evaluating a processing facility the criterion needed is bidimensional, i.e., criterions that simultaneously takes into account both time and space. Time standards refer to the time spent in the facility by a given percentage of the passengers, while space standards consider the amount of space per person that is available. For evaluating a holding facility only space standards are used and finally, for evaluating a flow facility, one has to consider the number of passengers that can cross a section of the facility per unit of time.

A variable called **Index of Service** (*IOS*), strictly related to the Level of Service (LOS) will be used in the following. The LOS is a qualitative statement, represented by a single letter (A to F). To most of the LOS there correspond internationally accepted standards (quantitative measurements). Index of Services (IOS) represents these quantitative measurements. For example, in a waiting lounge the LOS = B corresponds to $2.3 < IOS < 2.7$ (m^2 per person).

Typically, the aggregate model for a specific facility will consist of a simple formula, like the following:

$$IOS = \frac{Area}{AP * ADT}$$

that says that the Index of Service (IOS) for that facility can be computed dividing the **Area** by the product of the number of **Arriving Passengers** (*AP*) at that facility during one hour (the Peak Hour) times the **Average Dwell Time** (*ADT*) spent by a passenger in the facility. The IOS can then be used to obtain the LOS of that facility. For example, if the Area in front of the Check-In is 1500 m^2, the number of passengers arriving at the Check-In during the Peak Hour is 3600, and the average Dwell Time is 0.15 (hours), then the IOS for that facility is 2.78 (m^2 per person), which means that the corresponding LOS is A.

The example illustrates how to obtain the LOS for a given facility. The same formula can be used to answer other questions.

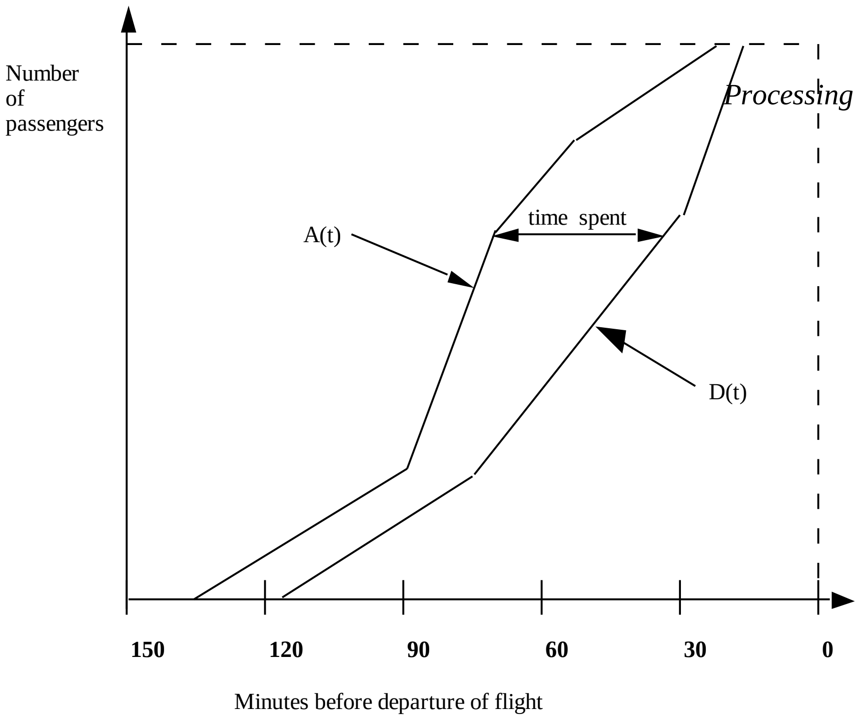
Computing Dwell Times in a processing facility

In this subsection "quick and dirty methods" to compute the Dwell Time (both its average and its distribution) at a processing facility are described. The Input required by SLAM can be extracted from the statistical data that are typically available to an airport manager. The output of a SLAM analysis refers to the peak hour (PH). However, the time window to consider is typically greater than one hour, since all the flights departing or arriving that can possibly interact with the PH have to be taken into account; for example, a Check-In counter at the Linate Airport is usually open two hours and fifteen minutes before the scheduled departure time.

