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Governing a complex social system with system dynamics: the management and economics of an airport hub

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Abstract
Managing a hub successfully imply the interaction of numerous actors, both public and private operating at a local, national and international level. Such a complexity imply that, rather than the content of the single decision, it is important to understand those dynamics emerging from an articulated system of decisions. In order to improve the quality of the single decisions, it is required the ability to generate valid systemic conceptual models aimed at the understanding of the long term consequences, avoiding counterintuitive and undesirable results.
This paper constitutes the outcome of the continuation of a research project started in 1999 and can be considered the result of the second evolution of the hub model. A first evalotion of the model had been presented in a paper written 2000. While the 2000 paper focused particularly on a hub creation, this paper focuses on hub management and the economic impact of managerial choices.
The paper is articulated in three parts: The first is dedicated to the statement of the problem; dilemmas, possible strategies and key decisions related to the creation of a hub are discussed. In the second part the systemic conceptual model is presented with reference to a simulated European airport context. In the last section some consideration about the implication in terms of decision making, economic impact, the directions proposed by the model and the possibility to generalise it in other systemic context are explored.

1. Introduction

The recent sharp reduction in passenger traffic caused by the September 11th events, has highlighted a wide debate on how to revitalise the industry as it was before. Now things are slowly returning normal but strict traffic controls in and among the airports request a even stronger planning and management of activities taking place in the airport through the improvement of managerial tools employed in this context. For this reason it is necessary to dominate complexity employing a methodology which allows to represent a system of actors and operations and to understand the key levers useful to generate a vicious circle which allows the growth of such a reality. Furthermore, we must underline the applicability of such an instrument in other industries showing similar characteristics, such as the infrastructure, the logistics, the transportation and the communication industry (telecommunications, cinema, etc.) among others.

In this paper, a brief analysis of the characteristics of a hub and the conditions which allows its development will be followed by a review of the literature on the hub development models. The identification of the most relevant variables for the creation of a hub will lead to the presentation of the model and its functioning. Finally, the main managerial implications of the model in terms of economic impact of managerial choices and its generalisation to other industries and contexts will be presented.

2. The functioning of a hub [1]

The name *hub* designates the airport which offers a wide variety of connections to national and international destinations, defined spokes, synchronised in order to allow a rapid transit of passengers from an arriving to a departing flight[2]; the synchronisation of flights allows the design of traffic "waves", whose number determines the quality of the connections and, consequently, of the service offered by the airport. A hub can be considered a clearing station and the synchronisation of the flights in arrival and departure allows to offer passengers a number of destinations wider than the number of the direct connections provided [3].

Furthermore one of the most relevant characteristics of a hub is its capacity to attract transit passengers rather than origin/destination passengers [4]. It must be underlined that not all the airports can become hubs; in fact their central positioning with respect to the main east-west traffic stream is a precondition. Nonetheless, the positioning is not the only requisite which can transform an airport in a hub. Another fundamental element is the presence of an airline which provide flight connections and their synchronisation. In fact, a hub is an organisational solution chosen by and airline and concerning the type of connections it offers [5].
Consequently, a single airline can decide to concentrate its whole fleet in an airport and exploit economies of scale and also benefit from a higher visibility deriving from the creation of a critical mass. The proper functioning of a hub, stimulated by and airline who has decided to invest in an airport, can attract other competing airlines which will try to synchronise their connections to the traffic waves designed by the dominant airline.

In reality, in countries where the hub and spokes system has been introduced decades ago, such as the United States, it is possible to identify two or three airlines operating in the same hub and exercising a partial domination over that hub. For example and airport like the Chicago airport is dominated by three airlines (American Airlines, Midway Airlines and United Airlines) as the Dallas airport (American Airlines, Delta Airlines and Southwest Airlines) (Bania et al., 1992) and many others could be cited. The airlines cannot be considered the only actors involved and responsible of the management of the hub. There are at least two other actors who manage the fundamental operations of the airport: the **airport authorities** and the **handling operators**, who can, in some cases, be a unique subject [6].

