TRANSPORT RESEARCH
FOURTH FRAMEWORK
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Total airport performance and evaluation

TAPE

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FOURTH FRAMEWORK PROGRAMME
AIR TRANSPORT
VII — 60

Total airport performance and evaluation

TAPE

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1. PARTNERSHIP

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2. EXECUTIVE SUMMARY

Traditionally, airport modelling has concentrated on specific subsystems of the airport complex. We find models for the Landside (terminal buildings, passenger handling), the Airside (runway / taxiway complex), or the access and egress system (roadways, terminal curbside, etc.). As many of these models have improved in detail and fidelity, as well as in "user friendliness", their use as design tools in airport development projects has been steadily increasing.

Despite this growth in popularity and acceptance of airport modelling techniques by the industry, the users must manually co-ordinate inputs and outputs for the various models in order to properly account for the interaction among the individual airport subsystems. Similar co-ordination is required in order for users to mix strategic models usually involving low level of modelling detail with tactical models requiring high level of detail in data and system definition. The TAPE project's principal objective is to develop a working prototype of an integrated environment, suitable for the study of the overall performance of airports, i.e. introduce both the airside and landside elements as well as different degree of detail in the analysis, under different scenaria of demand and airport configuration.

A methodology for integrating existing and future models that apply to different parts of the airport and that may have varying levels of modelling detail was developed. The central concept is to choose a common set of data that is of sufficient level of detail to accommodate all models of interest. This set of data constitutes the "common" database for all airport models to be used. Customised modules (called "input managers") can be built to translate from the common database format to individual input formats of each model. Similarly, customised "output managers" translate data from a model specific format to the common database format. The combination of input and output managers allows each model to run on data in the format of the common database and to generate outputs in the common format.

Furthermore, development of these customised I/O managers allows any existing model to be incorporated into the integrated environment without any modifications to the model itself.

For the purpose of demonstrating the concept, a specific set of models were incorporated into the TAPE environment. They were chosen under TAPE work packages WP2 (Models, Capacity and Efficiency of Landside Airport Elements) and WP3 (Models, Capacity and Efficiency of Airside Airport Elements) to include both Airside and Landside models, and to represent a proper mix with respect to the level of detail. In this second respect, the model mix consists of both macroscopic and microscopic models. The former are more appropriate for strategic (or planning) studies and the latter for tactical (or detailed design) studies. The models are:

- TAPECAP: an analytical model for estimating airfield capacity (Airside).
- DELAYS: an analytical model for estimating airfield delays (Airside).
- SIMMOD: a simulation model of the airfield (Airside).
- SLAM: an analytical model for estimating capacity and delays of airport passenger terminals (Landside).
- ARTS: a simulation model for estimating capacity and delays of airport passenger terminals (Landside).

TAPECAP, DELAYS and SLAM are macroscopic (strategic) models, while SIMMOD and ARTS are microscopic (tactical) ones. DELAYS, SIMMOD, and ARTS are existing models which have been used extensively in the past. TAPECAP has been developed within the TAPE project, and it combines features of a recently-developed model, the LMI Runway Capacity Model, and of an older model, the FAA Airfield Capacity Model. SLAM is also a model that has been developed by this project.

In summary, the most important aspects of the TAPE approach that distinguish it from other related work are the following:

1. The TAPE approach and prototype integrate Airside and Landside analysis.
2. The TAPE approach and prototype integrate microscopic (suitable for detailed analysis - require substantial time and significant resources) and macroscopic (suitable as tools for strategic planning - fast and easy to use) models
3. The TAPE approach and prototype use a common flight schedule to run different models.

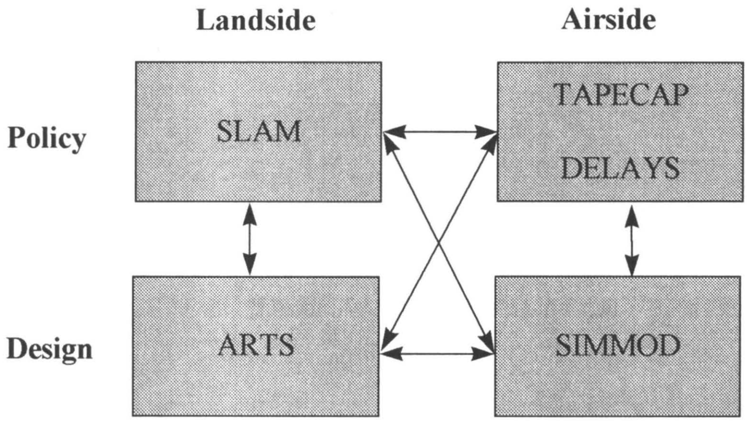

Figure: Integration of Airside, Landside, Aggregate and Detailed models

The TAPE prototype is the first model, that to the best of available knowledge, integrates landside and airside modelling. The TAPE prototype also provides integration of high-level-of-detail with low-level-of-detail models, so that the user can go from a preliminary examination at the aggregate level to a detailed analysis at the design level; or, stated differently, from "strategic" issues to "tactical" ones. It needs to be stated that the above provide an entirely original concept in airport modelling and consequently a unique contribution in this field.

The hypothetical experiment performed under WP7, "Evaluation of the TAPE Concept and Prototype", (bad weather during the morning at a Linate-like airport) has clearly proved that the TAPE prototype can “capture” and provide quantitative information on complex interactions between airside and landside operations which have never been modelled before. The model clearly shows the “ripple” (or “domino”) effects of the bad weather, indicating that early in the morning departure gates suffered from underutilisation (due to postponement of some departure times) while later on in the day there is overcrowding of the departure gates because postponed departures are competing with regularly scheduled ones for gate space. It is also interesting to see that the after effects of weather conditions that end at 8:45 am extend all the way until noon.

During the implementation phase of the TAPE prototype in two major European airports (Linate and future Malpensa airports of Milan), users have identified the following strengths:

a. Successful integration of airside and landside analysis.
b. Successful integration of macroscopic (low level of detail) and microscopic (high level of detail models).
c. Development of an entirely new, user-friendly and extremely fast model, SLAM, for macroscopic analysis of passenger terminal operations.
d. Development of a new extremely fast model, TAPECAP, for analysis of airside capacity and combination of TAPECAP with DELAYS, to compute quickly and efficiently airside delays.
e. Simplification of data preparation for analyses involving the entire airport (airside and landside) using a common flight schedule.

Future work aimed at strengthening further the TAPE prototype could expand its capabilities to include: additional model integration and improvements in database centralisation; further simplification of preparation and modification of inputs; some animation; environmental considerations, such as noise and air pollution; and further refinement of SLAM and TAPECAP. It should be noted that, with the exception of the first, all of these items fall outside the scope of the current TAPE project, but would undoubtedly constitute interesting possibilities for future pursuit.

This report summarises the final deliverables of the TAPE project and provides an overview of the outcome of each work package. In chapter 3, the objectives of the project are presented, while in chapter 4 the means used to achieve them are discussed. Chapter 5 is the main part of the report, describing the scientific and technical aspects of the project, as well as the evaluation process and outcome. Finally, in chapter 6, the conclusions from the TAPE project are summarised.

3. OBJECTIVES OF THE PROJECT

3.1 The Problem

Any busy commercial airport can be viewed as a complex system consisting of many interconnected elements each of which can act as a capacity bottleneck. Much work has been done over the last 25 years on modelling these individual elements and quantifying the sensitivity of their capacities to changes in the various airport parameters and characteristics. As many of these models have improved in detail and fidelity, as well as in "user friendliness", their use as design tools in airport development projects has been steadily increasing.

However, this large body of work still suffers from a lack of integration and from limited flexibility and usability. For example, there is a sharp separation between the modelling of "landside" and "airside" elements of airport (passenger terminals, baggage handling, ground access, etc.) and "airside" elements (the runway complex, taxiways, apron areas, aircraft stands, etc.) The two sets of models are typically incompatible, measure capacity and efficiency in different ways and make it difficult to adopt a system-wide viewpoint of airport operations and efficiencies. Thus, the users must manually co-ordinate inputs and outputs for the various models in order to properly account for the interaction among the individual airport subsystems. In a similar manner, existing models offer few options regarding level of detail in the analysis: each operates at its own pre-specified level (macroscopic of microscopic) making it impossible to reconcile the different levels of analysis across airport elements.

This situation creates major problems for airport planners, designers and, especially operators and managers. They often ask simple policy-level questions expecting quick, informed and approximate answers, and instead they must usually wait for weeks or longer until a highly detailed model is re-calibrated and utilised to provide answers at a level of microscopic detail which may be entirely inappropriate for the problem at hand. Thus, these planners, managers and operators are sometimes forced to devise ad hoc and inefficient methodologies for determining the impact of proposed alternatives on system-wide airport capacity efficiency, or, even worst, to make decisions without sufficient information.

3.2 The objectives of the TAPE project

The aim of this project has been to address the unfortunate state of affairs discussed in the above section, by developing and demonstrating a computer - aided approach for Total Airport Performance and Evaluation (TAPE), including both the airside and the landside elements of the airport.

The TAPE project's objective was to design, develop and demonstrate a working prototype of an integrated environment, suitable for the study of the performance of airports under different scenaria of demand and airport configuration. Within this environment, models of different levels of detail, suitable for the analysis of both airside and landside elements were to be included.

More specifically, the objectives of the TAPE project have been twofold:

1. To undertake a critical integration of the available body of knowledge and present a computer-aided approach that provides a flexible environment for examining a broad range of airport capacity and efficiency issues on a system-wide basis, including both the airport landside and the airside. This necessitates acquiring a capability for evaluating the impact on the entire airport with various alternatives for increasing airport capacity and efficiency. Furthermore, the objective has been to implement this capability in the form of a multi-layered tool-kit consisting of both aggregate (analytical) and detailed (simulation) models as well as an environment for their integration.

2. To demonstrate the potential of this approach through an application on major European airports and to draw some early generalised conclusions regarding (1) the usefulness of the TAPE concept, and (2) the design of an integrated environment for the implementation of this concept.

4. MEANS USED TO ACHIEVE THE OBJECTIVES

In order to achieve the objectives of the TAPE project the following tasks were performed:

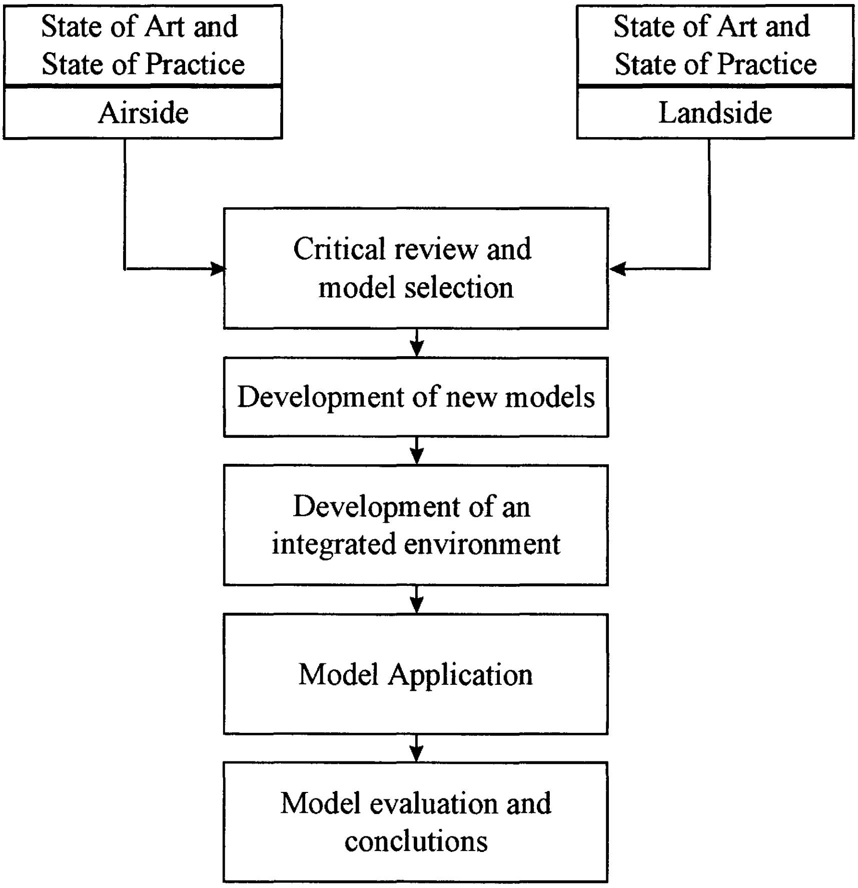

Figure 4-1: Methodology used to achieve the TAPE objectives

First, a critical review of existing airside and landside models, based on the state of art and state of practice for airport modelling, was performed. From this review the opportunity of development of new models for both airside and landside analysis with unique improved characteristics emerged. The next step was the design and development of two new aggregate modes, the Simple Landside Aggregate Model (SLAM) for landside analysis, and TAPECAP for the estimation of airside capacity.

Following the development of the new aggregate models, and the selection of existing simulation models, a prototype of an integrated environment was developed for the demonstration of the TAPE concept (see Chapter 3). This was one of the two major objectives of the TAPE project.

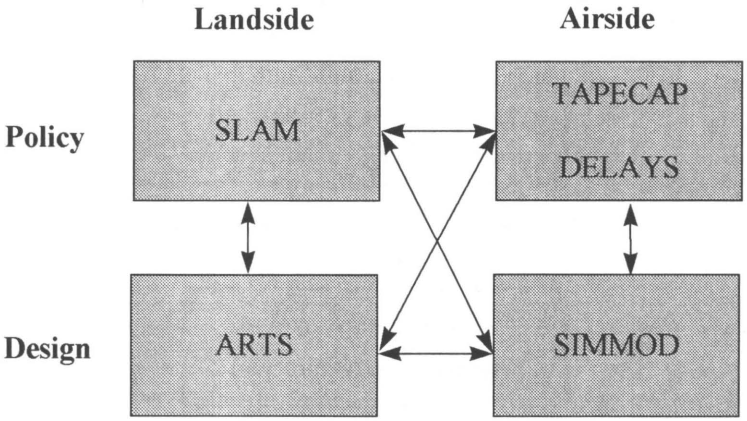

Figure 4-2: Integration of Airside, Landside, Aggregate and Detailed models

The models chosen to be integrated in this prototype include both Airside and Landside models, and represent a proper mix with respect to the level of detail. The models are:

1) TAPECAP: an analytical, aggregate, model for estimating airfield capacity (Airside).

2) DELAYS: an analytical, aggregate, model for estimating airfield delays (Airside).

3) SIMMOD: a simulation, detailed, model of the airfield (Airside).

4) SLAM: an analytical, aggregate, model for estimating capacity and delays of airport passenger terminals (Landside).

5) ARTS: a simulation, detailed, model for estimating capacity and delays of airport passenger terminals (Landside).

The integrated environment includes a "common" data base that is shared among the different models. Through this common data base, communication among the models is achieved, and runs with common data can be performed. Furthermore, sequential runs of models analysing different components of the airport, can be done within the TAPE environment without the need to manually "feed" output of models as input to others, but instead in an automated fashion through the "common" data base.