In order to estimate the Average Dwell Time (ADT) spent by a passenger in a processing facility, two different approaches are considered. The first one is based on classic Queuing models (M/M/s or similar) and provides a reasonable approximation of ADT under the assumptions that AP, the average number of customers arriving to the processing facility, and the average potential service volume of that same facility (let it be $\sigma \bullet \mu$) can both be considered approximately constant over a significant period of time. The main drawback of this approach is that it is difficult to obtain the steady state, i.e., AP must be strictly lower than $\sigma\mu$. Of course, this approach will not be able to capture the dynamic effects of variations over time of AP or $\sigma \bullet \mu$.

The second approach is suggested when these dynamic effects are too important to ignore. It utilizes a deterministic equivalent approximation that will follow exactly the evolution over time of AP and $\sigma \bullet \mu$. Basically, this is a graphical model that computes approximately the total waiting time of passengers, given the cumulative arrival function at the check-in counter and the service rate for each time period. This graphical model was initially proposed by Newell (1971) and extended (to represent more than one flight) by Tosic et al. (1983). In this second approach (called the **Deterministic Equivalent Approach**), the Dwell Time for each processing facility might be (under) estimated since the passenger arrival profile and the profile of the number of passengers served are considered as functions of time.

In the following, for the sake of clarity, the check-in facility is considered, instead of considering a generic processing facility. For each flight, the passenger entering profile (which must be given as input) is a function of time that provides the number of passengers that have already entered the system (i.e., the check-in facility). The profile of the passengers that have been served by the system (and therefore have left it) is again a function of time, but it also depends on the number of servers; this profile is not given as input, but can be inferred from the number of servers (counters) which are open and from the mean service time. The number of servers open by a given air carrier is sometimes conditioned upon the carrier's target level-of-service standards.



Processing facility dynamics

Let A(t) be the *number of passengers* that have *arrived* at the facility up to time t, and D(t) the overall *number of passengers* that have already *left* the facility by time t. Of course, A(t) and D(t) are non-decreasing functions.

Passenger profiles can be properly approximated by *piece-wise linear functions* (time is represented on the x-axis and number of passengers on the y-axis). Furthermore, the combined arrival profiles of the passengers of all flights assigned to the same Check-In counter (or block of counters) can be summed up by using the *arithmetic* of the piece-wise linear functions, thus producing an "overall piece-wise linear profile". It follows that A(t) and D(t) can be approximated by piece-wise linear functions.

In the figure above an hypothetical A(t) and a D(t) are represented in the case where a single flight is assigned to a given counter.

If a passenger is the n-th passenger to enter the system (called him/her passenger n), then his/her Dwell Time DT(n) can be computed as follows, under the natural assumption of a FIFO (first come - first served) discipline:

$$DT(n) = D^{-1}(n) - A^{-1}(n)$$

where $A^{-1}(n)$ and $D^{-1}(n)$ are the inverse functions of A(t) and D(t). Considering A(t) and D(t) as piece-wise linear functions, their inverses are again piece-wise linear functions (and so is their difference).

Since the dynamic effects of the system are too important to ignore and since it is difficult to obtain the *steady state* in a terminal system, the **Deterministic Equivalent Approach** is adopted in the software implementation of the SLAM model. The results of Tosic et al. (1983) are extended in the sense that by fully exploiting the geometry of piece-wise linear and finite automata, information for each facility that are unusual to aggregate models can be provided, such as the graphs of the following quantities, as functions of time: cumulative number of served passengers, number of passengers in queue, number of passengers in queue per counter, number of counters versus expected queue time, and an optimal allocation of the facility resources to reach a required level of service. Of course, average dwell time, average waiting time, and the space and time LOS are also estimated for each time interval.

Program Structure

SLAM is made of a GUI, called SLAM-Workbench (SLAM-Wkb for short) and by an engine (SLAM-Solver).

