

## A System Dynamics Tool for Economic Performance Assessment in Air Traffic Management

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### Summary

What will be the cost of European air traffic services in 20 years? How many controllers will we need to face the increasing demand and how much will they cost? Will technology provide enough productivity gains to solve capacity shortages? Despite an increasing interest in the economics of Air Traffic Management (ATM) in Europe, there is still a long way to go in this domain.

**The contributions of this paper are: 1) to present a tool for long term economic assessment, that models the supply of air traffic services in a systemic way, 2) to show the potential of this modelling approach.** Eurocontrol has developed a model, called PAMELA that covers all major aspects of the ATM system. It models aspects such as the recruitment of air traffic controllers, the direct and indirect cost of air navigation services, the number of sectors and their impact on centre capacity. An illustration of how PAMELA can be used to assess European strategic investment is also presented.

### 1 Introduction

The ATM world is already facing a very complex situation today, in terms of congestion and cost effectiveness of the service. As the situation will not magically improve, it is becoming urgent to provide appropriate tools to decision makers for simulating and testing the impact of management decision on the whole ATM system performance.

E. Mason (1957) has addressed performance analysis in Industrial economics by proposing a global methodology applicable to the industrial realities. At this early stage, the conceptual

framework was based on a criticism of microeconomics techniques, too difficult to apply to reality; a need to reinforce theory by empirical studies (and vice versa); and a reflection on whether to focus on industry instead of market. The final and most important orientation in E. Mason's concepts being the hypothesis that firm's behaviour is largely influenced by the structure of the activity.

Some years later, J. Bain (1959) formalised these ideas by stating the causal links from market structure to firm behaviour, and firm behaviour to their performance. Empirical studies have tested the correlation between the concentration on a market and the degree of profit. Such a methodology provides a systemic vision, where the focus is not only on the components of an industry but also, and above all, on the interaction between the components.

The scope of studies concerning economic analysis of ATM is still quite limited, and the first attempts, despite showing promising results, are often constrained by lack of appropriate data. The cost benchmarking of Air Navigation Service Providers (ANSPs), P.Enaud, *et al.*, (2000), identifies the main cost drivers and allows to distinguish economics of density, and economies of size. Other studies have investigated the use of pricing to alleviate congestion. N. Lenoir (1998) suggests the use of congestion pricing based on flight priorities selected by the airlines. She bases her approach on M. G. Marchand (1974) who describes the use of priorities in a service. In A. R. Odoni (1999) static and dynamic congestion pricing possibilities are examined. The technical difficulties involved in implementing a system that updates prices in real-time lead the author to conclude that they do not

appear to be feasible and he recommends the use of static systems.

However, those studies remain limited to particular domains of ATM economics, and an overall systemic analysis is missing. A global view of ATM structure and its possible effects on the ANSP strategies and performance could be very important to support ATM decisions.

The contribution of this paper is to highlight the importance of having macroscopic tools for long-term economic assessment and the potential applications of using a systemic model-based representation of ATM.

The tool called PAMELA, developed by EUROCONTROL, models factors such as: ATC capital base, ATC related investment made by airlines concerning on-board equipment, the impact of new technologies, recruitment and availability of operational staff, capacity, Air Traffic Flow Management (ATFM) delays, and the links between them. It practically covers the whole European airspace.

In contrast with other models, PAMELA enables economic analyses that take into account time lags. For example, it models the time it takes to train air traffic controllers or the time it takes airlines to equip an aircraft with new technologies.

Section 2 of the paper introduces the notion of “system dynamics” whilst section 3 details the most important economic factors in ATM using system dynamics. The potential applications of PAMELA are presented in section 4 and detailed simulation results in section 5. The conclusions of the paper are summarised in section 6.

## 2 System Dynamics

System dynamics is a method for analysing the behaviour of any kind of system: biological, physical, sociological, economic, etc. It provides a high level view of a system emphasising the interactions between its constituent parts, as well as the impact of time on its dynamic behaviour. J. W. Forrester pioneered this field at the end of the fifties.