The **airport authorities** are responsible of the project, the realisation and the management of the airport infrastructures. This means that they are in charge of the enlargement of the airport terminals, the construction and the equipping of the runways, rather than the parking or taxing areas for aeroplanes. The relevance of the role of the airport authority can be better understood if we consider that the characteristics of the airport infrastructures determine the major part of the quality standards offered. For example, the number of runways and the technological characteristics of the control towers define the number and the frequency of takeoff and landing in a time unit; on the other side, the number of parking areas or flying bridges determine the number of aeroplanes which can stop in airport in the same time; the shortage of parking places or flying bridges can increase the waiting time of the aeroplanes and cause domino effect delays. Quite often airport authorities operates as real estate agents, renting airport spaces to commercial operators in order to equip the airport with restaurants, shops and areas where passengers can relax while waiting for their flights or connections and, therefore, increasing the attraction power of the airport (Feldman and Shield, 1998). Some airports can be considered real commercial centres capable of attracting the inhabitants of the catching area [7]. The handling services can be distinguished in two macro categories which can be managed separately, the landside handling and the airside handling. While the first concerns all services connected to the management of passengers and their luggage (ticket sale, passenger registration and check-in, security control, luggage transfer and embark-disembark of passengers, etc.), the second deals with all the activities performed around the aeroplane (cleaning, catering, fuelling, etc.).

The ability of both the airport authorities and the handling operators can guarantee an adequate quality of the service by the airport, but also avoid flight delays. For example, an inadequate number of parking areas or the slowness in the downloading and the transfer of baggage or in the catering service, can cause delays in the schedule of one or more flight and lead, in some cases, to the paralyses of the airport.

Considering that the service offered by an airport is a public utility, also national, regional and county institutions are responsible of the definition of the minimum quality standards of the service offered by the airport and the realisation and management of the infrastructures which allow the accessibility of the airport. For example, ENAV, the State and the Ministry of Public Procurement and Transportation can be involved both in the regulation of flight activities and in the financing of the operations and the infrastructures, as well as international institution, such as BEI or World Bank. Instead, the airport accessibility is guaranteed by the presence of streets and railways, and therefore also the Ferrovie dello Stato (Italian railways) and ANAS [8] are subjects contributing to the quality of the services offered by the airport.

At the first analysis, it appears clearly the numerousness of airport operations, the complexity of their joint realisation, the number of actors involved and the need to co-ordinate their activities. This final element, in particular, has a determinant role in the definition of the general perception of the airport and of the entire flight by passengers; in fact, the average traveller will tend to attribute the responsibility of every single delay (a delay in the delivery of the baggage, the security control, etc.) or any malfunctioning to the airline they are flying with, even if most of the times this is not the case. And the unsatisfaction regarding these malfunctioning can also effect the flight *stricto sensu*.

At the end of such an analysis the management and growth of a hub could seems to be practically impossible because of the impossibility to synchronise the actions of such a numerous number of subjects and cultures. In reality, the analysis of the complex interaction among the subjects can be effectively performed employing the *system dynamics* which allows, not only to identify and analyse the direct consequences of the operation and choices taken by the various subjects, but also the counterintuitive effects, which could hardly be managed taking into consideration human rationality and the contribution offered by the traditional methodologies of quantitative analysis only. In the following paragraph we will describe the main qualitative-quantitative methods employed in the analysis and study of the creation of a hub and highlight their strengths and weaknesses.

3. The role of system dynamics

The literature, especially from the United States, is rich of interesting studies aimed at the representation and forecast of the hub dynamics, employing qualitative or quantitative analysis.

The qualitative analysis move from the identification of the variables which guarantee a correct development and functioning of a hub and continues with the identification of the minimum thresholds for each of them. The advantage and the limit of such an approach is, respectively, the possibility to take into consideration a considerable number of variables and the possibility to represent the interaction among the various variables. This means that it is possible to identify the ideal level of service ignoring the compensation and interaction effects among variables which can generate hardly foreseeable results.