The task of SLAM-Wkb is to assist the user in providing the input data, then to start a "well formed" elaboration, and finally to present graphical and textual output.

Both input and output files are text files composed of tables, that can be prepared, or read, via any ODBC Data Source (e.g.: *Excel* or *Access*); for this reason both SLAM-Wkb and SLAM-Solver perform a specific input check.

The SLAM Solver is implemented in ANSI C, while the SLAM Wkb is implemented in Java.

There are 3 major groups of data in the SLAM input: (1) scheduling of the flights, (2) terminal physical configuration, and (3) allocation of the terminal resources to manage the flights (policy data). Some of the input data are set by default (like the IATA standards) unless the user prefers to supply a different set of standards. In particular, if the user does not supply another set of standards, the Level Of Service (LOS) are computed according to the values in the *IATA Manual: Airport Development Reference Manual, 8th Edition - International Air Transport Association*, 1995.

The SLAM output is a file containing the results of a SLAM elaboration that are provided for each facility or facility component and a summary table with the LOS obtained for each facility. A facility component is a subsystem of a facility; the check-in counters dedicated to a specific airline, for instance, are a component of the "check-in" facility. The facilities considered are: Departure Concourse, Ticketing, Check-in, Security, Passport control, Flow, Gate Lounge, Baggage claim, Customs, Arrival Concourse. The security facility can be divided into "Schengen" and "Non-Schengen" components at many European airports (domestic or international components in the USA).

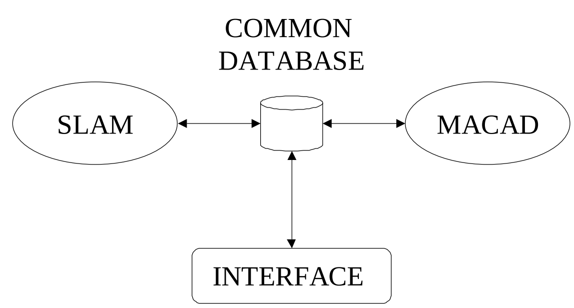
For each facility, or facility component, the following detailed information is provided: number of flights and number of passengers in the day, and, in each time interval, number of flights and number of passengers, Average Dwell Time, Average Waiting time, Space Los, Time Los.

For each facility, or facility component, the graphs of the following quantities, as functions of time, are provided: Facility throughput, i.e., cumulative number of served passengers, number of passengers in queue, number of passengers in queue per counter, number of counters versus number of passengers in queue per counters, number of counters versus expected queue time, An optimal allocation of the facility resources to reach a required level of service.

Connectivity of the Models

As already pointed out in the beginning of this paper there is a need to integrate the analysis of the "landside" and "airside" elements of the airport. This is particularly important for understanding the implications of changes in one side of the airport to the other, and for adopting a system-wide viewpoint of airport operations and efficiency. The concept of integration of "landside" and "airside" analysis has been addressed by the authors of this paper and demonstrated through the implementation of a prototype using data from Milan's airports Linate and Malpenca. [Zografos et al, 1996].

The models discussed in this paper can be integrated through a common database where information on the airport configuration, the airport usage, and flight schedule can be shared between the models. In this way, the delays estimated for one of the elements of the airport ("landside" or "airside") can be taken into account in the analysis of the other ("airside" or "landside") through the relevant modification of the flight schedule in the common database. This leads to a better understanding of the interactions between the airport elements and an easier identification of potential bottlenecks. Empirical evidence has shown that this approach provides helpful insights to airport planners in order to rationalise decisions concerning the development of airport infrastructure.



Integration of "airside" and "landside" models

Concluding Remarks

In this paper we have presented two macroscopic models, suitable for decision making at the strategic level, for the analysis of the "landside" and "airside" elements of the airport. Common characteristics of these models are that they can provide estimates of the capacity and performance of the airport quickly and with little effort. Also, in this paper we have discussed the need for an integrated analysis of the "landside" and "airside" elements of the airport, and the way to achieve this integration.

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