The demonstration of the TAPE concept and prototype was the second major objective of the TAPE project. This was achieved through (1) the use of the TAPE concept and prototype at two major European airports, Milan Linate and Milan Malpenca and (2) through test runs performed within the evaluation task of the TAPE project.

The use of the TAPE prototype at two major European airports, one of which is in the process of the design and implementation of major changes in its infrastructure has been successful. Airport authorities were heavily involved in the process, and it is important that the use of the TAPE concept has now been adopted as the best methodology of analysis by the users. Benefits from the use of the TAPE concept identified include (1) simplification of data preparation for analyses involving the entire airport (airside and landside) using a common flight schedule (2) integration of the analysis of the different components of the airport, at different level of detail, and

(3) two new fast and easy to use aggregate models for the analysis of the airside and the landside.

The scenario of the test runs performed within the evaluation task of the TAPE project were based roughly on operations at Linate Airport, and involved the analysis of the effects of a 90-minute period of poor weather conditions in the morning on airport operations throughout the day. The poor weather causes severe delays to arrivals in the morning. Due to the late arrival of aircraft at the airport, this, in turn, results into severe delays in departures scheduled for later in the morning. The late departures on airside mean that departing passengers must spend considerably more time in the passenger terminal than would have been the case had the schedule of departures not been disrupted. This means a lower level-of-service at the affected parts of the passenger terminal.

The combination of different models, all operating within the framework of the TAPE prototype, captured well the interactions between landside and airside that give rise to this type of "domino effect". This analysis also yielded interesting and non-obvious additional insights about the propagation of delays on airside.

5. SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE PROJECT

In this chapter, a summary of the results and findings within the TAPE project can be found.

5.1 Models Capacity and Efficiency of Landside Elements

The objective of this section is to examine each of the individual elements of landside, classify them and review the corresponding models. This has been an effort within Work Package 2 of the TAPE project. A significant part of the study presented is based on previous works. The identification and classification of landside elements refers mainly to the Special Report of the Transportation Research Board: "Measuring Airport Landside Capacity", (1987). An excellent review of airport passenger models is given by Tosic (1992). Methodological issues in passenger terminal design are proposed by Odoni and de Neufville (1992). Both papers were published in the special issue *Airport Landside Planning and Operation* of Transportation Research in 1992, which contains other useful references. For the analysis of simulation models we used information contained in the description of SABRE Decision Technologies products (see SABRE, 1994), and in the ARGO report by Pararas "ARTS: Airport Terminal Building Simulator", (1995). The data relative to the evaluation of the capacity of some landside elements of the Milano Linate Airport were provided by SEA in a recent report "The Level Of Service and the Sustained Capacity of the Linate Airport" ("I Livelli di Servizio e la Capacità Strutturale (Sustained Capacity) dell'Aeroporto di Linate", SEA 1995).

In this section of the report we (1) identify and classify landside elements and their corresponding models (2) examine the Level of Service indicators (3) review Airport simulation tools and (3) propose models and discuss the reasons why the selected models seem the most suitable to be integrated in the TAPE prototype.

5.1.1 BASIC DEFINITIONS

The airport landside includes the passenger terminal with all its components. In TAPE, we consider only "functional" components, i.e., elements providing services or amenities directly related to a passenger boarding or unboarding an aircraft. "Non functional" components such as concession areas, rest rooms, and telephones, although important passenger amenities, are not a basis for defining airport landside capacity.

In particular, we examine all facilities and services associated with an air passenger, from entrance in the terminal building to boarding on the aircraft (departing passenger), and from getting off a plane to the exit. Terminal curb and parking are often also considered to be parts of landside: the ground access system is simply modelled here as a set of "sources" and "sinks" of passengers.

The passenger's perception of the quality and conditions of service of one or a set of functional components constitutes the service level. Standard measures of the service level of components are waiting time, processing time, walking time, crowding, and availability of passenger amenities for comfort and convenience.

A high level of service may be provided if the airport landside has ample capability to accommodate passengers, baggage, and airport visitors. This airport landside capability is, of course, influenced by the **capacity** (in terms of persons processed per unit of time) of the facilities in the terminal. Capacity can be evaluated for each individual functional component of the airport landside. One or more of these components are likely to become the bottlenecks of landside capacity, i.e., the major constraints on serving additional passengers at the terminal.

Let us introduce some basic definitions. We define the **dwell time** as the average time a person is in a space or in a process. We will often speak of the **peak hour**, i.e., a representative hour of busy conditions within a functional component. A peak hour is typically defined from historical records by frequency of occurrence. In fact, it may be the 30th or 40th busiest hour of the year, or the average daily peak hour of the peak month, or the peak hour of the 95-percentile busy day.

5.1.2 CLASSIFICATION OF LANDSIDE ELEMENTS

Following the analysis presented in TRB (1987), landside elements may be subdivided into three classes: **Processing facilities** (they process passengers and their luggage), **Holding facilities** (areas in which passengers wait for some events, as the check-in opening for a flight, the start of flight boarding, etc), **Flow facilities** (the passengers use them to move among the landside elements).

The level of service (**LOS**) represents the quality and conditions of service of one or more facilities as experienced by passengers. Interrelationships exist among the typical measures of service level such as waiting time, processing time, walking time, and crowding. Service level targets are important because of their serious implications for airport costs and economics as well as for the "image" of the airport. In fact, maintaining a particular level of service at an airport may contribute to attracting new business and is also a reflection of the local or national community's goals.

Each component of an airport landside has its own unique operating characteristics and demands, hence it is hard to define service level in a unique way. Research conducted by the IATA (International Air Transport Association) Working Group on Traffic Peaks led to the need of standard definitions for evaluating levels of service and airport capacity (see IATA 1981). In order to specify the LOS standards, the working group suggested that potential congestion should be measured in different ways, according to the type of airport landside facility involved, i.e., depending on whether one is dealing with processing facilities, holding facilities or flow facilities. According to the facility being analysed, three fundamental measures of capacity can be used to estimate potential congestion (see Svrcek, 1994).

To specify the LOS, a set of letters from LOS = A (best) to LOS = F (unacceptable), are used. The levels of service are expressed in terms of flow, delays and level of comfort. System managers and designers should specify the desired or required level of service. Usually, level C is recommended as a minimum and level D is considered tolerable for crash periods.

5.1.3 PROPOSED MODELS

5.1.4 Aggregate models

In this section we outline an aggregate model for each facility of the terminal. We must point out that 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. This choice is reasonable, since a detailed analysis can always be provided by a detailed model. The Input requested by the models is extracted from the data, usually collected by every airport Authority, that are typically provided to a detailed model.

For evaluating a processing facility we need a criterion that is bidimensional, i.e., a criterion 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 the 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.

Let us introduce a variable that we will call Index Of Service (**IOS**), strictly related to the Level Of Service (LOS). 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). We will call Index Of Service (IOS) these quantitative measurements. For example, in a waiting lounge the LOS = B corresponds to 2.3 ^{2} IOS ^{2} 2.7 (m^2 per person).

Typically, the aggregate model for a specific facility will consist of a simple formula, like the following: IOS = Area / (AP $\cdot$ 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.

In the sequel, when we present a formula that gives the IOS as a function of other variables, it should be understood that from that same formula any variable could be obtained as a function of the others.

When we want to analyse a peak period of time shorter than one hour, let it be a period of duration 1/k (hours), then we can use the following approach. As an example, if we are interested in the peak 20 minutes (= 1/3 of 1 hour), the value of k to consider is 3. In this case, we can model the number of arriving persons as a Poisson distribution P(l) of parameter l, where l represents the average number of persons arriving in one hour. P(l) is approximated very well by the normal distribution N(l, l) if l is large enough.

As suggested in the IATA manual (IATA, 1982), if we are really interested in calculating the passenger throughput during the peak portion of the peak hour, rather than the average throughput taken over the whole peak hour, we may compute the AP equivalent peak hour by:

$AP = (l/k + x_a \div \overline{(l/k)}) \cdot k$.

The proper choice of x_a in this formula is made according to a fixed target probability. If one wants the probability of the event that "the number of passengers arriving during the peak period of 1/k hour is less than AP/k" to be at least 99% then $x_a = 2.33$, if this probability is 95% then $x_a = 1.64$, if it is 90% then $x_a = 1.28$, if it is 80% then $x_a = 0.84$, etc. The correct value of x_a can be obtained from the table of the Normal Distribution as: $\text{Prob}\{ N(0, 1)^{2} x_a \}$ = Desired Probability.

5.1.4.1 Computing Dwell Times in a processing facility

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

In order to estimate the Average Dwell Time (ADT) spent by a passenger in a processing facility, we recommend two different approaches. 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 $s \cdot m$) can both be considered approximately constant over a significant period of time. Furthermore, AP must be strictly lower than $s \cdot m$. Of course, this approach will not be able to take into account the dynamic effects of variations over time of AP or $s \cdot m$.

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 $s \cdot m$. The drawback of the second approach is that it ignores the intrinsic stochastic delays due to actual deviations from mean values. As a result no single approach is to be preferred always, but instead one has to choose the most appropriate approximation, according to the actual situation.

In the first approach (let us call it Queuing approach) the Average Dwell Time can be estimated through:

$$ADT = 1/m + [s^2_a + (s^2_{serv} / s)] \cdot AP / [2 \cdot (1 - AP / s \cdot m)]$$

where s^2_a is the variance of the interarrival time, and s^2_{serv} is the variance of the service time.

In the second approach (let us call it Deterministic Equivalent approach), we may (under)estimate the Dwell Time for each processing facility by considering the passenger arrival profile and the profile of the number of passengers served, as functions of time.

In the following, for the sake of clarity, we shall refer to the check-in facility, instead of considering a generic processing facility. For each flight, the passenger arrival profile (which must be given as input) is a function of time that provides the number of passengers that have already arrived in 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 which are open and from the mean service time. The number of servers opened by a given air carrier is sometimes conditioned upon the carrier's target level-of-service standards.

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 (we represent time 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 we can approximate A(t) and D(t) by piece-wise linear functions.

If a passenger is the n-th passenger to enter the system (let us call 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).

The Air Carriers are typically concerned about the level of service they can provide to a large percentage of passengers. For example, they may require that 95% of passengers entering check-in must wait 12 minutes, at the most. The arithmetic of piece-wise linear functions can be used to take into account also this target.

5.1.4.2 The Baggage Claim case

In this section we analyse a facility that is difficult to model analytically. This facility is extremely important in shaping passenger impressions of the level of service provided. We follow the model outlined by Odoni in his lecture notes (Odoni and de Neufville, course notes).

The model is based on the assumptions that the passenger arrival time distribution (T^P) and the baggage arrival time distribution (T^B) at a baggage claim device is uniform ($T^P \sim U(t^P_1, t^P_L)$ and $T^B \sim U(t^B_1, t^B_L)$).

We recall that the mean of a uniform distribution ($T \sim U(t_1, t_L)$) is $E(T) = (t_1 + t_L) / 2$, and its variance is $V(T) = (t_L - t_1)^2 / 12$. The Input parameters for these models are:

area, the passenger arrival time distribution (T^P), the baggage arrival distribution (T^B), the time of arrival of the first and the last passenger at the baggage claim device ($t^P{}_1$, $t^P{}_L$); the time of arrival of the first and the last baggage at the baggage claim device ($t^B{}_1$, $t^B{}_L$); average number of pieces of baggage per passenger with at least one piece of baggage (**nbag**). We have to point out that the time of arrival of the last passenger and that of the last baggage are parameters that may be estimated by considering the service rate, the number of passengers (with and without bags), and nbag.

Let us assume that all the pieces of baggage belonging to a given passenger show up together at the baggage claim and that the passenger and baggage arrival time distributions are independent.

We have different ways of estimating the expected dwell time a passenger spends in the baggage claim area, according to each combination of ($t^P{}_1$, $t^P{}_L$, $t^B{}_1$, $t^B{}_L$), if $t^P{}_L < t^B{}_1$ holds, or not.

The formula for computing the IOS is the usual one, where we indicate with AP the number of passengers arrived and ADT = E(WT).

5.1.4.3 Aggregate models for holding facilities

In this section we analyse those facilities dedicated to holding passengers. The Average Dwell Time (ADT) for these facilities has to be given as input together with area, number of passengers (**Pax**), and number of well-wishers (NWW). The number of persons entering (AP) a holding facility has to be estimated considering the number of passengers and that of the well-wishers: AP = Pax + NWW

In lounges and waiting and assembly areas, the model is the general one proposed above. Notice that, in computing the number of persons in the area (AP = Pax +

NWW), the number of well wishers is equal to zero if the area is placed after the security check on departure, or before customs on arrival.

Departure Lounge

The input data of our model for a departure lounge are: area, number of seats (**k**), number of passengers (Pax), number of passengers carrying a trolley (**PaxT**), the space standard for persons carrying a trolley (**SST**), the space standard for persons standing without a trolley (**SSS**), the space standard for seated persons (**SSK**) and the average dwell time (ADT).

We can estimate the number of persons standing without a trolley (**PaxS**) in the area by:

PaxS = MAX{0, Pax - PaxT - k}.Of course, it may happen that PaxS is zero.

The area needed to meet the minimum standard of service is the following:

Area = ADT $\cdot$ [PaxT $\cdot$ SST + PaxS $\cdot$ SSS + k $\cdot$ SSK].

Gate Lounge

For this facility we have to consider the fact that a certain number of passengers may still have to go through Check-In; furthermore some of them may be carrying a bag.

The Input data of the model for a gate lounge are: Area, number of passengers (Pax), number of passengers carrying a bag that have to go through Check-In (**PaxB**), number of passengers not carrying a bag that have to go through Check-In (**PaxNB**), recommended minimum space per passenger carrying a bag (**SSB**), recommended minimum space per passenger not carrying a bag (**SSNB**), recommended minimum space per passenger that does not have to go through Check-In (**SSC**), average dwell time (ADT), average dwell time at Check-In (**ADT_{CI}**), passenger arrival profile A(t).

The number of passengers that do not have to go through Check-In (**PaxC**) can be computed by:

PaxC = Pax - PaxB - PaxNB.

The area needed to provide the minimum level of service is given by:

$\text{Area} = \text{ADT}_{\text{CI}}\,[\text{PaxB} \cdot \text{SSB}] + (\text{ADT} - \text{ADT}_{\text{CI}})\,[\text{PaxB} \cdot \text{SSC}] + \text{ADT}_{\text{CI}}\,[\text{PaxNB} \cdot \text{SSNB}]$

$+ (\text{ADT} - \text{ADT}_{\text{CI}})\,[\text{PaxNB} \cdot \text{SSC}] + \text{ADT}_{\text{CI}}\,[\text{PaxC} \cdot \text{SSC}]$

Arrival Concourse

In the arrival concourse, the number of persons in the area is the number of arriving passengers (Pax) plus the number of greeters (**NG**), (AP = Pax + NG).