Finally, the qualitative approach make it difficult to forecast the effect of small but relevant changes in the variables within the entire airport system and the use of historical series rends the entire approach more oriented to the past than to the future.

On the other side, the quantitative analysis are based mainly on linear combinations of variables. As an example we should take into consideration the model proposed by Bania et al. (1992) which is constituted by three equations which represents, respectively, the *hub* (H), the service level (S) and the competition level (C). The three equations show a different combination of the regional economic activities (R), of the distance (D), of the airport characteristics (A) and the weather conditions (W). In other words:

$H = h\ (R,D,A,W)$

$S = s\ (R,D,A,W)$

$C = c\ (R,D,A,W)$

Models similar to the previous are presented also by Bauer (1987) and Huston and Butler (1993). Variables such as the population (POP), the highest pro-capita income (INCOME), the business or leisure purpose of the travels (BUSTOUR) and a widest number of headquarters and subsidiaries of multinationals (CORP) effect the demand for flights and, therefore, lead to an increase in the service level, rendering the airport suitable for becoming a hub. The definition of estimator of the model allows, on the base of a database composed by a sample of the 112 major USA airports, the evaluation of the impact of the different variables on the dynamics of the traffic of the airports.

Another model (Berry et al., 1997 e 1996) determines the price mark-up which can be applied by a specific airline in a certain airport on the base of the estimation of the utility function of the consumer/traveller and the demand elasticity. Even if the airline’s point of view is assumed in this analysis, the usefulness of this model is clear, especially because it takes into consideration variables relevant in the definition of the characteristics of the hub and the service offered. Some further studies have been performed on the entry and exit mode from a hub (Hendricks et al., 1995).

In the quantitative models, differently from the qualitative, the limited number of variables enhance their significance; this leads to a noticeable reduction in the complexity, if compared to the reality, and to the impossibility to isolate residual factors which, under certain conditions, could lead to a paralysis of the activities and, therefore, of the development of a hub. The advantages of such models are associated to the rigour and the objectivity of the data employed in the statistical elaboration and in their capability to forecast the effects of actions on the variables included in the simple model.
The disadvantage of such an approach is its rigidity and, consequently, a limited generalizability, beside the bounded validity in case of changes in the context; in fact, they require the introduction of new variables and the recalibration of the model.

Finally, some authors (Berdy, 1998) do not believe in the possibility of managing a network without advanced scheduling systems, fleet optimisation models, software for the definition of the prices, models for the measurement and forecast of profits, origin and destination databases and a staff trained and organised to manage the network process.

Moving from these considerations it is possible to clarify how a system dynamics model can allow to blend the advantages of both the approaches proposed so far. This means that, as in the case of the qualitative models, it is possible to use a rather high number of variables without any risk of loosing significance and controllability. On the other side, as in the case of the quantitative models, it is possible to apply a rigorous methodology to estimate the effects and the interactions among variables due to the changes in their values. Therefore, such an approach combines the rigour of the quantitative approach and the versatility and the descriptive power of the qualitative models. In the following paragraph, after a brief description of the variables employed in the model, it will be provided a brief outline of the model.

4. The model

The model has been created with the purpose to understand the factors which stimulate the growth of passenger traffic in an airport. It has been projected taking in consideration a start-up airport. Therefore, the variables have been selected according to their role in the development of a hub; such a criteria has been also employed to identify four variables categories (Figure 1):

- **general indicators**, namely those which allow the functioning of an airport; they are the minimum conditions for the correct functioning of an airport.
- **Indicators specific for transit traffic**, such as those which favour the development of transit traffic.
- **Indicators specific for terminal traffic**, namely those which allow the development of terminal traffic.
- **Structural indicators of a hub**, such as the requisites necessary for the development of a hub.