J. W. Forrester (1961) has argued that system dynamics should be applied in management, to bridge the gap between descriptive economics (or “practicing management”) and mathematical methods, such as econometrics which are often

too far from real problems. If an engineer simulates the impact of actions via simplified models prior to implementation, why should a manager not test political or economical ideas before implementing them? The number of variables is probably higher and the potential interactions are probably of a different nature, but from a systemic viewpoint it makes no difference.

D. Kauffman (1980) defines a system as “*a collection of parts which interact with each other to function as a whole*”. The notion of *interaction* is essential in the definition of a system. When some parts of a system influence others, which themselves in turn influence others, so as to finally impact on the first part, we are in the presence of a feedback loop. Systems dynamics rely on two kinds of feedback loop. The negative ones that provide stability, or oscillations around a state, and positive ones that create change and growth.

A negative feedback loop does not mean that the consequences are bad but simply that an increase somewhere leads to a decrease elsewhere, which ultimately just results in a succession of increases and decreases, which are stabilising the system. For example, a heating appliance makes the air temperature warmer, a thermostat detects that the target temperature has been reached, and stops the heater, with the ultimate effect that, over time, the temperature will reduce, etc.

On the other hand, the positive feedback loop does not mean that what happens is good for the system, but that we are in the presence of a self-reinforcing mechanism. For example, money in a bank account increases with the interest rate. The earned interest is added to the initial stock of money, and finally, the same interest rate will allow accumulation of more and more money.

## 3 ATM modelling with PAMELA

### 3.1 History and scope of the model

PAMELA is a model representation of the air traffic management system. It uses the system dynamics framework (see Section 2), and Vensim assures the software support. The modelling itself has been possible thanks to a working group composed of ATM experts. PAMELA is currently at validation stage, and it is planned to be used beginning of 2002.

The PAMELA tool is an economic model of the supply side of ATM. It links the recruitment process of air traffic controllers to the implementation of capacity plans, taking into account the cost issue, the implementation of new technologies, as well as the creation of new sectors and their impact on service quality (i.e. delays, flight cancellations etc).

It is a wide scope model focusing on long-term strategic issues. PAMELA models the period 2000-2020, in 34 countries, which broadly corresponds to the European Civil Aviation Conference (ECAC) area. Wherever possible, PAMELA performs analysis at the airspace region level. However, when resources are shared between regions they are modelled at national or even at system level.

There are some limitations to the scope of the model. At present, airport capacity is not modelled in PAMELA. The combined effect of new technologies, that is one technology enhancing (or reducing) the benefits provided by another technology, is also not explicitly modelled in PAMELA. Moreover, PAMELA doesn't replace the validation of new technology. Such technologies need to 'prove' their benefit before long term assessment in PAMELA can be performed.

As explained, PAMELA models the supply of air traffic services but not the air traffic demand, which is an input to the model. Therefore, analyses such as the impact of changes in air navigation charges on air traffic demand are not within the scope of the model. Moreover, PAMELA is not suited for detailed spatial studies, such as the result of air route changes on capacity because they require time-consuming and considerable data alterations.

The heart of the model is composed of three interrelated domains: Recruitment, Centre Capacity, and Delays.

### 3.2 Recruitment process and capacity enhancement

Recruitment is an essential part of the model for different reasons: 1/ Staff cost is the greatest cost in the ATM business (on average it represents more than 50% of total cost in Europe and more than 60% in the US). 2/ Recruitment is central to the dynamic part of the model, because it

determines capacity and therefore the impact on ATFM delays and indirect user costs. 3/ The lag between the recruitment time and the impact on capacity is also important. Given the time required for controller recruitment and training, a human resource strategy is essential to any proactive management policy.