The Input data of our model for an Arrival Concourse are: area, number of seats (**k**), number of passengers (Pax), number of greeters (NG), recommended minimum space per passenger (**SPax**), recommended minimum space per greeter (**STG**), recommended minimum space per seated greeter (**SSG**).

We can estimate the number of greeters (**NTG**) standing in the area by: NTG = MAX{0, NG - k}. Of course, NTG = 0, if there are more seats than greeters. The area needed to provide the minimum level of service is given by: Area = [Pax $\cdot$ SPax + NTG $\cdot$ STG + k $\cdot$ SSG].

5.1.4.4 Aggregate models for flow facilities

In this section we analyse the models related to flow facilities. We are interested in the pedestrian density in a flow area. The number of persons going through a flow area has to be estimated considering the number of passengers and that of well-wishers. Of course, the number of well wishers is zero if the flow facility is beyond the security check (on departure), or before customs (on arrival).

The input parameters for the level of service are: the volume of passenger traffic and the corridor width. By corridor width we mean the "effective corridor width", which is the corridor width reduced by 1.5 meters (i.e., we do not consider the space near the edges of the facility).The IOS for flow facilities can be computed in terms of persons per meter width by: IOS = (traffic volume) / (corridor width).

5.1.5 Detailed models

To obtain detailed information, we need a simulation tool. ARTS (Airport Terminal Building Simulator) is a discrete-event simulation model of the actions and decisions made by individual arriving, departing and transfer passengers in the airport terminal building, developed by Argo Research. The basic feature of ARTS is the flexible implementation of **behavioural models** representing the way passengers make decisions in the terminal building on one hand, and of the decision policies related to the operations in the terminal facilities on the other. ARTS is a new generation model that overcomes, on a low-cost platform, typical problems of the old packages, such as large data requirements and lack of flexibility. ARTS stresses flexibility in the definition and implementation of alternative terminal building operating policies and in the modelling of passenger behaviour. ARTS has been designed to be extensible (so that, in addition to the set of built-in behavioural models provided with the system, new policies can be incorporated seamlessly) and, at the same time, flexible enough to allow multiple, and possibly conflicting, policies to co-exist.

Behavioural models are realised by a simple representation of the way passengers make decisions when moving in the terminal building (e.g. choose a ticket counter, spend time in a lounge, select a specific path, etc.). The same abstraction mechanism has been adopted to model the decision making and the policy of a specific facility within the terminal building by means of **facility selectors**. For what concerns the layout of the terminal and the physical relationship among facilities, the user can define the location of each facility and the surface area of each lobby. The user does not need to define connectivity among the various facilities, since this information is implied in the definition of the behavioural model. The behavioural models represent the dynamic behaviour of the passengers in a very realistic way. In fact, as it happens in reality, passenger decisions are not made *a priori*, but rather are dependent on the situation of the facility at the time the decision must be made.

Decisions like the selection of a check-in counter or a security machine they must go through are usually made at the time they are needed and past decisions may affect future actions. Also specific types of behaviour, like a longer stay in a lounge because of a delay announcement, can be easily represented. These are dependent on the on-line information on the flight schedule. This is implemented in ARTS by means of an **information manager**, which simulates the Flight Information Display System and the public address system within the terminal building.

ARTS can model in a single run the landside of an airport of any size, including multiple terminal airports, since it has no internal limits in the number of facilities or the number of passengers it can accommodate. The hardware platform used is the only factor limiting the size of the model. ARTS runs on a PC.

5.1.6 FINAL REMARKS

The main contribution of the work presented in this section (Work Package 2) in relation to the TAPE project, has been to identify models of landside elements which have been integrated during Work Package 4 with models of airside elements from Work Package 3. The models must be capable of measuring the capacity of an element under different operating conditions. Generally, the efficiency of the element is evaluated by comparing its capacity values with standard measures of the level of service provided to passengers.

Thus, our main goals were to select adequate tools to measure capacity and to identify reference values for level-of-service standards. Unfortunately, many of the existing tools are not publicly available. In addition, the existing level-of-service standards are not accepted universally. (However, the models presented here can work with any specified level-of-service standard that uses the same performance metrics.) We have also examined the scientific literature on terminal design and management, and a brief survey is presented in the TAPE deliverable D1. For a given facility, we adopt the models and formulas found in the literature, whenever available, and we provide them ourselves when they are missing. Different levels of detail were sought for the models of interest, so we have proposed both aggregate and detailed models of landside elements of an airport.

The aggregate models are based on relatively simple 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 by specifying a limited set of parameters and operating conditions.

As far as detailed analysis and evaluation of landside elements is concerned, we examined a simulation package (ARTS) and reported on some of the successful models for airport terminal evaluation implemented by SABRE. ARTS was selected as the model for the TAPE project for three main reasons. First, it compares favourably in terms of performance/cost ratio (in relation to the specific technical requirements of TAPE and to the project's budget). Second, it overcomes the problems of large data requirements and of lack of flexibility that made earlier simulation packages difficult to use.

5.2 Models, Capacity and Efficiency of Airside Airport Elements

In this section, we summarise the findings of Work Package 3 of the TAPE project.

5.2.1 BACKGROUND

Airports and the air traffic control (ATC) system are the two principal types of infrastructure for the air transportation system. Airport services and facilities are subdivided into "airside" and "landside". Runways, taxiways, apron areas and hangars are the principal airside facilities and they are collectively referred to as the airfield. Landside facilities consist primarily of passenger and cargo terminal buildings, access roads on the airport proper and such supporting facilities as automobile parking areas, power generation stations, etc. This summary report deals only with the modelling of airside facilities, as called for by Task WP3 of the TAPE project.

The objectives of Task WP3 are:

1. To carry out a critical review of the best-known available analytical models and
   simulation models of all types of airside facilities.
2. To identify the principal strengths and deficiencies of these models.
3. To select for use in the TAPE project a subset of these models.
4. To adapt these models appropriately for use within the TAPE environment, taking
   into consideration the deficiencies identified under item 2 above.

This chapter provides a brief overview of some of our principal findings with regard to all of these objectives. Most of the effort is dedicated to analytical models, because (1) they are the ones that pose the principal technical challenges to the accomplishment of the eventual TAPE objectives and (2) will provide one of the principal features that will make the TAPE environment distinguishable from other existing landside and/or airside models, which are, for the most part, simulations.

5.2.2 ANALYTICAL MODELS

In this section we review analytical models of airside capacity and delay, with most of the discussion devoted to the capacity of the runway system and to delays caused by congestion at the runway system.

5.2.2.1 Analytical Capacity Models

5.2.2.1.1 The Blumstein Model

Even though this is the first Analytical Model that can be found in the literature (1959), its basic principles are still valid today. The Blumstein model approximates the capacity of single runway systems used for arrivals only. It calculates the minimum time interval between all possible pairs of successive arrivals at the runway such that no ATC separation requirements are violated. It also adds a safety buffer to account for imperfections in the final approach spacing and the resulting conservatism of both air traffic controllers and pilots.

5.2.2.1.2 The LMI (Logistics Management Institute) Runway Capacity Model

This model was recently developed (1995) by the Logistics Management Institute for the NASA Terminal Area Productivity (TAP) Program. The LMI model is a generalised analytical and stochastic model for computing runway capacity, when the runway is used for arrivals only or for departures only or for mixed operations (arrivals and departures). We discuss this model in some detail next.

An important feature of the LMI model is that it takes explicitly into account the random nature of aircraft operations. So, for example, the approach speeds, the runway occupancy times and the delay in communication time between airport controllers and pilots are all incorporated into the model as normal random variables. Another important feature of the LMI model is that it takes a "controller-based view" of operations. In this respect, it calculates the spacing between aircraft as they enter the common approach path such that, with reasonable confidence, no violations will occur later.

Key input parameters to the model include: the mix and number of aircraft types at the runway (p_i); the length of the common approach path (D); the mean and standard deviation of the approach speed of each aircraft type (V_i, σV_i); the mean and standard deviation of the arrival and departure runway occupancy times (RA_i, σRA_i, RD_i, σRD_i); the miles-in-trail separation minima for all pairs of aircraft types (S_{ij}); and the mean and standard deviation of the communication time delay (c, σ_c). All the input random variables are assumed to be normally distributed.

The LMI model is designed to compute the so-called "runway capacity envelope", i.e., the set of points that define the envelope of the maximum throughput capacities that can be achieved at the runway, under the entire range of possible arrival and departure mixes. Specifically, the LMI model identifies four points on the runway capacity curve. By interpolating between pairs of points with straight-line segments one can then obtain (approximately) the full runway capacity curve. The four points are the following:

(i) Point 1: The "all arrivals" point, i.e., the capacity of the runway when it is used for arrivals only.

(ii) Point 2: The "freely inserted departures" point which has the same arrivals capacity as Point 1 and a departures capacity equal to the number of departures that can be inserted into the arrival stream "for free" by only exploiting large interarrival gaps, i.e., without increasing the separations between successive arrivals.

(iii) Point 3: The "alternating arrivals and departures" point, i.e., the point at which an equal number of departures and arrivals is performed. This is achieved through an arrival-departure-arrival-departure-... sequencing, implemented by "stretching", when necessary, the interarrival gaps, so that a departure can always be inserted between two successive arrivals.

(iv) Point 4: The "all departures" point, i.e., the capacity of the runway when it is used for departures only.

5.2.2.1.3 The Airfield Capacity Model (FAA)

The Airfield Capacity Model was developed by the FAA. It is based on the fundamental concepts of the Blumstein model, but it extends the analysis to include several runway complex configurations. More specifically, it estimates the hourly capacity of 15 common airfield configurations (1-4 runways). The most important inputs required are the mix of aircraft, the miles-in-trail separation minima, the runway occupancy times, the mix of arrivals and departures and the approach speeds.

The operating strategy for mixed operations in this model is as follows:

i. Insert departures between arrivals whenever possible, without changing the separations between arriving aircraft.

ii. Allow for a prespecified (by the user) stretching of the interarrival times to increase the number of departures inserted.

iii. Achieve a specified ratio of arrivals to departures by interpolation (time sharing) between the "all arrivals plus "free" departures" point and the "all departures point".

5.2.2.2 Analytical Delay Models

A natural consequence of airport congestion is the widespread incidence of significant airport delays. Airport delays are generally considered as one of the most vexing (and apparently long-term) problems of air transportation in much of the world. Estimating airport delays, given actual or anticipated demand and capacity data, is thus a very important aspect of airport planning and design.

Classical steady-state queuing theory does not apply because (1) arrival and service rates are not constant over time and (2) arrival rates are not strictly less than service rates. Koopman (1972) was first to model airports as dynamic queueing systems with a non-homogeneous Poisson arrival processes. Later (1976), Kivestu introduced the Erlang family of service time distributions and a very fast and accurate approximation method for solving system equations. The software package DELAYS is based on these principles. The inputs for DELAYS are the dynamic demand profile (typically specified via hourly demand rates), and the dynamic capacity profile (typically hourly capacity). Starting with initial conditions at time t=0, it solves quickly equations describing formation of queues at times $t = \Delta t, 2\Delta t, 3\Delta t, \ldots$ up to the end of the time period of interest. The outputs provided are statistics about queues including average waiting time, fraction of flights delayed more than X minutes and others.

Another approximation method that estimates delays due to the congestion of runway complexes is the State Probability Vector Approximation. This method parallels the analysis of M/G/1 queueing systems; and it provides an alternative approach to DELAYS.

5.2.3 SIMULATION MODELS

We now turn to simulation models of airport operations with particular emphasis on models that emphasise aspects of capacity and delay. Beginning in the early 1970's, a large number of general-purpose simulation packages have been developed for application to the analysis of airport airside operations, often covering not only runways but also aircraft movements on taxiways and aprons. Some of these simulation packages are publicly available, while others are proprietary. Most of them represent the airfield as a network of nodes and links. Aircraft move on this network along prescribed paths that consist of strings of nodes and links. Typically each link can be occupied by a single aircraft at a time. Thus a delay occurs whenever an aircraft attempts to use a link which is already occupied by another aircraft. Whenever two or more aircraft attempt to occupy a free link at the same time (e.g., two aircraft approach a taxiway intersection from different directions) the logic of the model resolves the conflict according to ATC priorities and assigns the free link to one of the candidate aircraft.

The network representation has both advantages and disadvantages. On the positive side, the network structure is intuitively appealing, can be used to develop a highly-detailed representation of the airfield and provides a convenient base for collecting and reporting occupancy and delay statistics. On the negative side, the network structure can impose high set-up costs, reduce flexibility and slow down program execution.

The three most important models that exist in the public domain (i.e., are available, from a supplier at a cost) are the Airport Machine, SIMMOD, and TAAM. They are extensively used by airport or ATC organisations throughout the world. The first is a simulation model that covers the airfield only (runways, taxiways, aprons) while SIMMOD and TAAM are modelling tools for both airspace and airfield operations and can, in fact, be used to simulate a regional ATM system that may include several major airports. SIMMOD enjoys strong and continued support from the FAA and from several companies involved in its application and its further development, while the Airport Machine and TAAM, both sold by commercial vendors have also been widely adopted in recent years -- The Airport Machine since the early 1980s and TAAM since the early 1990s. These three models are thus acquiring (at least for a while) the status of the "standard" simulation models for highly-detailed airfield and airspace analyses. A very brief overview of the characteristics of these models follows.

- *SIMMOD* has a “node-and-link” structure, high fidelity if desired, reasonable modelling of uncertainty, low initial cost ($400 PC version, $4000 workstation version), a steep learning curve, it is not user-friendly and it is labour intensive.
- *The Airport Machine* has a “node-and-link” structure, high fidelity if desired, is essentially deterministic, costs $20-25K for first site license and $10-12K for each additional site, has a good user interface and good graphics but requires significant training.
- *TAAM* has a waypoint structure and a rule-based logic, high fidelity if desired, limited modelling of uncertainty, costs $350K for license or $15K per month for access, a good user interface and excellent graphics, but requires significant training.

5.2.4 TAPECAP

The model reviews conducted indicated that significant improvements in the macroscopic models that currently exist for studying runway capacity can be achieved. For this reason TAPECAP was developed by the TAPE project team, a model that combines the methods of the LMI Runway Capacity Model, and of the FAA Airfield Capacity Model.

TAPECAP computes the capacity of a runway system as a function of numerous parameters which depend on the allocation of arrivals and departures to different runways as well as restrictions on the arrival and departure processed. For any given runway configuration and any given set of runway capacities, TAPECAP thus computes a "Runway Capacity Envelope" that gives the entire range of capacities achievable under all possible mixes of arrivals and departures. An illustration of the Runway Capacity Envelope for the case of a single runway is given in Figure 5-1. Points 1 and 4 correspond to the capacity when the runway is used only for arrivals and only for departures, respectively. Point 2 corresponds to the capacity when as many departures as possible are inserted between arrivals, without reducing the arrivals capacity. Point 3 indicates the capacity of the runway when an equal number of arrivals and departures operate on it. Capacities for any other mix of arrivals and departures can be read from the Runway Capacity Envelope which is obtained (approximately) by interpolation using these four points.