Figure 1 – The indicators used in the model

Category	Variables
General indicators	• Number of connections • Type of connections • Location of the connections • Frequency of connections • Number of slot • Weather conditions • Organisation conditions (strikes, etc.) • Airport infrastructures • Number of runways • Cost of the airport for the airlines
Indicators specific for transit traffic	• Synchrony of connections • Centrality in the transit traffic [9] • Quality of the service offered to airlines • Quality of the service offered to passengers in transit areas (transfer time from a gate to another, availability of waiting lounges and refreshment/shopping areas, etc.)
Indicators specific for terminal traffic	• Catchment area • Accessibility • Number of parking • Quality of service offered to terminal passengers entering and exiting the airport (time required for ticket issuing, number of ticket offices, number of luggage trays available, time required for custom control, baggage delivery time, etc.)
Structural indicators of a hub	• Critical mass of connections - connectivity/average lay-over time • Speed of service/turnaround - average turnaround time offered by the airport • Interconnection infrastructures - qualitative standard for passenger connections (people-mover, flying-bridges, etc.) • Minimal infrastructures - runways and control towers qualitative standards • Riqualification of accessibility - high speed railways links

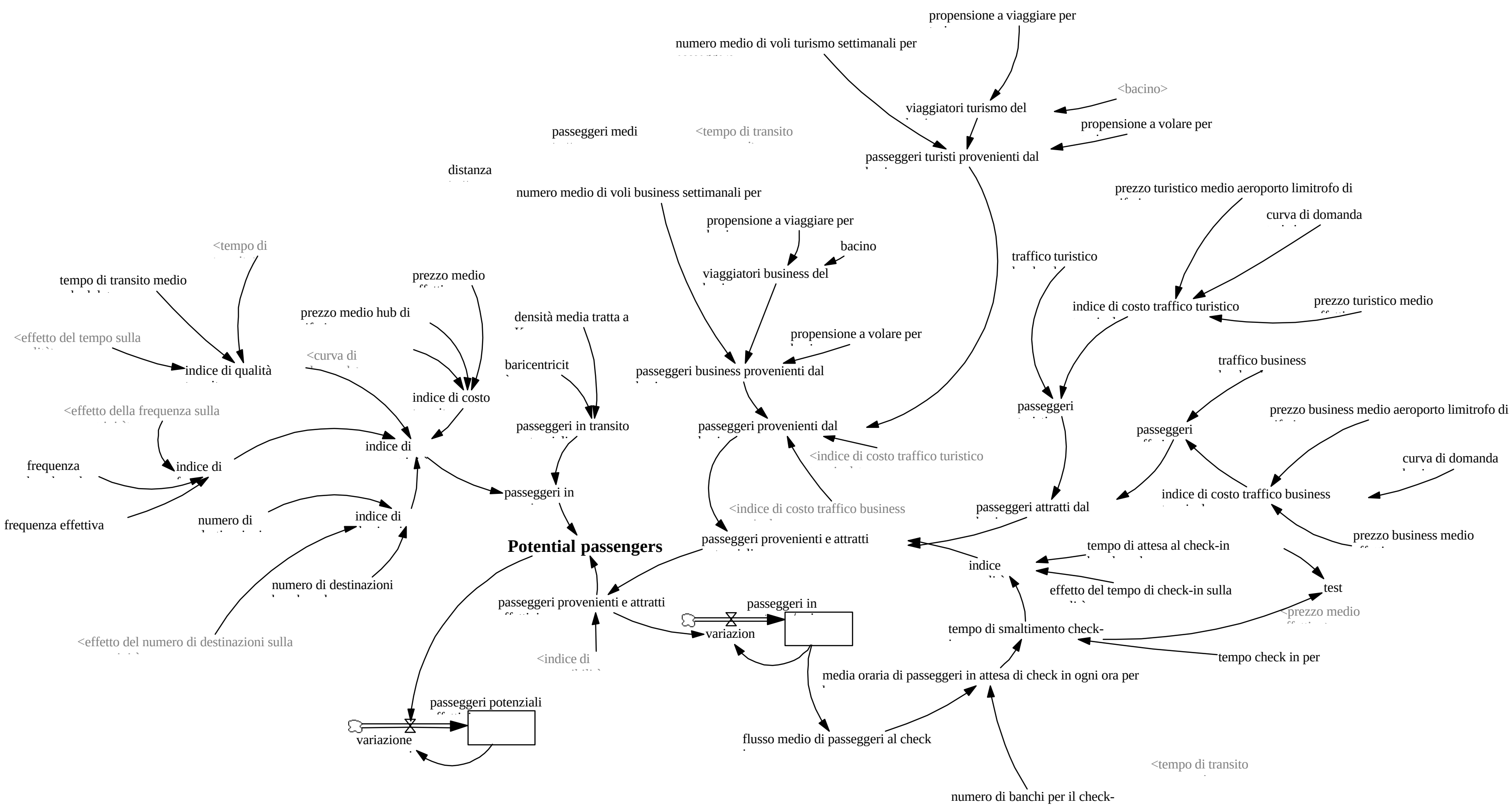
	- interconnectivity

Source: authors' elaboration

The combination of the above mentioned variables and the representation of their reciprocal influences has allowed the identification of four interconnected subsystems:

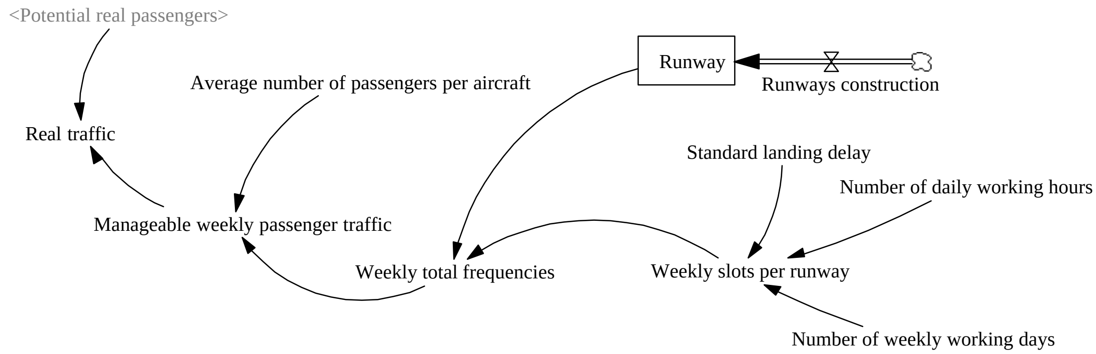
- potential passenger traffic (Figure 1);
- traffic and infrastructures (Figure 2);
- logistics and service quality (Figure 3);
- airport accessibility (Figure 4).