In the system dynamics terminology, one can say that there is a negative feedback loop involving recruitment, capacity, and delays. (Figure 1)

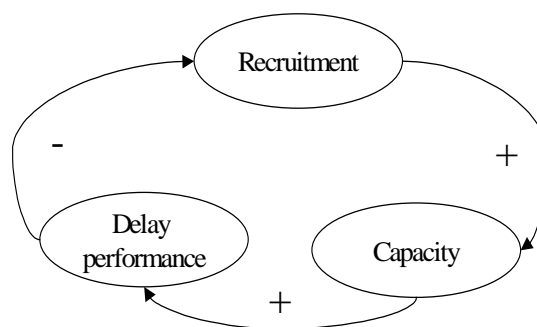


Figure 1

As newly trained controllers join operations, they enable the opening of new sectors, thus enhancing centre capacity and improving the delay situation. However, as delay goes down, recruitment is stopped because it becomes less urgent. Over time this leads to a decrease in capacity, and a new increase in delay.

### 3.3 Sectors and centre capacity

The variable "capacity", present in the recruitment loop, is itself a source of complexity. What is a centre capacity? How will it vary with the quality of the sectorisation? What is the marginal capacity provided by opening new sectors? PAMELA does not provide answers to all these questions, but it allows to model different hypotheses and to link them to the rest of the ATM system. The most realistic hypothesis to be used as a base case is to admit the existence of diminishing returns, as shown in Figure 2. In order to increase capacity, and in the absence of any technological or infrastructure changes, splitting the airspace volume in smaller pieces allows concentration of controller workload on traffic levels that are sustainable. However, for the same controlled volume, co-ordination tasks are multiplied and the time left for the controller to execute the required action is limited. As a conclusion, we assume that new sectors cannot be

created when the average transit time fails below 6 minutes.

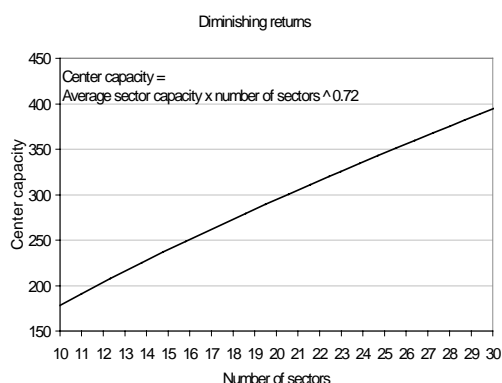


Figure 2

### 3.4 Demand capacity and delay

Recruitment and capacity are key elements in ATM, but their real dimension can only be perceived when demand for air navigation services is added to the model. Demand is growing and airspace users are paying both direct capacity costs and indirect cost caused by capacity shortage. Therefore, the links between capacity, demand and delay are crucial and have many economic consequences. Provision of excess capacity would solve part, if not all the delay, but conversely, the cost to the airspace user would not be optimal. On the other hand, when capacity is too low, or not flexible enough to meet initial demand, then delays occur, inducing costs for both airlines and passengers.

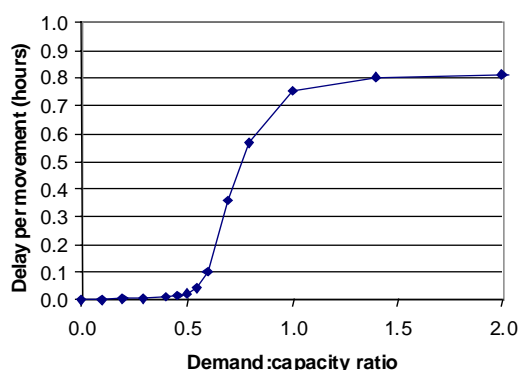


Figure 3

Historical statistics show that, at European level, the delay tends to increase exponentially with the traffic (Figure 3). The capacity problem already exists in several Air Traffic Control Centres

(ACCs), but there is still no clear evidence on how it could be solved, and on how the system will behave in the absence of quick solutions. If delays reach “unacceptable limits” it is probable that some flights are cancelled. PAMELA allows to make assumptions on the “unaccommodated” demand, (i.e. cancelled flights), and to compute the potential economic impact.