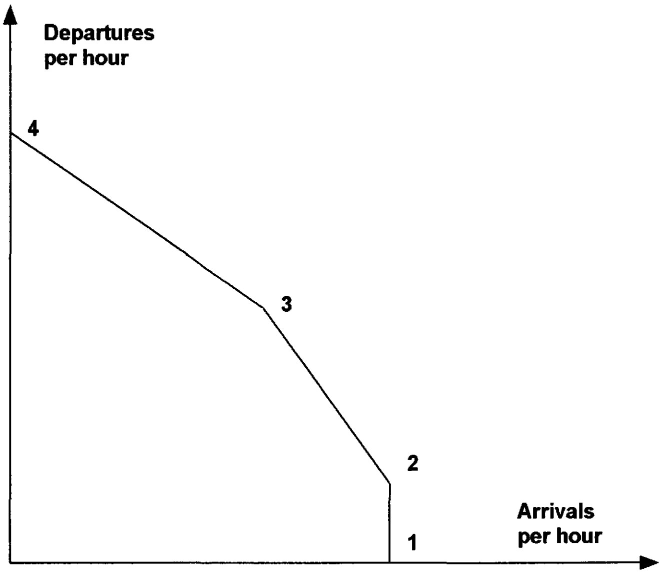

Figure 5-1 A Runway Capacity Envelope

As already discussed, this is a concept and methodology developed by the LMI Runway Capacity Model for a single runway and has been extended, in an approximate manner, in TAPECAP to two-active runway systems by using the logic of the FAA Airfield Capacity Model for this purpose. Since the TAPE environment is modular and flexible, if a new model is developed in the future that contains further improvements to the current TAPECAP model, that new capacity model will replace the current one.

5.2.5 CONCLUSIONS

The most important conclusions drawn from work package 3 are the following:

1. A comprehensive review of analytical models of airside capacity and delays and of simulation models of airport operations has been performed.

2. To satisfy the TAPE project's objectives, both low-level-of-detail models (appropriate for policy analysis and strategic planning) and high-level-of-detail models (appropriate for detailed design of facilities) will be necessary.

3. Existing low-level-of-detail models deal with capacity and delays associated with the runway system of each airport and the models of this type that will be included in the TAPE environment will address this aspect of airside operations. This is sufficient at the low level of detail because, in practically every major airport, the principal "bottleneck" of airside operations is the runway system and the great majority of delays experienced on airside are associated with waiting for access to the runway system, either on arrival or on departure. Thus, for the purposes of an approximate analysis required by policy studies and strategic planning, the modelling of runway capacity and delay are the paramount concern. Most strategic planning exercises are indeed concerned with expanding runway system capacity and/or reducing airside delays associated with the runway system.

In addition, it is generally true that delays associated with the runway system or with en route airspace (as distinct from --the usually minor-- delays associated with the taxiway system or with the temporary unavailability of aircraft stands) are the ones that contribute to passenger terminal congestion by prolonging the amount of time that departing passengers must spend in the terminal buildings.

4. The high-level-of-detail models deal with operations at all elements of the airside (runway system, taxiway system, apron areas) and this will also be the case for the TAPE environment. This is necessary because, for the purposes of detailed planning of airport operations and of detailed airport design (both of which high-level-of-detail models are intended to support) all elements of the airside system are of interest. Indeed apron/gate operations are often the focus of such studies.

5. With respect to analytical capacity models, the LMI Capacity Model for a single runway and the FAA Airfield Capacity Model for multiple runway operations represent the state of the art in low-level of detail models, appropriate for policy analysis and strategic planning Both, however, require modifications to address sets of deficiencies which are different in each case. The TAPE project has utilised an analytical capacity model (TAPECAP) which combines these two models. More specifically, it uses the LMI model for the capacity estimation in the case of a single runway, and combines it with algorithms similar to those used by the FAA model to extend the analysis to more complex runway configurations. This model has been developed within the framework of the TAPE project.

Since the TAPE environment is modular and flexible, if a new model is developed in the future that contains further improvements to the current combined model that new capacity model will replace the current one.

6. With respect to analytical delay models, the DELAYS model represents the state of the art and is satisfactory as a low-level of detail model, appropriate for

policy analysis and strategic planning. It will therefore be utilised by the TAPE project.

7. With respect to simulation models of airport operations, the candidate models are The Airport Machine, SIMMOD and TAAM. The use of TAAM is infeasible at this point because of the extremely high cost of acquiring a license to the model. This cost far surpasses the resources available to the TAPE project. With respect to the choice between The Airport Machine and SIMMOD, we have selected the second, because it is a more widely used model with an active user group in SEA, one of the partners in TAPE. SIMMOD will thus be the high-level-of-detail model to be used in the TAPE environment. Once again, given the modularity and flexibility of that environment, it will be possible to replace SIMMOD by another high-level-of-detail model in the future, if desired.

8. It should be noted that the terms "high level of detail" and "low level of detail" are relative ones. A high-level-of-detail model may still not contain every single detail of airside operations. For example, none of the three main existing high-level-of-detail simulation models (The Airport Machine, TAAM and SIMMOD) simulates aircraft stand operations to a minute level of detail, such as the loading and unloading of pieces of luggage, the cleaning of the aircraft, the fuelling operation, etc., etc. Instead stand operations are described in these models by a "stand occupancy time" which must satisfy certain constraints: it must be longer than the minimum turn-around time needed at the airport in question for the particular type of aircraft involved; and it cannot begin before the *actual* arrival time of the aircraft in question, nor can it end before the aircraft's *scheduled* departure time. The effects of any changes, such as improved bag processing and loading, in the way stand operations ("ramp handling procedures") are conducted are then reflected in changes in stand occupancy times. Thus, other, even more detailed models of stand operations may be necessary to compute the impacts of such changes in ramp handling procedures on stand occupancy times. Models such as SIMMOD, TAAM

and The Airport Machine would become hopelessly slow and complex if they were to represent every airside operation to such an extreme level of detail.

5.3 An Integrated Approach to the Modelling of Airport Capacity and Efficiency

This section describes the work done under Work Package 4 of the Total Airport Performance Evaluation (TAPE) project. Traditionally, airport modelling has concentrated on specific subsystems of the airport complex. We find models for the Landside (terminal buildings, passenger handling), the Airside (runway / taxiway complex), or the access and egress system (roadways, terminal curbside, etc.). As many of these models have improved in detail and fidelity, as well as in "user friendliness", their use as design tools in airport development projects has been steadily increasing.

Despite this growth in popularity and acceptance of airport modelling techniques by the industry, the users must manually co-ordinate inputs and outputs for the various models in order to properly account for the interaction among the individual airport subsystems. Similar co-ordination is required in order for users to mix strategic models usually involving low level of modelling detail with tactical models requiring high level of detail in data and system definition.

Work Package 4 concentrated on four areas of development necessary to integrate existing and future airport models :

- *Model integration,*
- *Data path modelling,*
- *Airport database organisation, and*

- *Sensitivity analysis*

5.3.1 MODEL INTEGRATION

A methodology for integrating existing and future models that apply to different areas of the airport and that may have varying levels of modelling detail was developed. The central concept is to choose a common set of data that is of sufficient level of detail to accommodate all models of interest. This set of data constitutes the "common" database for all airport models to be used. Customised modules (called "input managers") can be built to translate from the common database format to individual input formats of each model. Similarly, customised "output managers" translate data from a model specific format to the common database format. The combination of input and output managers allows each model to run on data in the format of the common database and to generate outputs in the common format. Furthermore, development of these customised I/O managers allows any existing model to be incorporated into the integrated environment without any modifications to the model itself.

Once a model is integrated into the overall environment, it can be run on its own (as is common practice today) or in combination with other models in the environment. Of course, in order to take full advantage of the integration, the user has to make modifications on the data resident in the common database and not the normal model input data. This is accomplished by using a set of common data editors that operate directly on the common data format. These editors are a critical component of the integrated format since they insure that all models will run on the same data and that data modifications are applied to all models uniformly and without the need for data duplication and repetitive editing. Figure 5-2 shows an integrated model's data flow.

The TAPE project's principal objective is to develop a working prototype of such an integrated environment, that proves the validity of the overall concept. For the purpose of demonstrating the concept, a specific set of models were incorporated into the TAPE environment. They were chosen under TAPE work packages WP2 and WP3 to include both Airside and Landside models, and to represent a proper mix with respect to the level of detail. In this second respect, the model mix consists of both macroscopic and microscopic models. The former are more appropriate for strategic (or planning) studies and the latter for tactical (or detailed design) studies. The models are:

- TAPECAP: an analytical model for estimating airfield capacity (Airside).
- DELAYS: an analytical model for estimating airfield delays (Airside).
- SIMMOD: a simulation model of the airfield (Airside).
- SLAM: an analytical model for estimating capacity and delays of airport passenger terminals (Landside).
- ARTS: a simulation model for estimating capacity and delays of airport passenger terminals (Landside).

TAPECAP, DELAYS and SLAM are macroscopic (strategic) models, while SIMMOD and ARTS are microscopic (tactical) ones. DELAYS, SIMMOD, and ARTS are existing models which have been used extensively used in the past. TAPECAP has been developed within the TAPE project, and it combines features of a recently-developed model, the LMI Runway Capacity Model, and of an older model, the FAA Airfield Capacity Model. SLAM is also a model that has been developed by this project.

5.3.2 DATA PATH MODELLING

The methodology treats the integrated airport model as a data network. Each node in the network represents a model or an I/O manager. Data are the links connecting the various models. Figure 5-3 shows an example network. It represents the Airside portion of the actual network chosen for the implementation of the prototype TAPE model. Figure 5-4 shows the equivalent network representation for the Landside.

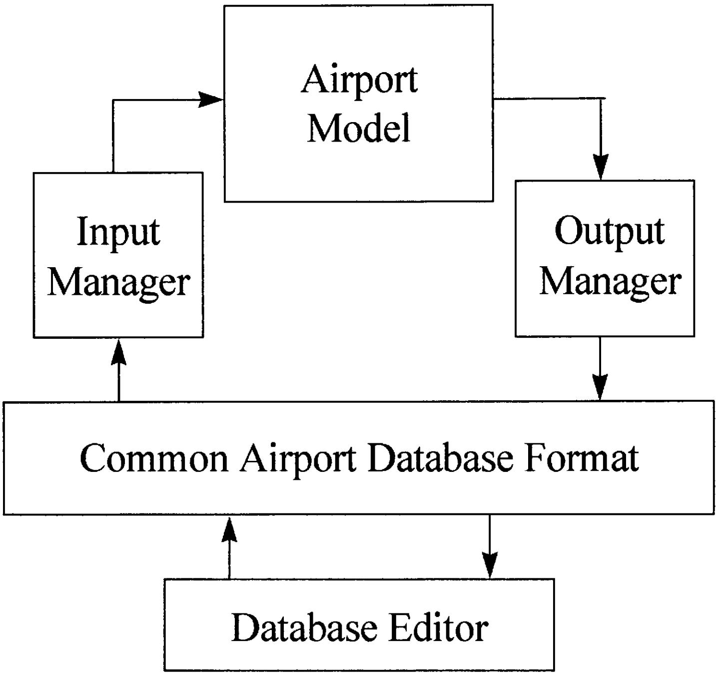

Figure 5-2: Integrated Model Data Flow

In general, multiple data paths can be identified from the input data (Airside Inputs in Figure 5-2) to the output data (DELAYS and detailed SIMMOD outputs in Figure 5-2). Each path represents a combination of models used to generate the desired results from the inputs. If one is only interested in the Airside of the airport, the outputs of this sub-network represent the final outputs of the model. In an integrated approach however, arrival and departure delays, as well as other Airside outputs are also inputs to the Landside models. In the overall airport model network, therefore, the coupling of the Airside and the Landside of the airport is immediately and directly manifest.

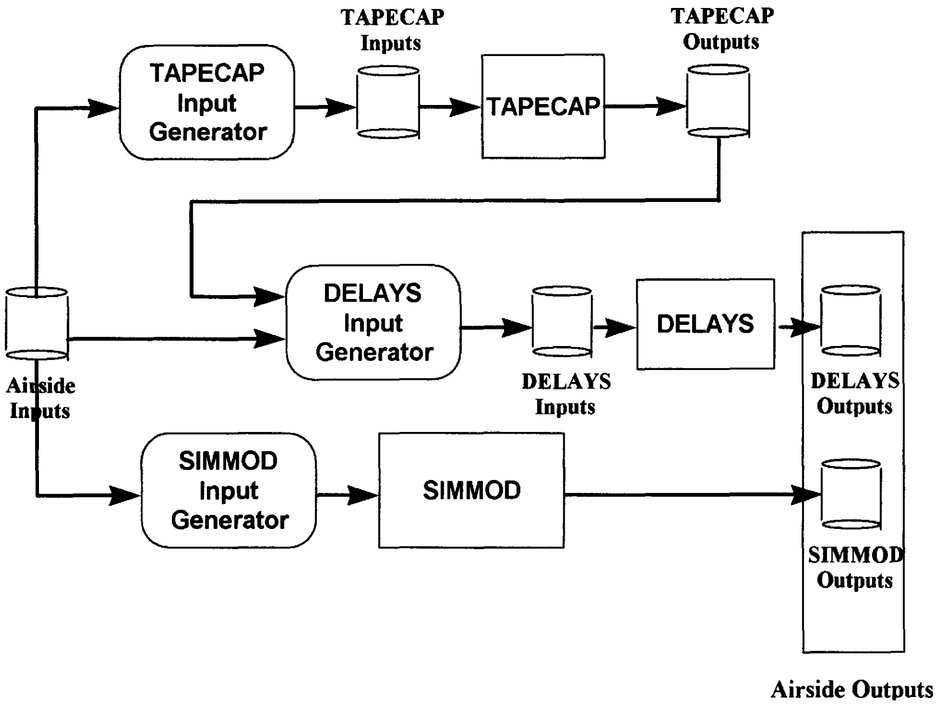

Figure 5-3: Airside of an Integrated Model Network

The representation of the overall airport model as a network of models of its various parts can be extended in a number of ways:

1. It can be applied to any type of model, independent of its level of detail and its scope. Each model only needs to be accompanied by the proper I/O modules to handle the translation of data to and from the common database format.

2. It can accommodate any number of "similar" models, i.e. models that require inputs of approximately the same type and level of detail, and produce similar results. In general, each such model creates a unique new data path. By choosing the specific data path the user can, in effect, vary the level of detail or the modelling technique with which each part of the airport is being modelled.