Figure 1 – Potential passenger traffic



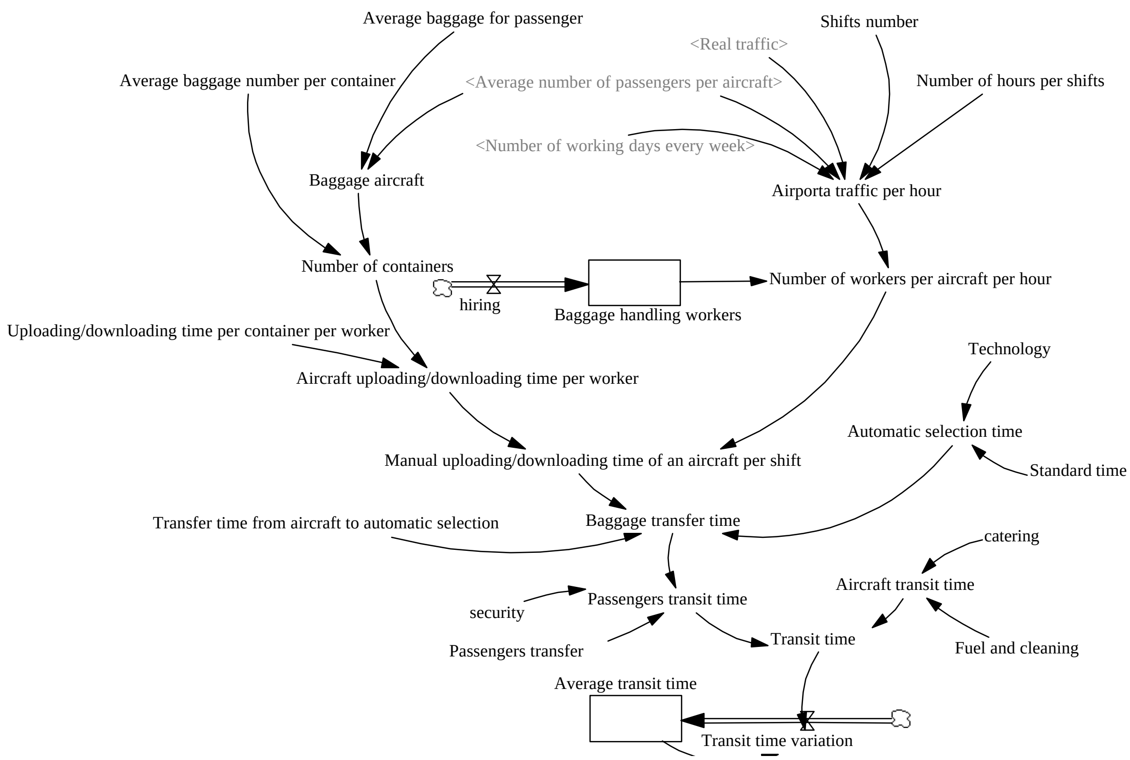
Source: authors' elaboration

Figure 2 – Traffic and infrastructures



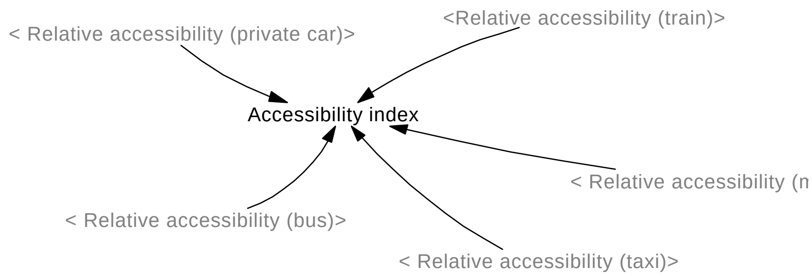
Source: authors' elaboration

Figure 3– Logistics and service quality



Source: authors' elaboration

Figure 4– Airport accessibility



Source: authors' elaboration

The part of the model focalised on the estimation of the **traffic and infrastructures** describes the role of the infrastructures (runways, control technologies, etc.) in the definition of the maximum traffic level the airport can manage; hence, this constitutes the threshold which limit the possibility for the airlines to develop traffic in the airport, particularly if it is measured in terms of landing and takeoffs. For this reason, in this part of the model variables as the control towers, the runways and the functioning conditions of the airport are taken into consideration. The actors influencing such a subsystem are the airport authorities but also the national and international institutions managing the slots [10]. Finally this part of the model can be also considered as a useful instrument to measure the airport efficiency and the quality of the services it offers.

The sub-system describing **logistics and service quality** reveals the connections between the quality-level of airport's services and logistics (the quality-level is calculated as the time needed both to load and unload luggage and to complete all the operations required to prepare the aircraft while this latter stops in an airport) and actual traffic of passengers which make use of the airport. More specifically, within the subsystem, the quality-level of airport's services and logistics allows to define passengers transit time and the average terminal passengers waiting time thereby educing the airport's potential to function as an hub. Obviously, an higher quality-level leads to a larger number of users. In case of exponential growth of airport's operations, however, a number of feedback mechanisms are activated which increase the congestion of airport's operations along with a decrease in quality-level of services and performances (for example, queues are created of passengers waiting to embark, disembark and transfer). Thus, such feedback mechanisms eventually motivate passengers to choose alternative routes and other airport leading, in the long term, to reduction in the airport's traffic and congestion.