## 4 Potential use of PAMELA

### 4.1 Simulation modes

PAMELA can be used in three different modes depending on the kind of simulation you want to run.

- The first and most simple use is to input into PAMELA some potential actions. For example the introduction of a technology that increases controller productivity by 3% can be simulated with an assessment of the impact on both delays (air traffic control and reactionary delays) and system costs (direct and indirect air navigation costs) for the next 20 years.

- The second mode corresponds to “target simulations”. For example, PAMELA can simulate the number of additional air traffic controllers needed to reduce en-route delays across all European ATC centres to a certain level within a specified time horizon, (and compute the related costs).

- The third mode allows users to perform sensitivity analysis, to identify the risks associated with key hypotheses.

### 4.2 An application to assess European strategic investment

The following example is presented to illustrate PAMELA applications in a more tangible way. It addresses the following question: *Are European strategic investments cost-effective and what is their impact on overall cost per flight?*

Eurocontrol is costing the strategic investments planned for the next 20 years in Europe and analysing their impact on performance of European air traffic services. PAMELA is a suitable tool for this analysis since it simulates long-term developments and the impact of new technologies and procedures on Air Traffic Services (ATS) production factors, labour and

capital, including also airline investment on-board of aircraft.

Two scenarios can be compared:

- Scenario 1: capacity is increased by traditional means, that is by increasing the number of controllers and by opening more air traffic control sectors.

- Scenario 2: capacity is increased by means of new technologies or operational changes. Examples of technologies and changes included in the European ATM strategy up to year 2015 are: free routing, data link, automated support for conflict detection and resolution and delegation of separation responsibility (ECAC and Eurocontrol, 1999).

Initially, PAMELA can be used to assess the viability of these scenarios, for example, can ‘traditional’ means of increasing capacity provide the additional capacity needed for the next 15 years?

In a second stage, PAMELA can provide economic information for each scenario. The cost of scenario 1 includes mostly the cost of equipping and opening new sectors and of recruiting additional staff together with maintenance costs of present technology. The cost of scenario 2 comprises the investment cost in new technologies by both ANSP and airlines together with all other associated operational costs.

One of the main strategic objectives of European ATM strategy is to reduce the overall air navigation cost (including congestion cost) per flight. PAMELA can simulate the evolution of these costs over time for each scenario.

PAMELA not only provides the above costs but also a wealth of additional results such as annual recruitment per ACC, annual delay per movement, annual air navigation charges, evolution of number of sectors per centre overtime, to name but a few.

## 5 Simulating with PAMELA

### 5.1 Set up of the simulator

The simulation mode used for the following examples is a forward-looking mechanism. This means that the model will compute requirements

in function of the future state of the system. In reactive capacity management, the current demand is taken into account. However, since it takes 4 years before recruited trainees will become available, and since our demand grows steadily, the result always comes 4 years too late. In the proactive policy, the model looks at the demand one training period ahead. It is therefore possible to recruit now the number of controllers that will be needed at the end of the training period. Figure 4 shows the advantage in term of delays of being proactive.

Simulations are performed with a performance target related to delays. Each ACC aims at the same average delay per flight over one year (1 minute). As a flight transits on average 3 ACCs, it should lead to a 3-minute average at European level.

The table below summarises the main assumptions constraining the model behaviour. These inputs are the result of a consensus between the experts having participated in the development of PAMELA. Each input could obviously be changed, depending on the simulations, especially if the introduction of a new technology or other organisational changes were to modify those baseline assumptions.

| <b>Baseline assumptions</b>   |
|---|
| Ab-initio training time for controllers: 4 years  |
| Recruitment constraint: maximum +13% of the staff per year                              |
| Productivity gains (all kind of sources): 1% per year                                   |
| Number of sectors constraint: minimum sector transit time at 6 minutes                  |
| Number of staff for the first 4 years: as declared by ANSPs to the CRCO                 |
| Traffic increase: As forecasted by STATFOR, 3.5% in average, depending on years and ACC |

From the delay target of 1 minute per ACC, the model computes the capacity required, the number of sectors needed to achieve the capacity, the staff needed, and thus the recruitment, as explained in the previous section. A cost evaluation of the capacity and the delays is also performed.