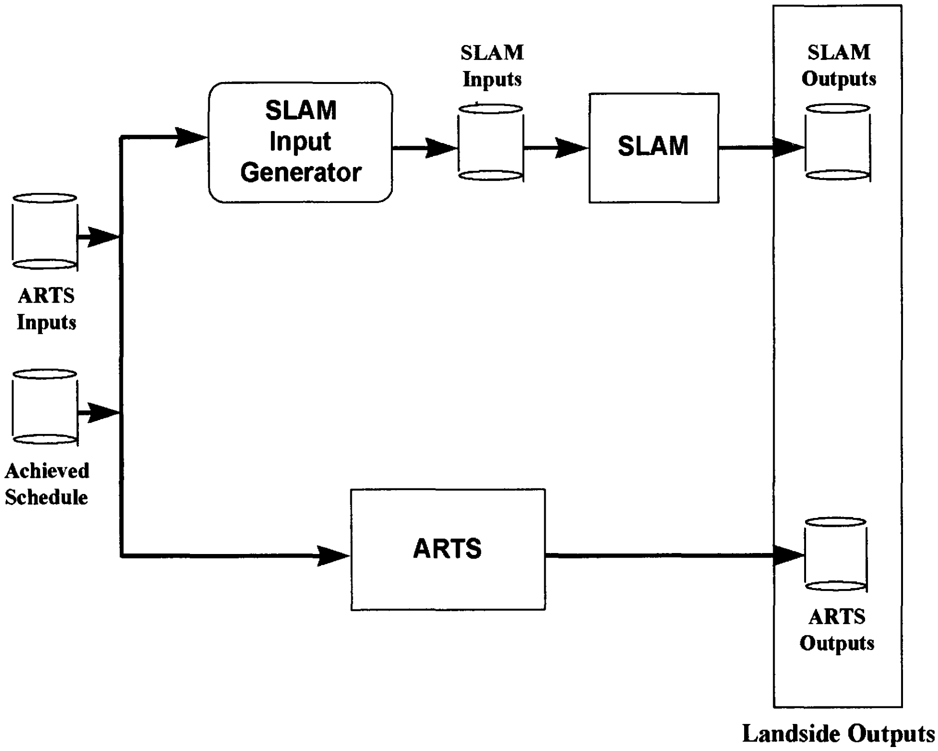

Figure 5-4: Landside of an Integrated Model Network

3. Even though, so far, the airport has been divided into Airside and Landside, the approach can be applied to finer subdivisions. The Landside, for example, can be subdivided into a network of servers each modelled as a separate subsystem and connected through their inputs and outputs. Furthermore, particular subsystems with complex behaviour can be modelled separately and produce results that are merged into the common database. This approach can be used for example to produce airport-specific baggage handling statistics using a detailed model which can subsequently be used in a "traditional" landside simulation model.

5.3.3 IMPLEMENTATION

A prototype implementation of the conceptual framework for the integrated airport evaluation system has been implemented on an IBM compatible computer under Microsoft Windows. The application involves a high level controller shell, called the TAPE Executive Shell, responsible for managing the individual models, I/O modules and data editors. Any model can be incorporated into the TAPE Executive Shell. For each model, the user needs to define: the executable to be invoked, the default directory and other environment parameters in which the model is to be run, the input categories, and the output categories. Input categories are conceptual groupings of data from the underlying airport database that are necessary for the model to run. Output categories are groupings of data a model produces. Input/ Output categories are the links in the integrated airport model data network. By matching the output categories of one model with the input categories of another, the user implicitly defines the data paths for the specific set of models incorporated in the TAPE Executive. Once the complete network has been defined in this manner, the user can build scenaria. A scenario corresponds to a specific choice of a data path and the selection of specific input data to associate with the input categories associated with the chosen models.

Typically, multiple scenaria, corresponding to alternative airport configurations and/or assumptions about the operational procedures used (e.g. air traffic control separation standards) are defined for a complete analysis of an airport. For each airport, the TAPE Executive allows such scenaria to be created, edited and saved by the users. Once a scenario is completely defined, the TAPE executive can run the individual models in the proper sequence and present the results. The user can also step through the path by manually executing the models in sequence and viewing intermediate results as needed.

To demonstrate the concept, a specific set of models (TAPECAP, DELAYS, SIMMOD, SLAM and ARTS) were incorporated into the TAPE Executive Shell, as noted earlier.

5.3.4 DATABASE ORGANISATION

The prototype development has adopted the SIMMOD and the ARTS database formats as the common database for the system and has developed I/O modules to manage the data transformation to the formats for each individual model used. The choice was guided by the fact that the two databases taken together cover practically all types of data required for TAPE.

For the Airside the data needed include:

1. Airfield geometry, i.e., runway, taxiway, apron configuration (including runway lengths, exit locations, etc.).
2. A description of the runway configurations in use, depending on weather and wind conditions, including identification of active runways for each configuration, kinds of operations (arrivals? departures? both?) assigned to each runway and aircraft types assigned to each runway.
3. Air traffic control separation rules for each runway configuration. Includes: (i) any aircraft categories (e.g., "Heavy", "Large", "Small") identified for ATC purposes; (ii) separation requirements between arrival and following arrival to the same runway, departure and following departure from the same runway, departure and following arrival to the same runway, arrival and following departure from the same runway; (iii) separation requirements for operations on different runways, if some of the runways are not operated independently. These data can be specified with reference to specific types of aircraft in each pair (e.g. "Heavy" aircraft type followed by "Small" aircraft type).

4. Detailed layout of the apron area, including all aviobridge aircraft parking positions and all remote aircraft parking positions. The types of aircraft that can be accommodated at each stand should be indicated.
5. Minimum ramp-handling service times for each type of aircraft and for each type of apron position.

For the Landside, the data needed include:

I. Terminal Building Geometry: Locations of all relevant facilities, along with associated space availability at each facility.

II. Additional data for each facility type as indicated below:

  A. Entry/Exit Points to/from terminal

  B. Check-in / Ticketing counters:

    1. Number of banks, # of agents in each bank
    2. Mode of use (by airline, common, etc.)
    3. Service times by passenger type or other relevant breakdown

  C. Security Points:

    1. Number of positions
    2. Service time average/distribution
    3. Association with gates

  D. Gates/Stands:

    1. Capacity of area
    2. Presence of gate check-in?
    3. Wide/Narrow body restrictions

  E. Passport Control:

        1. Number of positions, agents
        2. Service time distribution/average

    F. Customs Control:

        1. Number of positions, agents
        2. Service time distribution/average
        3. "Green"/"red" procedures

    G. Baggage Claims:

        1. Number of carousels or other conveyance devices
        2. Capacity and speed of carousels;
        3. Association with gates;
        4. Association with flight types;
        5. Baggage loading/unloading rates;

    H. Lobby and Gate Areas:

        1. Restrictions on visitors, etc.
        2. Size in square meters.

III. Passenger Information

    A. Passenger distribution by type: business vs. leisure, international vs. domestic, transfers vs. originating/terminating.

    B. Passenger arrival profiles (time they arrive before a flight, possibly by flight type).

    C. Pre-ticketed passenger percentage (preferably by type).

    D. Baggage count by passenger type.

    E. Greeter and well-wisher count by passenger type.

    F. Passengers per flight. This can be specified either on a flight-by-flight basis or as an average by aircraft type or flight type.

G. Passenger routes (e.g. international arrivals need to pass through customs, passport control, baggage claim) particularly if any unusual procedures are in place.

In addition detailed flight schedules (typical and/or peak) are needed to describe demand on Landside and Airside. For each flight, provide scheduled time of arrival or of departure, airline, type of aircraft and flight origin or destination, as well as typical passenger loads and passenger characteristics, as best available.

The combined data sets of these two models are a superset of all data required by all the models chosen for the TAPE prototype development. A SLAM data module was developed to extract the necessary data from ARTS inputs and a equivalent module was developed to extract TAPECAP and DELAYS data from SIMMOD inputs. Finally, modules to develop ARTS schedule inputs from SIMMOD and Delays outputs are incorporated in the TAPE prototype.

The evaluation of the prototype system will be done through case studies involving three European airports: Linate and Malpensa in Milan, Italy, and Manchester International Airport in the U.K. This effort is currently in progress.

5.4 Integrated Models of the Linate and Malpensa Airports and Assessment to the TAPE Approach

In this section, a summary of the findings of Work Package 5 of the TAPE project is presented.

5.4.1 OVERVIEW

The TAPE model is an integrated model of both landside and airside, and includes aggregate and detailed models. The name of the four models are: TAPECAP/DELAYS and SIMMOD for the airside, SLAM and ARTS for the landside. Each of the four models of TAPE requires some particular data that are provided by a database that allows transfer of information from one module to the other. The objective of this section of the report is to describe the application of the TAPE concept (i) to the Linate airport and (ii) to two scenaria of the future Malpensa 2000 airport.

The application of the TAPE prototype to a third airport (Work Package 6) has been cancelled, in agreement with the European Commission sponsors of the project, due to difficulties in getting support and retrieving all the necessary data from other airports. However, the application of TAPE to the actual Linate and two forecast Malpensa situations is felt to satisfactorily demonstrate the practical potential of TAPE as an airport operational planning tool. We also want to stress the "prototype" status of TAPE: before becoming a commercial tool it needs to address also other components not considered in the present project (e.g. handling, sorting, retrieval and loading of baggage). Furthermore, even in its present status, TAPE cannot be used as a "black box": it is important that airport planners work with the modellers for airport-specific use. This will not only lead to a higher collaboration among planners of the different components of an airport since they will be forced to share common data, but also to a higher quality of the information that can be retrieved by the model.

The Linate scenario analysed in this paper refers to the "busy day" selected by SEA for Linate: November 27th, 1995. That was the busiest day, in terms of number of movements, for Linate in 1995. The results obtained for the Linate airport are reviewed in Section 2.

The two scenaria for the future Malpensa 2000 airport analysed in this study and presented in Section 3, represent a "busy day" of 1998 as foreseen by SEA according to whether Malpensa 2000 will become a "hub" for the Italian national air carrier (scenario #2) or not (scenario #1).

Section 4 contains the assessment on how successful the run of the models for landside and airside elements has been for the two airports considered.

5.4.2 TAPE MODELS OF LINATE

In the past 16 years Milan's airports have recorded very high growth rate (a yearly average of about 5,7%) with a shift from approximately 6 million passengers in 1979 to 15 million in 1995. Linate is by far the busiest airport in today's Milan system, with about 75% of the Milan total air traffic. In 1996 the Milan Airport system registered one of the highest growth rates in Europe and is now the seventh busiest airport system in Europe, in terms of annual number of passengers.

During the "busy day" for Linate, 428 movements were recorded (213 arrivals and 215 departures) with a total of 28,964 passengers (14,635 arriving to Linate and 14,329 leaving from Linate; transit passengers counted both as arriving and as departing passengers). The registration desks are divided in 13 groups, each group serving one or more airlines. There are 2 security checks, 20 gates, and 2 Baggage claim units.

The main result we could obtain from the experiments with SIMMOD is that the airside absolutely needed five new apron stands, otherwise it had no place for aircraft to park. Apron stands are automatically assigned to arriving flights by SIMMOD with some optimality criterion: during the three peak periods of the day even the general aviation apron had to be used to serve the traffic movements. This result does not come as a surprise, since we are considering the busy day in terms of number of plane movements.

With the use of the TAPECAP model, the capacity of the single runway of Linate was estimated to be 35 movements per hour, an estimate that coincides with the current capacity assessment by SEA. Then, DELAYS used as input the hourly movements demanded and the total maximum runway capacity (35 movements/hour) as computed by TAPECAP. Next a run with the same scenario with the SIMMOD model was conducted. The input requirements of the two programs are different: while SIMMOD requires the scheduled time of each flight, DELAYS uses only the hourly movement demand. Of course, outputs are also different: DELAYS produces the hourly average minutes of delay, while SIMMOD treats arrivals and departures simultaneously but presents separate statistics for arrivals and departures. Therefore, in order to compare the results, we combined the arrivals and departures average delays into a global hourly average delay.

At this point, it is important to recall the relative roles of TAPECAP/DELAYS and of SIMMOD in an integrated package such as TAPE. The purpose of TAPECAP and of DELAYS is to give an approximate indication of the magnitude and time pattern of capacity and delays at the runway system with very little time (possibly less than 30 minutes) devoted to input preparation and only a few seconds needed to run the models. By contrast, SIMMOD provides a far more detailed analysis, including analysis of any taxiway and apron delays that may occur. The two can be used sequentially, with TAPECAP/DELAYS giving a preliminary indication of whether significant congestion can be expected and with SIMMOD providing a more accurate estimate of the associated delays.

A run of TAPECAP and DELAYS (that took about 2 seconds to complete) indicated that delays at Linate, for the particular set of demand/capacity conditions analysed (runway capacity of 35 movements/hour) are small throughout the day with the exception of the peak set of hours in the morning and in the evening when they are moderate (in the 4-8 minute range). The detailed simulation with SIMMOD (which requires extensive input preparation and about three minutes for one day's run) then confirms the order of magnitude of delays (as given by TAPECAP/DELAYS) but also suggests that congestion, even during peak hours are small (in the 2-3 minute range). By looking at Figure 5-4 from the airside detailed and aggregate models, we may notice that the expected hourly amount of delay imposed on aircraft differs. During the peak hours of the day DELAYS assigns a greater amount of delay than SIMMOD: this is probably due to the different assumptions regarding the demand patterns and on the level of detail for the flight schedule. DELAYS assumes a probabilistic (Poisson) arrival process for the demand (arrivals and departures), while SIMMOD uses as input a detailed schedule. However, it should be stressed that both models indicate that the runway capacity is adequate, and delays small, for the demand specified in the scenario of the particular runs.

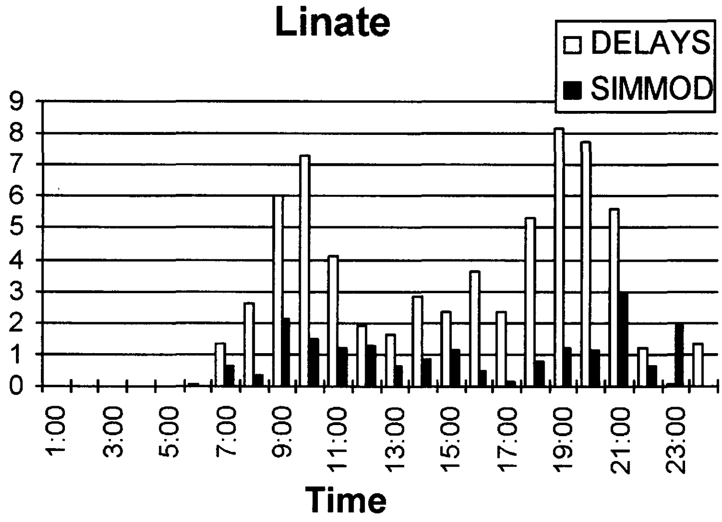

Figure 5-5 Comparison of SIMMOD vs. DELAYS (Linate)

On the landside part, the level of service provided by the Linate airport is computed by ARTS and by SLAM. Congestion at the terminal is detected by SLAM during the two peak hours (8:30 - 9:30 A.M.; 9:30 - 10:30 A.M.). The area in front of each

Check-In counter is assumed to be equal to 15 sq. m. If we consider all 53 international counters as part of a unique "common" Check-In facility (i.e., a passenger can check-in for her/his flight at anyone of the open counters), then the resulting LOS is A during both Peak Hours. However, if we consider the more realistic situation where international Check-In counters are dedicated to specific airlines, then the LOS varies from A to F.