In the sub-system, relevant variables are: the number of employees managing the handling operations, technology used for luggage logistics (in particular, two main alternatives are considered: centralised and decentralised system of luggage logistics), time required to load and unload the aircraft, the time needed for aircraft's catering, cleaning and fuelling. Such a subsystem is either completely managed by the airport authority or, sometime, (in the case of self-handling for some operations) jointly managed by the airport authority and the carriers. The subsystem described plays a fundamental role to define the quality-level of services provided to airports' users and, therefore, in the formation of airport's image. Indeed, delays in luggage transfers, or losses, contribute to strongly influence the perceived image of an airport.

The **airport accessibility** subsystem considers variables that are especially relevant for passengers reaching their final destinations rather than for those in transit. The subsystem describes types and quality of connections offered to passengers who both land and take-off from an airport. In particular, four categories of connections are considered: subway, cars, bus, train and taxi. Each type of connection has different characteristics in terms of uncertainty of arriving time, frequency, time and cost. The characteristics of an airport's connections are used to give the airport an overall measure of the passengers traffic that the airport is able to attract. This measure has been defined the "accessibility index". Hence, a low "accessibility index" would jeopardise the airport's capability to exploit the catchment area of potential users while an high "accessibility index" demonstrate an airport's capability to fully take advantage of its geographical location. The "accessibility index" not only defines the airport's effective attractiveness, rather it also contributes to shape the airport's public image and, thus, the airport's perceived attractiveness.

The last subsystem is the **potential passenger traffic**. Within such a subsystem it is possible to distinguish two areas: **transit passengers** e and **terminal passengers** (passengers coming from, or arriving to, the airport catchment area).
Passengers in transit are determined using a "connectivity index" which results from the aggregation of four indexes (frequency index, destination index, quality index and cost of transit index) which convey to this section of the model the effects of constraints emerging elsewhere. For example, quality index emerges as the result of the calculation of transit time in the **logistics and service quality** subsystem. To obtain the number of transit passengers, the "connectivity index" is adjusted by considering both the demographic characteristics of the airport's location and the number of connections offered.
Hence, the variables which are considered in this area of the model are partly under the control of airport authorities and partly under control of handling service providers.
A second area of the potential passenger traffic subsystem considers passengers who arrive at their final destination in an airport or leave from that airport. In particular, this category of passengers can be divided into two groups. In the first group are passengers who live in the catchment area (within 150 km from the airport) in which the airport is located and may decide to choose to fly from that airport. The second group includes passengers who live elsewhere but are directed to the catchment area where the airport is located. This second group of passengers chooses the airport because it is close to the place where they want to go.

The potential passengers living in the airport catchment area are determined by considering both demographic (for example, population size) and cultural (for example, propensity to fly and frequency of flights) characteristics of the area and assuming that two kinds of travellers are relevant: tourists and business people.

Passengers flying to the airport catchment area are determined by considering the attractiveness of the area in terms of volume of business, cultural events, relevance of tourism and relative costs of airport's services compared to competing airports. However, passengers actually using the airport are estimated by considering the effect of the quality of connections that provide access to the airport. In other words, given two airports located in geographical areas with similar demographic characteristics and that offer a similar product in terms of number of destinations and flight connections, passengers will choose the airport which is more easily and cheaply accessible.

Both transit and terminal passengers define the number of passengers that potentially may use the airport. In order to define the quality–level of the airport, the number of potential passengers is then compared with an “equilibrium” number of passengers that reflects the number of users which can be effectively managed by the airport, given its infrastructure. Had the potential number of passengers be higher than the equilibrium one, quality-level of services erodes.