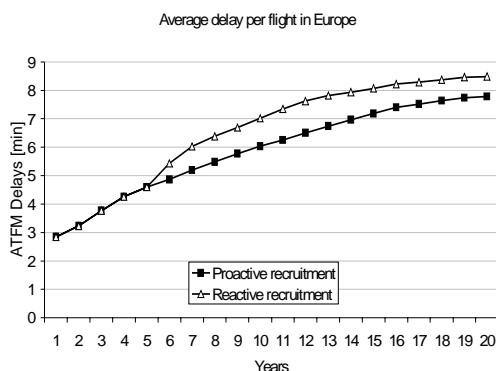


Figure 4

### 5.2 Identification of constraints

Under those assumptions, Figure 4 shows that the performance observed in the first year cannot be maintained over time at system level. PAMELA will help to identify the source of the constraints, the time at which they become restrictive, and the ACCs that are mostly concerned.

Until year 5, the model simply projects the declared staff plan into the capacity and delay mechanism. The effect of the targeting policy (1 minute per flight for all ACCs) should become visible only at the beginning of year 6, when the additional staff recruited at year 2 are operational. However, delays are still rising, showing that other constraints are limiting the effect of the recruitment policy.

This quite pessimistic trend masks two phenomena:

- Not all ACCs have problems to reach the target, and their proportion varies over time. Figure 5 shows that the proportion of ACCs that cannot reach their target increases in two steps. Until year 9, there is a gradual increase rising from 15% to 30%. During this period, most of the ACCs do not achieve the expected performance because the staff plans do not properly anticipate the need for capacity. In the second stage, after year 10, there is a major degradation of the situation with around 40% of ACCs missing their target. The issue then seems related to physical constraints that are due to the sector splitting limits (as explained in section 3).

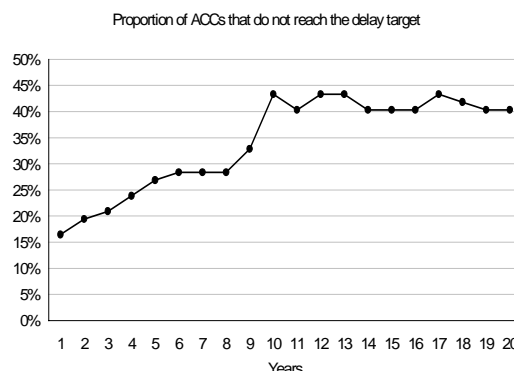


Figure 5

- Not all ACCs have the same problems at the same time. Depending on time and location, either the recruitment or the number of sectors are limiting the improvements in terms of delays. This is now shown based on simulation results for one particular ACC.

### 5.3 Analysis of one particular ACC

Looking at a particular ACC that cannot reach its target, the causal links between target delay, capacity, number of sectors, and recruitment can be illustrated.

Three different scenarios have been simulated to show the impact of each constraint.

|   | Limit on recruitment | Limit on the number of sectors |
|---|----------------------|--------------------------------|
| No constraint (black triangles)         | no                   | no                             |
| Recruitment constrained (white squares) | yes                  | no                             |
| Sector constrained (line)               | no                   | yes                            |

Without constraints, figure 6 shows that the target is reached in year 6. This implies that the current staff plan seems dimensioned more to keep a constant level of delay rather than to improve the situation.