For domestic Check-In, there are 28 counters 4 of which are reserved for VIP passengers. The remaining 24 counters are split in the following way: 15 are positioned before the security check and 9 after. If we consider all 24 counters to be in "common" use, then the resulting LOS is A in both Peak Hours. The same A LOS is observed if we cluster the counters according to the dedicated airlines. The LOS at Baggage Claim areas is always A for both domestic and international areas.

5.4.3 TAPE MODEL OF MALPENSA 2000

We should begin this section by mentioning the fact that no simulation with the "hub effect" was ever done for the airside or the landside of the Malpensa 2000 airport. All the data were collected for preparing the runs for this report. There are 6 security checks, the gates are grouped in four clusters (North, South, Satellite, Remote Satellite) for an overall sum of 36, and there are 2 Baggage claim units (Schengen, Non-Schengen), each with 5 devices.

In the "non hub scenario" the Central Body Registration Desks are divided in 6 islands that can be grouped in 2 main clusters each one dedicated to the type of flight it is serving: Schengen, Non-Schengen (North American and Other Continents). During the "non hub busy day" 614 movements are considered (312 arrivals and 302 departures) with a total of 37,928 passengers (18,964 arriving to Malpensa and 18,964 leaving from Malpensa; transit passengers counted both as arriving and as departing passengers).

In the "hub effect busy day" 838 movements are considered: 434 arrivals (62 cargoes) and 404 (32 cargo) departures, with a total of 69,915 passengers: 34,398 arriving to Malpensa and 35,517 leaving from Malpensa; 6,035 transit (23% of commercial flight passengers). The Central Body Registration Desks are divided in 13 clusters: AA, AF, AP, AZ, BA, DL, IB, KL, LASI, SR, TW, UA, JOLLY.

In the scenario with "hub effect", we first considered a "raw" schedule provided to us by SEA that corresponds to a busy day as forecasted for the year 1998. We then ran TAPECAP and obtained a capacity estimation of 33 movements per hour for the arrival runway and 30 movements per hour for the departure runway. These capacities were given in input to DELAYS while SIMMOD jointly computes capacities and delays, by considering many more data in input such as apron occupancy, interactions among the two runways, taxiing time etc. The comparison of SIMMOD and DELAYS outputs, carried out within the TAPE model, gave us the opportunity to detect that the input schedule was not appropriate. Had we used only SIMMOD (or only DELAYS) we could have overlooked this fact.

What we did then, was to rearrange the original schedule into a "reasonable" schedule: flights originally scheduled to land during a specific hour were rescheduled in that hour so that they became uniformly spread during that hour and the same modifications were done for the departures schedule.

The average departure delay computed by DELAYS is 10 minutes which matches exactly that of SIMMOD; the average arrival delay computed by DELAYS is 10 minutes whereas SIMMOD estimates it in 12 minutes. This minor difference can be explained by the apron congestion, which is considered by SIMMOD and not by DELAYS.

We want to emphasise the fact that the two programs are not intended to compete one against the other. They simply serve different purposes. The exercise outlined in this Section does confirm that the results obtained by the two packages are within an acceptable agreement, and that the same conclusions can be drawn by airport authorities about the feasibility of different options.

In the scenario without "hub effect", the airside is less congested than described above. The results of DELAYS and SIMMOD are again in very good agreement for the departures were the delays estimate by the two programs never differ by more than 2.5 minutes and are typically within one minute of each other. For the arrivals, the larger delays estimated by SIMMOD (7.5 minutes on the average against the 2.4 minutes estimated by DELAYS) can be explained by the fact that SIMMOD considers taxiway and apron delays in addition to runway delays. The latter are the only delays estimated by TAPECAP/DELAYS. This result confirms what we already observed, i. e., the Malpensa apron area with the configuration used in this study, will be very congested: this explains the higher delays obtained by SIMMOD.

We believe that our experience on the Malpensa Hub scenario is a good example of the advantages of the use of an integrated model vs. a single model. If we had used SIMMOD alone it would have been difficult to understand that the high delay imposed on arrival flights by SIMMOD was due to a poor input preparation. The combined information obtained by the runs of the two models led us to prepare a more accurate input and to a more successful run.

On the landside part, the level of service provided by the Malpensa 2000 airport is computed by ARTS and SLAM: the level of service provided by the processing facilities is in general A for the case without the hub effect, while it goes from A to F in the scenario with the Hub effect. This is due not only to a higher number of flights (from 614 to 838) and higher number of passengers (from 38 to 70 thousands), but also to a more detailed analysis of the passengers flow.

5.4.4 ASSESSMENT

The application of the TAPE approach to Linate airport has demonstrated the fact that the Airport Authority collects a great amount of data and statistics that are recorded in various ways often with duplication and sometimes with inconsistencies among the data themselves. As a first useful result TAPE has made clear the need of validating the data in order to obtain a globally correct and consistent database.

TAPE model has correctly pointed out the weaknesses of Linate, that is the Apron area, the fact that many flights have to suffer a delay and the fact that the Check-In area is not always satisfactory for all companies.

The main result we could obtain from the experiments with TAPECAP is that, in order to achieve the capacity of 72 mo/hour (foreseen by SEA when the entire new airport will be completed), the separation requirements among flights had to be reduced. This first result is perfectly consistent with the new safety rules released by the European Civil Aviation and the modern radar equipment that are going to be used in Malpensa 2000. However, for the "busy day" considered it is more appropriate to use the standard separation of 4 nautical miles on arrival and 2 minutes on departure. If this separation is used then the capacity is estimated by TAPECAP at 60 mo/hour which again is in agreement with the SEA assessed capacity for Malpensa 2000.

At the operational level the application of the TAPE approach to Malpensa 2000 airport has pointed out some critical factors: the Check-In configuration for some airlines is not sufficient in certain time slots; the passport control configuration provides a level of service C from 12:30 to 14:30. On the airside we may notice that in the hub effect scenario there is a need of increasing the runway capacity since, for example, SIMMOD expects 131 flights on arrival to suffer a delay greater than 20 minutes (on a total of 434). Indeed, there is a general agreement on the fact that Malpensa 2000 will become an effective hub airport only if the capacity will increase above 70 mo/hour which will be possible, for instance, through reductions in separation requirements.

As pointed out in the previous sections, some work has still to be done to collect correct parameters for the different TAPE modules. However, the application of the TAPE approach to Linate and Malpensa 2000 airports has already pointed out several operational critical factors. Apron deficiency for Linate, or the need of higher runway capacity, for MXP 2000 with the hub effect, are examples of these results.

As expected, when all elements of the airport scenario are working properly, the level of service provided to passengers is reasonable. In the scenaria we examined in this report no serious consequences were propagated from the airside to the landside or vice versa. Other scenaria could be conceived where this interaction could have significant effect. Also, the TAPE approach does take into account only endogenous delays and completely ignores exogenous delays (those due for instance to congestion elsewhere, or to ATC strikes or other reasons beyond the control of the specific Airport Authority).

5.5 Evaluation of the TAPE concept and prototype

In this section we discuss the evaluation of the TAPE concept and prototype performed under Work Package 7 of the TAPE project.

5.5.1 OVERVIEW OF THE EVALUATION PROCESS

The evaluation task of Work Package 7 consisted of three parts: (1) development of an evaluation methodology and associated questionnaire and scenaria; (2)

subjective evaluation through interviews with some of the TAPE's prospective users, more specifically with airport planners and managers of SEA, the Milan Airport Authority, as well as through a parallel assessment of TAPE carried out by ICON; and (3) further testing of the TAPE prototype with a difficult scenario that generates interactions between airside and landside events and thus demonstrates the advantages and importance of integrating airside and landside analysis tools.

5.5.2 EVALUATION METHODOLOGY

The evaluation of the TAPE concept consists of two distinct parts: First, a subjective evaluation part which is primarily concerned with the acceptance of the TAPE concept by its prospective users, airport planners and managers; and, second, an objective evaluation part that is based on the technical performance of the TAPE prototype in a case that requires the integration of airside and landside modelling.

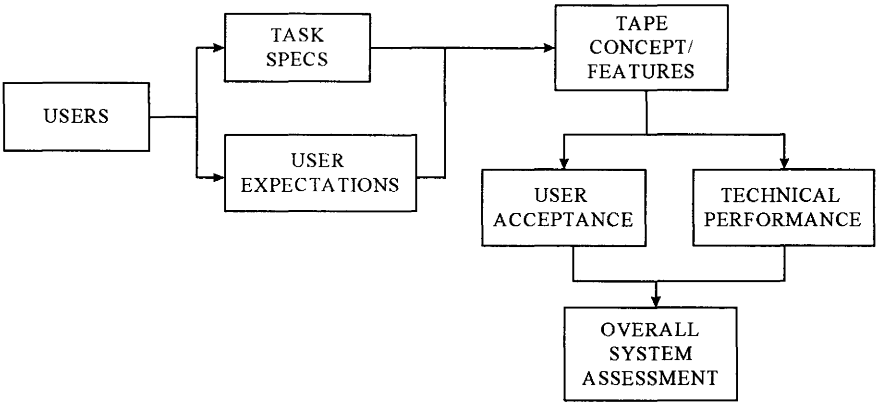

Figure 5-6 The evaluation process.

The flowchart of Figure 5.6 illustrates the logic of the evaluation process. The potential users of the system were consulted when the task specifications and user expectations were defined. Then, the TAPE concept and features were developed taking into account the user needs and expectations. Finally, the user acceptance, and the technical performance of the system were assessed.

The evaluation has been performed in the following two distinct phases:

a. *Evaluation of results of Work Package 5*

As already discussed, the TAPE prototype was demonstrated Linate and Malpensa airports of Milan. The results obtained have been evaluated and discussed with airport authorities. The airport authorities and personnel involved with the project have been asked to comment and provide their professional assessment on several subjects regarding the usefulness of the TAPE concept and prototype. The discussion of this phase of the evaluation can be found in section 5.5.4.

b. *Use the TAPE prototype to run different scenaria*

A scenario where interactions between the airside and the landside are expected to play a crucial role on the performance of the airport was constructed. Then, the following questions were investigated.

1. Does the TAPE prototype capture the interactions between landside and airside, and is this an important factor?

This question has been answered by running the same scenario with the airside and landside models used separately and with the TAPE prototype.

2. How easy was it to construct the different scenaria with the various models?

Assessment on how the aggregate models can provide estimates of the performance of airports quickly and without the use of too many resources. Also, assessment of the effort required to change some parameters of the detailed models.

3. Are the results obtained reasonable?

The results obtained from the various runs have been reviewed with a “critical eye”.

The way the above questions have been answered through the evaluation process is discussed in Section 5.5.4.3.

5.5.3 PHASE 1: EVALUATION (PARTLY) BASED ON INTERVIEWS WITH USERS

This phase of the evaluation of the TAPE concept and prototype was undertaken through case studies involving two European airports: Linate and Malpensa in Milan, Italy. As it has already been discussed, under Work Package 5, the TAPE prototype was used for the evaluation of the performance of Linate and Malpensa airports of Milan. The results obtained have been evaluated and discussed with airport authorities. The airport authorities and personnel involved with the project have been asked to comment and provide their professional assessment on several subjects regarding the usefulness of the TAPE concept and prototype. Thus, to undertake this evaluation of TAPE, it was necessary to conduct interviews at SEA, which is the organisation in charge of the two Milan airports, who have been the prime users of the TAPE approach thus far. The research undertaken with the operators concerned the following major areas, with a considerable degree of overlap among them:

- *The Conceptual Framework*
- *The Modelling Preparation and the Common Database*
- *Scenario Building*
- *Performance Confidence*

- *Bottleneck detection*
- *Future Usage and Research Needs*

The subjective evaluation of the TAPE prototype was generally very favourable. In summary, strengths identified included:

a. Successful integration of airside and landside analysis.
b. Successful integration of macroscopic (low level of detail) and microscopic (high level of detail models).
c. Development of an entirely new, user-friendly and extremely fast model, SLAM, for macroscopic analysis of passenger terminal operations.
d. Development of a new extremely fast model, TAPECAP, for analysis of airside capacity and combination of TAPECAP with DELAYS, to compute quickly and efficiently airside delays.
e. Simplification of data preparation for analyses involving the entire airport (airside and landside) using a common flight schedule.
f. Significant reduction of time and effort spent for airport analysis.
g. Tool for the identification of bottlenecks, i.e. identification of the component(s) of the airport that are most likely to be congested.

The TAPE prototype is the first model, that to the best of available knowledge, integrates landside and airside modelling. The TAPE prototype also provides integration of high-level-of-detail with low-level-of-detail models, so that the user can go from a preliminary examination at the aggregate level to a detailed analysis at the design level; or, stated differently, from "strategic" issues to "tactical" ones. It needs to be stated that the above provide an entirely original concept in airport modelling and consequently a unique contribution in this field.

Prior to TAPE, suppose that an airport authority made a simulation of the runway. Whilst the results from this simulation may show that there are no problems occurring on the runway, this simulation provided no indication of the kind of problems to be encountered on the terminal side, for example at the check-in desks. Similarly, a simulation on terminal capacity, e.g. check-in desks, can show it to be possible to increase the number of flights in a certain hour because there is enough capacity at the check-in desks. But this possible increase in capacity must be checked with a runway capacity evaluation to ensure that any increase in flights does not lead to any delays on the runway. All of this is both laborious and time consuming. The TAPE concept and prototype take this effect into account and the possibility of propagation of delays on the different components (landside and airside) of the airport are accounted for.

Another very important task undertaken by the TAPE project, with several advantages identified during the evaluation process, was the design and development of a centralised data base within the TAPE prototype. Through the use of a common data base, airport modellers in different departments can share the same data, and be confident that they run their models under the same assumptions. The TAPE common database, that was defined by SEA together with the other partners, facilitates communications between airside planners and managers and landside planners and managers within large Airport Authorities. Traditionally, airside and landside planners have been working separately, often in distinct parts of these Airport Authorities, communicating only periodically with their counterparts. Such organisational barriers may sometimes lead to situations in which airside and landside planners find themselves working with mutually inconsistent assumptions and data. Serious and costly mistakes may result. TAPE-like software may result in the future in a much better integration and co-ordination of planning functions within such large institutions. Thus, one of the most important eventual contributions of such integrated software concepts may be their positive impacts on organisational structures and internal communications.

Furthermore, with the use of this common database, the TAPE prototype provides a kind of rule-based approach - by having the same input format for all the software -

to the simulation of the total airport environment, i.e. the same busy day with same number of passengers, same number of baggage, etc. Though seemingly easy to do, it is far from trivial to be able to define a common base for the start of a global airport simulation, and this has taken considerable effort.

The TAPE concept and prototype has already gained wide acceptance within SEA, one of the largest Airport Authorities in Europe, and have provided support in the planning for one of the few major new airports now under development. Some of the components of the TAPE prototype have proven to be particularly useful, for example the simple software that permits SEA to obtain the input events file for SIMMOD in Excel format. This major breakthrough saves considerable time, as in the past this would have taken almost a week of typing. Given that the input format for SIMMOD is very difficult, cryptic and complex with its consequent demands on time, e.g. a forgotten comma in the correct location during typing leads to a failure of SIMMOD, the input software developed in TAPE for SIMMOD has certainly reduced these difficulties.

The application of the TAPE approach to Linate and Malpensa 2000 airports has pointed out several operational critical factors. Apron deficiency for Linate, or the need of higher runway capacity, for MXP 2000 with the hub effect, are examples of these results.

Besides the above conclusions, the evaluation process has also recommended future work aimed at strengthening further the TAPE prototype by expanding its capabilities to include: additional model integration and improvements in database centralisation; further simplification of preparation and modification of inputs; some animation; environmental considerations, such as noise and air pollution; and further refinement of SLAM. It should be noted that, with the exception of the first, all of these items fall outside the scope of the current TAPE project, but would undoubtedly constitute interesting possibilities for future pursuit.

5.5.4 PHASE 2: DEMONSTRATION OF THE VALUE OF INTEGRATION

In this section, we present results from a scenario constructed mainly for the purpose of demonstrating the value of integration of landside with airside models. The scenario tested, based roughly on operations at Linate Airport, involved the analysis of the effects of a 90-minute period of poor weather conditions in the morning on airport operations throughout the day. The poor weather causes severe delays to arrivals in the morning. Due to the late arrival of aircraft at the airport, this, in turn, results into severe delays in departures scheduled for later in the morning. The late departures on airside mean that departing passengers must spend considerably more time in the passenger terminal than would have been the case had the schedule of departures not been disrupted. This means a lower level-of-service at the affected parts of the passenger terminal.

5.5.4.1 Description of the Scenario and Method Used

The scenario constructed for the demonstration of the value of integration involves an airport with one runway (and 32 apron stands) and landside facilities similar to the ones of the Linate airport. The most notable characteristic of the scenario is that exceptionally poor weather appears in the morning at 7 o'clock, and lasts for one and a half hours (90 mins). The consequence of this poor weather is a serious reduction of the capacity of the airfield, caused mainly by a large increase in the separation requirements, the inaccuracy of the reported position of the aircraft and the variation of the speed of the aircraft due to winds. Furthermore, there is significant demand in the morning during the poor weather, and as one would expect, the aircraft scheduled to arrive during that interval are delayed significantly. Another important aspect of the flight schedule is that most of these aircraft are scheduled to depart soon after their scheduled arrival time, i.e. in the next hour or so. as a result, the departures that employ the delayed aircraft are significantly delayed as well.

In order to demonstrate the effect of integration of airside and landside models, two separate runs of the aggregate models used in the TAPE prototype were done. In both runs, the exact same scenario was used. In the first case, the landside and airside models were run separately, without taking into account the possibility of propagation of the effects of airside delays to the landside, while in the second case, the TAPE prototype was used to investigate the possibility of such propagation. Then, a comparison of the estimates of the performance of the airport, with and without the TAPE approach was done. Furthermore, a similar analysis was performed with the more detailed model for the landside taking the place of the aggregate one.

5.5.4.2 Results of the runs performed

First, TAPECAP and DELAYS were used to provide an estimate of the capacity and delays to be expected due to congestion of the runway. The output of these models, presented in Figures 5-7 and 5-8, combined provided an estimate of the delays to be expected throughout the day.

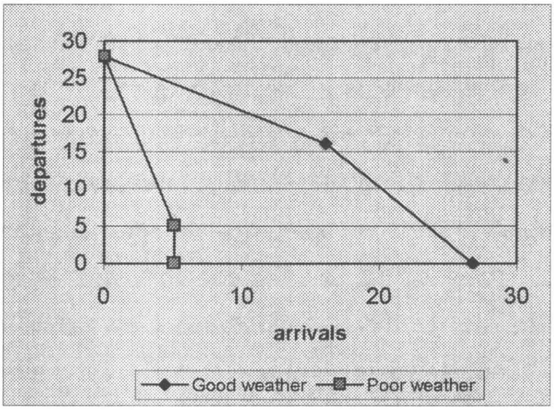

Figure 5-7 Runway capacity envelopes

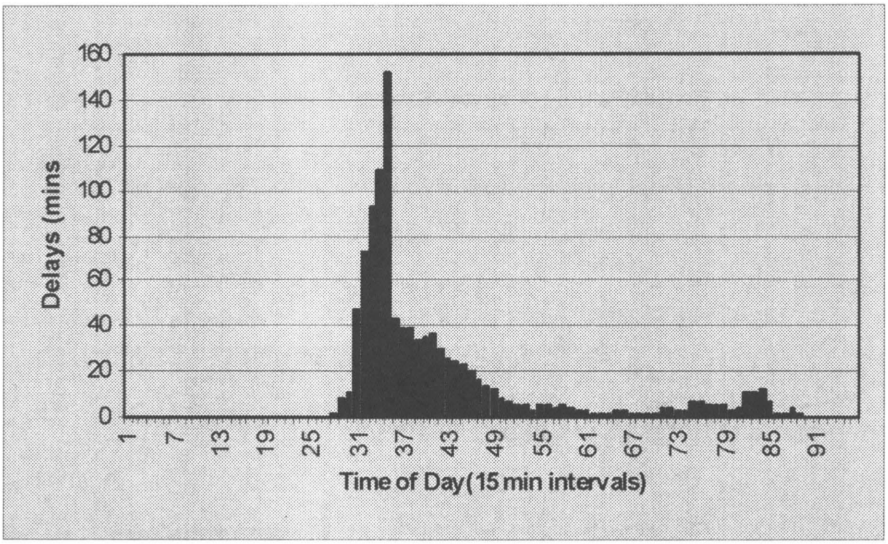

Figure 5-8 Delays reported on 15-min intervals

Two runs of the SLAM model (landside aggregate model) were performed to provide an estimate of the performance of the landside. In the first run, delays at the airside were ignored i.e. the TAPE approach was not used, while in the second run, the TAPE approach was used and the output of DELAYS was utilised in order to construct a revised schedule for arrivals and departures. In this way a comparison of results with and without the TAPE approach has been done. It should be stressed that with the TAPE prototype this process is done automatically, without the need to manually "feed" the output of the airside models to the landside models.

The propagation of airside delays from arrivals to departures (when the TAPE approach was used) was computed based on the following method:

```
If ARRTIM + ARRDELAYS + TURNAROUND > DEPTIME
DEPTIMENEW = ARRTIM + ARRDELAYS + TURNAROUND
otherwise
DEPTIMENEW = DEPTIME
```

Where,

`ARRTIM:`	Scheduled time of aircraft arrival.
`ARRDELAYS:`	Delay of arriving aircraft.
`TURNAROUND:`	The minimum time required to complete aircraft turnaround activities on the Apron.
`DEPTIMENEW:`	Revised aircraft departure time.

The minimum turnaround time used in the scenario was 25 minutes.

The results indicated that there is considerably more congestion reported at the gate lounge area when the delays at the airside are taken into account. More specifically, as a result of airside delays, two phenomena can be observed: First, mostly between 8:00 and 9:00 but later as well, the departure gate lounges are sometimes not used due to the delays incurred to aircraft scheduled to depart during that interval. This effect, captured only due to the integration of landside and airside models, is caused by the fact that the aircraft scheduled to depart were significantly delayed in arriving on account of the poor weather conditions in the morning, and consequently they were not able to depart on time.

On the other hand (second phenomenon) between 9:45 and 11:15, a significant deterioration of the reported LOS can be observed when the TAPE approach is used. This is due to the fact that passengers waiting to depart with the flights that were delayed, coincide with those waiting to depart with flights scheduled later, causing congestion in the landside, and a significant deterioration of the LOS standards. Again, this effect was captured only due to the integration of landside and airside models.

Time of Day	LOS without taking into account delays at the airside		LOS taking into account delays at the airside	
	Domestic	Internat.	Domestic	Internat.
7:00-7:15	A	A	A	A
7:15-7:30	A	A	A	A
7:30-7:45	A	A	A	A
7:45-8:00	A	A	A	A
8:00-8:15	A	A	N*	A
8:15-8:30	A	A	A	A
8:30-8:45	A	A	N	N
8:45-9:00	A	A	N	N
9:00-9:15	A	N	A	N
9:15-9:30	A	A	A	N
9:30-9:45	A	A	N	A
9:45-10:00	A	A	C	A
10:00-10:15	A	A	B	N
10:15-10:30	A	A	B	A
10:30-10:45	A	A	A	A
10:45-11:00	A	A	C	A
11:00-11:15	A	A	B	A
11:15-11:30	A	A	A	A
11:30-11:45	N	A	A	A
11:45-12:00	A	A	N	N

Table 5-1 LOS standards for the Gate-Lounge Area

*N: Not in use.

The same experiment was performed with the ARTS model (landside detailed simulation model) in the place of SLAM, such that the integration of aggregate and detailed models would be tested. As before, two runs of the landside model were performed, once in isolation, and once in combination with the output the TAPECAP plus DELAYS. With the use of the TAPE prototype, it was possible to make these runs using a common flight schedule with the runs made with SLAM. In this way, the integration of aggregate and detailed models within the TAPE prototype was tested. As expected, the results indicated the same effects as with the runs made with SLAM, i.e. an increase on landside congestion was observed when the airside delays were taken into account.

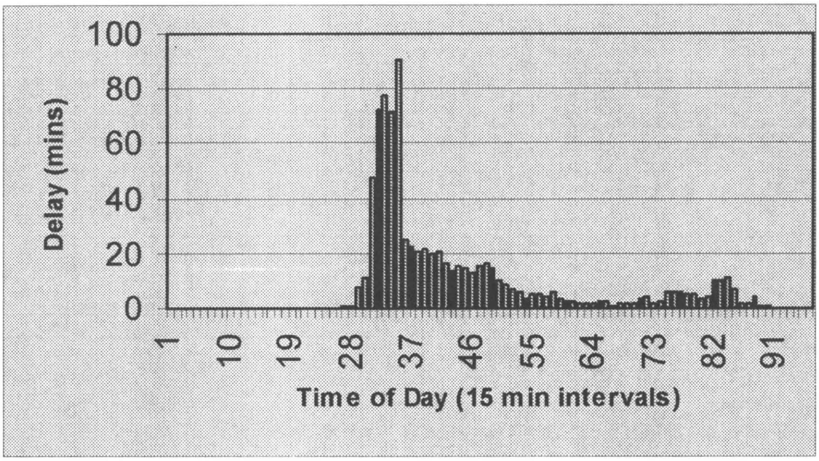

Figure 5-9 Delays based on the revised demand for aircraft operations

Finally, the effects of delays on the airside were investigated through one more experiment. As discussed earlier, the arrivals that were delayed due to the poor weather in the morning cause a delay in the departure of some flights. Then, the original schedule of departures is no longer valid, and it is thus recomputed by TAPE.

The revised demand profile differs from the original demand schedule during the morning hours, due to the effects of the morning congestion. Based on this revised schedule, a second run of DELAYS was carried out. The results (see 5-9) indicate a significant decrease on the magnitude of the morning delays compared to the ones computed with the original schedule. This result, even though not intuitive, is reasonable, and caused by the smoothing of the demand distribution. More specifically, some of the departures scheduled during a time of high congestion are now moved at a later time with less congestion and therefore the magnitude of the peak delays is decreased.

5.5.4.3 Conclusions and Discussion

The additional testing of the TAPE prototype provided further confirmation of the validity of the TAPE concept. The combination of TAPECAP, DELAYS and SLAM, all operating within the framework of the TAPE prototype, captures well the interactions between landside and airside that give rise to this type of "domino effect". This analysis also yielded interesting and non-obvious additional insights about the propagation of delays on airside. ARTS, the detailed model of landside operations, was subsequently used to provide some corroboration of the findings of the approximate macroscopic analysis for this scenario that was obtained through SLAM. This illustrates the soundness of combining the capabilities of high- and low-level-of-detail models in the TAPE approach. Finally, the evaluation task has also indicated that the airside part of the TAPE prototype is capable of providing an analysis of the effects of 14 out of the 15 capacity-enhancing APATSI procedures.

As a result of the computational experiments described above, the following answers to the questions posed are suggested.

1. Does the TAPE prototype capture the interactions between landside and airside, and is this an important factor?

As it can be seen by comparing results of the landside before and after having taken into account the delays on the airside, the assessment of the performance of the landside is quite different. This clearly shows that (1) the TAPE concept and prototype captures the interactions between landside and airside and (2) that this is an important factor that must be taken into account when performing airport analysis.

2. How easy was it to construct the different scenaria with the various models?

TAPECAP and DELAYS have proven to be easy to use, mainly due to their limited input requirements. In combination, they can provide, quickly and with little effort, a good assessment of the capacity and delays to be expected due to congestion of the runway system.

SLAM is also easy to use, it has a user-friendly environment and a very clear way for demonstration of results. The input requirements are quite extensive for an aggregate model, and therefore some effort is required to provide the specifics of the landside configuration of the airport under study. However, after this initial stage, it is very easy to model variations of the scenario under study.

As far as the detailed simulation models are concerned, namely SIMMOD and ARTS, they have proven to be somewhat difficult to use, and significant effort was required before any results could be obtained. In the case of ARTS, additional work would be needed before the model can be brought in total accordance with SEA practices with regard to allocation of gate lounges and opening and closing of gates.

3. Are the results obtained reasonable?

The results of this part of the evaluation are very positive in terms of confirming the TAPE prototype's ability to model with reasonable accuracy, even at the aggregate level, interactions among airside and landside. The following complex sequence of events has been modelled successfully: "Aircraft arrival delays cause aircraft departure delays; aircraft departure delays cause, first, some disruption of passenger terminal operations and, later in the day, increased congestion in the passenger terminals; aircraft departure delays also 'spread' the demand schedule on airside, so that increases in airside delays later in the day are somewhat smaller than what might be expected". The numerical values obtained for the capacities, delays and LOS also appear reasonable. The weakest estimates are those of airside delays near the end of the period of bad weather. This is due to the fact that DELAYS always uses the current runway service rate to project expected waiting times. Because the weather suddenly improves, the delay estimates at the end of the period of bad weather are almost certainly on the high side.

Sensitivity of TAPE to the APATSI capacity-enhancing procedures

Finally, one more important issue is the sensitivity of the TAPE airside models to capacity-enhancing APATSI Procedures.

The TAPE airside models are sensitive to and thus capable of capturing the effects on airport capacity and delays of 14 out of the 15 ATC capacity-enhancing procedures proposed under APATSI. The one exception is Procedure 11 ("Strategic deconfliction of arrival and departure routes") which lies outside the scope of TAPE. However, SIMMOD, which is one of the constituent parts of TAPE, is also an airspace modelling tool and can, if desired, be extended to cover terminal airspace and thus to model the effects of Procedure 11.

6. CONCLUSIONS

Traditionally, airport modelling has concentrated on specific subsystems of the airport complex. We find models for the Landside (terminal buildings, passenger handling), the Airside (runway / taxiway complex), or the access and egress system (roadways, terminal curbside, etc.). As many of these models have improved in detail and fidelity, as well as in "user friendliness", their use as design tools in airport development projects has been steadily increasing.