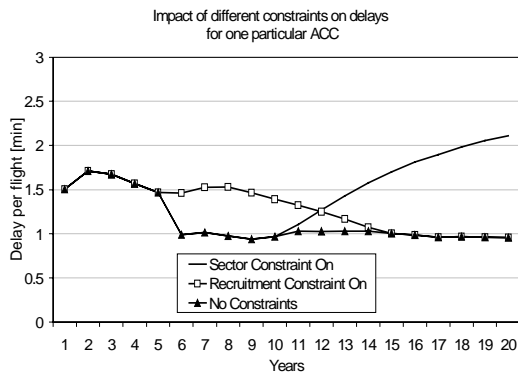


Figure 6

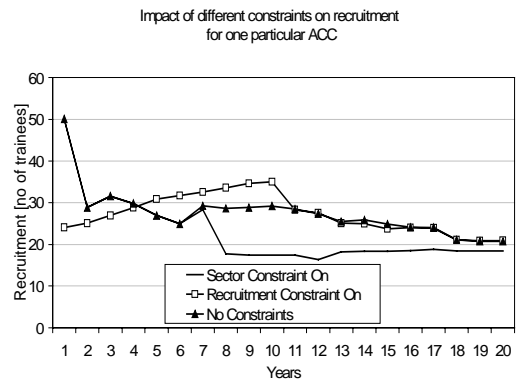


Figure 7

However, if the target is reached in year 6 it is at a price of a drastic increase in capacity that requires the recruitment of 50 trainees, which is not realistic, being far above the training school capacity. In the more reasonable case of a maximum 13% increase per year (recruitment constraint on), the target is reached only in year 14.

In conclusion, due to the long training time (4 years) and the fact that both schools and on-the-job training have limited capacities, it takes 9 years to reach the performance target in our example. That is of course a strong argument in favour of proactive recruitment but it could also encourage very congested centres to recruit already trained controllers, coming from other ACC, or even from other countries...

Comparing the recruitment curve with the capacity or delay curves allows a clear visualisation of the lag existing between the decision to recruit and the impact on delays. PAMELA, with its ability to look forward (dynamic aspects) can estimate the time required to see the impact of an action. Moreover, and this may be even more important, PAMELA can identify the moment after which recruitment becomes useless (systemic aspects). The stabilisation of the recruitment in year 8 (figure 7, sector constraint on) is due to the anticipation that in year 13, additional controllers are not needed because the number of sectors has reached its limit (figure 8).

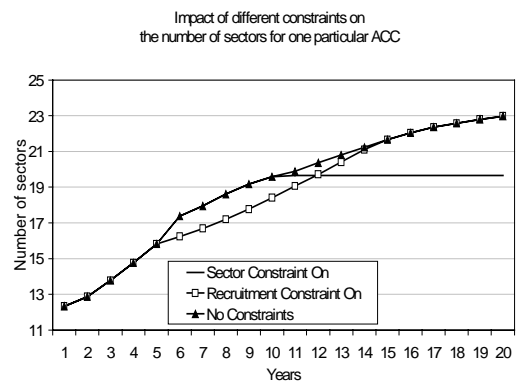


Figure 8

As the capacity requirements grow over time, in year 13, the number of sectors needed to create additional capacity becomes incredibly high. That is most probable that the average transit time of a sector would be too short to perform the control safely. Considering this absolute limit, recruitment should be limited to covering the operational staff attrition. Delays per flight are thus rising until the end of the simulation.

Looking at the ACC capacity, figure 9 illustrates that, even with a constrained number of sectors, the capacity still increases. That is the straightforward consequence of the assumption of a 1% increase in productivity per year.

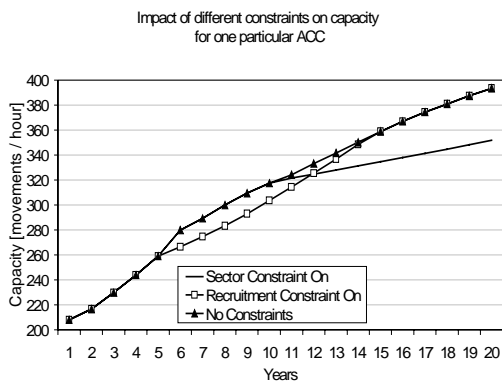


Figure 9

The productivity increase is actually a very sensitive parameter. Over the last years, we have seen that some ACCs were able to increase their capacity without using more staff. New procedures, better training, or some kind of new technology can have a significant impact on the controller's productivity. However, quantifying this parameter is complex, and projecting it in the future could be seen as pure guess.

Admitting this point let us take a look at the problem the other way round. For the ACC shown in the example and that cannot reach its target, what are the productivity gains that would be needed to achieve the goal? PAMELA can easily run new scenarios, changing the productivity parameter. Figure 10 shows that two boosts of +5% at year 3 and 9 would allow the ACC to get very close to the target. The interesting question now, but which PAMELA will not answer, is: Will the introduction of Reduced Vertical Separation Minimum (RVSM) and data link, to name but a few, allow two cumulative 5% boosts in productivity?

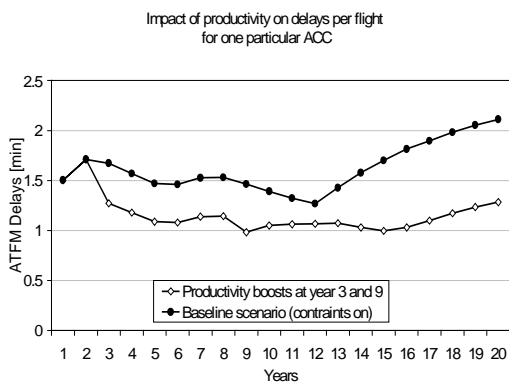


Figure 10

Finally, PAMELA provides the cost impact for each scenario. In a cost benefit analysis context it is also able to compute the break-even year and other associated indicators.

At system level, Figure 11 shows the decomposition between direct (capacity) and indirect (delays) costs, using a 53 euros cost per minute of ATFM delays, under the assumption of no constraint in sector and in recruitment.

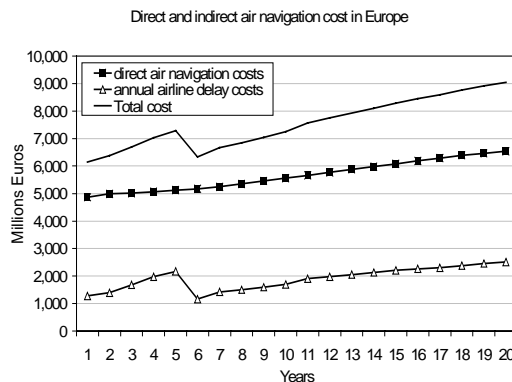


Figure 11

## 6 Conclusion

This paper has presented a model for economic performance analysis called PAMELA. PAMELA simulates the main components of air traffic services supply over the long-term using system dynamics. This enables economic analyses that take into account the links between the different components of air traffic services such as, operational staff, air traffic services infrastructure, airlines' fleet, technology and capacity and their evolution over time.

An example illustrating the versatility of PAMELA has been described. Preliminary work has shown that PAMELA can provide valuable insights, both at system and ACC level.

However, further validation and development work is needed in the following directions:

- Initial validation of PAMELA has shown that it provides results that are in line with results provided by other means but additional and more detailed validation of data is still required.
- PAMELA models en-route capacity but not airport capacity. Airport capacity should be added to the model.



- The benefits of a new technology can be increased or reduced if that technology is combined with other technologies. PAMELA should take this combined effect explicitly into account.

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Graduated in computer science, he has worked as a software engineer in the space business (in

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Graduated in Air Transportation Economics, he has been working since 1997 in the field of air navigation economics, contributing to several projects such as the Future ATM Profile (FAP), the analysis of air traffic complexity, and the cost benchmarking of ANS providers in Europe.

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