Despite this growth in popularity and acceptance of airport modelling techniques by the industry, the users must manually co-ordinate inputs and outputs for the various models in order to properly account for the interaction among the individual airport subsystems. Similar co-ordination is required in order for users to mix strategic models usually involving low level of modelling detail with tactical models requiring high level of detail in data and system definition.

The TAPE prototype is the first model, that to the best of available knowledge, integrates landside and airside modelling. The TAPE prototype also provides integration of high-level-of-detail with low-level-of-detail models, so that the user can go from a preliminary examination at the aggregate level to a detailed analysis at the design level; or, stated differently, from "strategic" issues to "tactical" ones. It needs to be stated that the above provide an entirely original concept in airport modelling and consequently a unique contribution in this field.

The hypothetical experiment performed under Work Package 7 (bad weather during the morning at a Linate-like airport) has clearly demonstrated that the TAPE prototype can "capture" and provide quantitative information on complex interactions between airside and landside operations which have never been modelled before.

The model clearly shows the “ripple” (or “domino”) effects of the bad weather, indicating that early in the morning departure gates suffered from underutilisation (due to postponement of some departure times) while later on in the day there is overcrowding of the departure gates because postponed departures are competing with regularly scheduled ones for gate space. It is also interesting to see that the after effects of weather conditions that end at 8:45 am extend all the way until noon.

The TAPE prototype also provides integration of high-level-of-detail with low-level-of-detail models, so that the user can go from a preliminary examination at the aggregate level to a detailed analysis at the design level; or, stated differently, from “strategic” issues to “tactical” ones.

Therefore the TAPE prototype is able to define a methodology to be used for a global simulation of the airport system, especially in considering the runway and apron capacity on the airside, and terminal capacity on the landside, combining the results and noting the impact of the airside on the landside and vice-versa.

Prior to TAPE, suppose that an airport authority made a simulation of the runway. Whilst the results from this simulation may show that there are no problems occurring on the runway, this simulation provided no indication of the kind of problems to be encountered on the terminal side, for example at the check-in desks. Similarly, a simulation on terminal capacity, e.g. check-in desks, can show that it is possible to increase the number of flights in a certain hour because there is enough capacity at the check-in desks. But this possible increase in capacity must be checked with a runway capacity evaluation to ensure that any increase in flights does not lead to any delays on the runway. All of this is both laborious and time consuming. The complexity of the problem increases in situations where the effects of congestion on the airside extent to the landside or vice versa. The TAPE concept and prototype take this effect into account and the possibility of propagation of delays on the different components (landside and airside) of the airport are accounted for.

The current TAPE prototype, contains and integrates five different programs (having different maturity levels), namely SIMMOD (airside detail simulation model), ARTS (landside detail simulation model), SLAM (landside aggregate analytical model), TAPECAP and DELAYS (airside aggregate analytical models). Of these programs, SIMMOD is widely used and highly mature, and has been used as an "off-the-shelf" component of TAPE. Although SIMMOD requires considerable user expertise and is occasionally difficult to use, it is generally considered a validated program. ARTS is again a program taken off the shelf; it was not developed specifically for TAPE, and therefore its validity has not been questioned. DELAYS was developed at MIT and has been used in numerous applications for approximate analyses of congestion and queuing at airports; as a result its validity has not been questioned by the TAPE project. SLAM and TAPECAP have been developed specifically for TAPE and therefore have been tested and validated during this project.

Besides the integrated environment for the evaluation of the total airport performance, another major gain from the TAPE project is the development of two entirely new, "strategic" planning models:

- SLAM for landside, and
- TAPECAP for airside.

The SLAM model is a macroscopic (strategic) model developed by the University of Padova for this project. It is an analytical model for estimating capacity and delays of airport passenger terminals (landside).

SLAM is the only quick and easy aggregate model available, at present, for determining terminal capacity. The importance of having a software which allows many trials and replications to be made rapidly cannot be overstated. Such software makes it possible, within a few hours, to define various scenaria and obtain immediately the results, especially for the facilities that are more critical from the point of view of their configuration, and in the cases where configurations can change, with results from multiple scenaria.

The performance of such a model is very important for airport authorities in general, and SEA in particular, in its planning for Malpensa 2000. At present there is no software product on the market which provides the user with an easy and quick simulation model for terminal capacity. In the past, SEA have utilised the AIRSIM simulation model for terminal capacity. But in common with other such simulation models, this is a model difficult to learn and to manage, requiring a lot of cryptic input. Such a model utilises a very detailed language like C++, a knowledge of which is a prerequisite in order to change some performance characteristics. Therefore whilst AIRSIM is a good software model for its required tasks, it is not user friendly.

SEA together with Padova worked to develop the performance requirements of such a macroscopic airport terminal model in SLAM, making considerable progress, though further development is still continuing. The most noteworthy performance of the SLAM model is its speed of run. SLAM needs about 4 seconds of CPU with a normal Pentium to run the complete scenario of the 24-hour busy day used in the Malpensa 2000 runs consisting of 740 flights and 66,000 passengers. SLAM can manage and divide this into, e.g. Schengen and non-Schengen flights, and various categories of baggage check, check-in gates.

Similarly on the airside component of TAPE, the two models TAPECAP and DELAYS have played an analogous role to that of SLAM. TAPECAP is an extremely fast and easy to use model for computing the runway capacity of airports operating with one or two active runways. This is adequate for practically every European airport. Even in cases where more than two active runways are sometimes in use (as is the situation at Frankfurt Airport which often uses three runways), TAPECAP can provide adequate approximations to the capacity of the airport, as long as the runway configuration in use can be "decomposed" into relatively independent parts, each part consisting of one or two runways.

The DELAYS model enables delays on the airside to be determined quickly, a fact which is very important for the airports in Milan where at present 60% of scheduled flights at Linate are delayed for more than 5 minutes in their arrival. The results obtained can be a first step before further simulation with SIMMOD (or another detailed simulation model) for a more detailed analysis of the airside, appropriate at the design level.

DELAYS and TAPECAP combined provide approximate estimates of the capacity and delays on the airside. They are very quick - the run times on a Pentium PC for the Malpensa 2000 scenario for TAPECAP and DELAYS is just two seconds, and the levels of accuracy are more than sufficient for airport policy makers and planners.

The great prominence of TAPE is that it provides a kind of rule-based approach - by having the same input format for all the software - to the simulation of the total airport environment, i.e. the same busy day with same number of passengers, same number of baggage, etc. Though seemingly easy to do, it is far from trivial to be able to define a common base for the start of a global airport simulation, and this has taken considerable effort.

With the advent of the TAPE approach, SEA have already utilised certain software modules developed inside the TAPE project, e.g. simple software that permits SEA to obtain the input events file for SIMMOD in Excel format. This major breakthrough saves considerable time, as in the past this would have taken almost a week of typing. Given that the input format for SIMMOD is very difficult, cryptic and complex with its consequent demands on time, e.g. a forgotten comma in the correct location during typing leads to a failure of SIMMOD, the input software developed in TAPE for SIMMOD has certainly reduced these difficulties.

In the ideal software for testing various simulation scenaria, a centralised database with all the performance that a rational database is able to render in terms of flexibility, availability, linkage, etc. is a requisite. In addition, this centralised database becomes indispensable as the input for all the models that are utilised in TAPE.

This common database, that was defined by SEA together with the other partners, facilitates communications between airside planners and managers and landside planners and managers within large Airport Authorities. Traditionally, airside and landside planners have been working separately, often in distinct parts of these Airport Authorities, communicating only periodically with their counterparts. Such organisational barriers may sometimes lead to situations in which airside and landside planners find themselves working with mutually inconsistent assumptions and data. Serious and costly mistakes may result. TAPE-like software may result in the future in a much better integration and co-ordination of planning functions within such large institutions. Thus, one of the most important eventual contributions of such integrated software concepts may be their positive impacts on organisational structures and internal communications.

For example, the simple and easy to utilise software which obtains the tested input for SIMMOD, a by-product from the TAPE project, is a big advantage for SEA. The software for SIMMOD is a PERL script that converts a text file in a SIMMOD events file. This software is in the TAPE prototype currently used by SEA for their simulations.

The application of the TAPE approach to Linate and Malpensa 2000 airports has pointed out several operational critical factors. Apron deficiency for Linate, or the need of higher runway capacity, for MXP 2000 with the hub effect, are examples of these results.

The TAPE concept and prototype have already gained wide acceptance within SEA, one of the largest Airport Authorities in Europe, and have provided support in the planning for one of the few major new airports now under development. However, one can equally say that the TAPE prototype has been utilised and tested so far only by SEA, that is, just by one Airport Authority to date. Additional future testing sites/environments should increase confidence in the model and facilitate eventual wide acceptance of the concept.

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8. ANNEX - List of Publications, Conferences and Presentations

1. Presentation of TAPE to Conferences

The overall TAPE project and/or partial results have been presented to several conferences:

a) "Airport Capacity and Delays Research in Europe" by K. Zografos, at the 76th Annual Meeting of the Transportation Research Board January 12-16, 1997

b) "Development of Mathematical Models and Solution Techniques for the Computation of the Capacity and Delays in Airports" (in Greek) by K. Zografos, M. Stamatopoulos, and A. Odoni, Hellenic Company of Operations Research Symposium, Glyfada, Greece, May 1997.

c) "An Analytical Model for Runway System Capacity Analysis" by K. Zografos, M. Stamatopoulos and A. Odoni at the VIII IFAC/IFIP/IFORS Symposium on Transportation, Chania, Greece, 16-18 June 1997

d) "A Simple Landside Aggregate Model for the Evaluation of an Airport Terminal" by L.Brunetta, G.Andreatta and L.Righi at the XV EURO Conference, Barcelona, Spain, 14-17 July 1997

e) "SLAM: An Operations Research Model for the Performance Evaluation of an Airport Passenger Terminal" by L.Brunetta, L.Righi and G.Andreatta at the 1997 AIRO (Italian Operations Research Association) Conference, Saint Vincent, Italy, 16-19 September 1997 (in Italian)

f) "Total Airport Performance and Evaluation" by K. Zografos at the Conference on Airports of the Future, Toulouse, France, 27-28 October 1997

g) "Using Analytical Models For Evaluating Airport Airside Performance" by K. Zografos and M. Stamatopoulos, at the 77th Annual Meeting of the Transportation Research Board January 11-15, 1998

2. Dissertations about TAPE

a) Massimo MORIN got a laurea degree from the University of Venice (Italy) in Computer Science on November 15th, 1996, discussing the dissertation "Un modello aggregato per la valutazione della capacità di un terminal aeroportuale" (An aggregate model for the evaluation of an airport terminal capacity) under the supervision of Prof. G. Andreatta, Dr. L.Brunetta and Dr. L.Righi.

b) Sabina PICCOLO got a laurea degree from the University of Padova (Italy) in Statistical and economic Sciences on November 22nd, 1996, discussing the dissertation "Modelli di ricerca operativa per l'analisi e la valutazione di un terminal aeroportuale: la gestione dei passeggeri" (Operations Research models for the analysis and the evaluation of an airport terminal: Passengers Management) under the supervision of Prof. G.Andreatta and Dr. L.Brunetta.

c) Denise BELTRAMIN got a laurea degree from the University of Padova (Italy) in Statistical and economic Sciences on November 22nd, 1996, discussing the dissertation "Modelli di ricerca operativa per l'analisi e la valutazione di un terminal aeroportuale: il sistema delle sale d'attesa e la gestione dei bagagli" (Operations Research models for the analysis and the evaluation of an airport terminal: The Waiting Lounge System and the Baggage Management) under the supervision of Prof. G. Andreatta and Dr. L.Brunetta.

d) Elvira FIASCONE got a laurea degree from the University of Padova (Italy) in Statistical and economic Sciences on November 22nd, 1996, discussing the dissertation “Modelli di ricerca operativa per l’analisi e la valutazione di un terminal aeroportuale: il servizio di riconsegna bagagli ed il sistema dei flussi pedonali” (Operations Research models for the analysis and the evaluation of an airport terminal: Baggage Claim Service and Flow Facilities Analysis) under the supervision of Prof. G. Andreatta and Dr. L.Brunetta.

e) Angelo FAZI got a laurea degree from the University “Tor Vergata” of Rome (Italy) in Management Engineering on March 12th, 1997, discussing the dissertation “Problematiche e metodologie per l’integrazione di modelli di reti di flussi stocastici e loro applicazione alla gestione ottima di un terminal aeroportuale” (Problems and Methodologies for the integration of Stochastic Flow Network Models and their Application to the Optimal Management of an Airport Terminal) under the supervision of Prof. M.Lucertini and Dr. P.Dell’Olmo.

f) Fabrizio LANCIOTTI got a laurea degree from the University “Tor Vergata” of Rome (Italy) in Management Engineering on July 9th, 1997, discussing the dissertation “Metodi e strumenti interattivi per la simulazione di processi decisionali: applicazione alla gestione di un terminal aeroportuale” (Interactive Tools and Methods for the Simulation of Decision Processes: an Application to the Management of an Airport Terminal) under the supervision of Prof. M. Lucertini and Dr. P.Dell’Olmo.

g) Arnab MAJUMDAR is preparing a Ph.D. thesis on topics related to TAPE at the Imperial College in London, UK, under the supervision of Prof. K.Axhausen.

h) Miltos A. STAMATOPOULOS is completing a Ph.D. thesis on topics related to TAPE at AUEB, Athens, Greece, under the supervision of Prof. K.G.Zografos.

i) Maria ROSSATO is preparing a laurea thesis on topics related to TAPE at the University of Padova, under the supervision of Prof. G. Romanin-Jacur and Dr. L. Brunetta.

j) Claudia SACCA' is preparing a laurea thesis on topics related to TAPE at the University of Padova, under the supervision of Prof. G. Romanin-Jacur and Dr. L. Brunetta.

k) Fabio DE ROSA is preparing a laurea thesis on topics related to TAPE at the University of Padova, under the supervision of Prof. G. Romanin-Jacur and Dr. L. Brunetta.

l) Salvatore CAPRI' is preparing a laurea thesis on topics related to TAPE at the University of Catania, under the supervision of Dr. M.Ignaccolo and Dr. L. Brunetta.

m) Giuseppe INTURRI is preparing a Ph.D. thesis on topics related to TAPE at the University of Padova, under the supervision of Dr. M.Ignaccolo and Dr. L. Brunetta.

3. Publication

The following publication was done:

G.Andreatta, L.Brunetta and P.Dell'olmo: "Valutazione della capacità di un terminal aeroportuale" (Capacity Evaluation of an Airport Terminal) that will appear as a chapter in the book **Modelli e metodi della Ricerca Operativa nei Trasporti** (Models and Methods of Operations Research in Transportation), S. Pallottino and A. Sciomachen eds., Mc Graw-Hill.

4. The TAPE brochure

A brochure for the TAPE project has been designed and is being produced. This brochure contains information on the TAPE objectives and achievements, including examples of output of the models developed within the project. The list of the TAPE partners and contact persons for further information is also included. The brochure is printed in 5 colors, and provided in a convenient format for distribution to airport authorities, European institutions, researchers, and airport related industries.

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