The described model has been tested in order to check for internal coherency, to appropriately calibrate the parameters and to assess the acceptability of emerging behaviour. Behavioural tests of the model have been conducted by comparing model-generated time series and historical data relative to an average European hub.

The reference to an average European hub has also been the base to create benchmarks to calculate the focal airport’s performances (in terms, for example, of quality-level and costs of service, and quality and costs of access to the airport). In this way, the focal airport’s performances not only is a function of the level of infrastructures of this latter, rather they also depend on the average characteristics of comparable airports. Choices and decisions taken by actors located in other airport systems have an impact on the behaviour and performances of the focal airport.

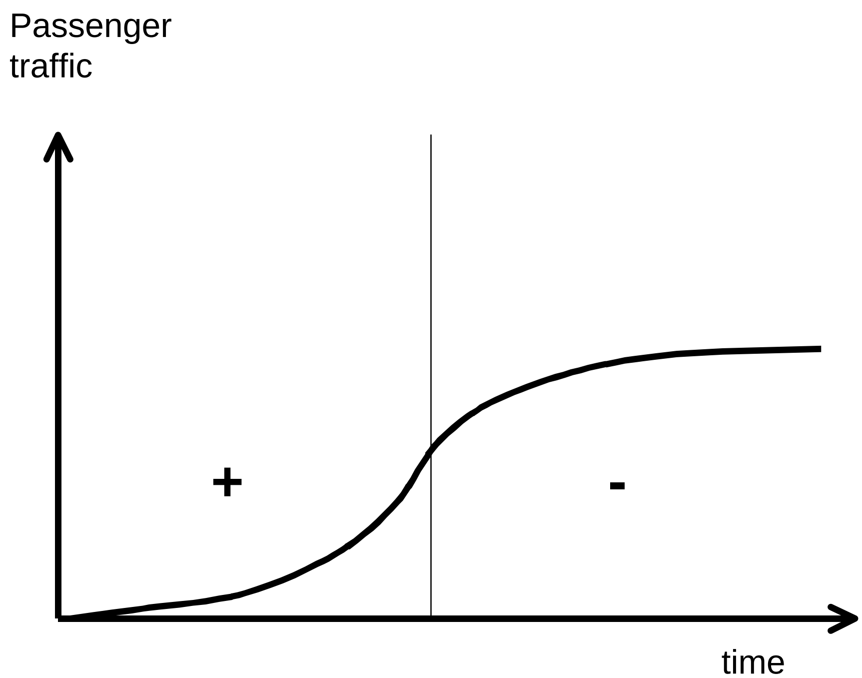
On the other hand, the airport’s performances are not influenced, in the model, by discontinuities emerging in the technological and socio-political environment. More precisely, albeit in the model a number of parameters incorporate environmental conditions, simulations has been run without considering evolution and leaving relatively stable the characteristics of the environment of the airport. The choice of leaving aside environmental evolution was justified by the focus of the model. Indeed, the model was built to aid the management of an airport by exploring the complexity endogenously generated by the interaction of a number of subsystems.

In this light, great value has been added during the modelling process, when the relations among variables and crucial operating mechanisms have been teased out. In addition, simulation facilitated the understanding of relative roles played by variables in moulding emerging dynamics elucidating causes of counterintuitive consequences of policies. Variables that originally seemed peripheral and only loosely connected to the behaviours of interest, emerged as fundamental in shaping aggregate dynamics while variables that seemed to play a crucial role had a minor impact. In this light, the fundamental advantage of system dynamics modelling is the chance offered to deeply understand and govern the complexity of systems of interconnected actors and processes. In particular, two characteristics of system dynamics modelling appeared fundamental. First, the availability of a clear and effective symbolic language, easily transferable into computer graphical representation, to represent complex system favours the interaction with non-modellers thereby facilitating the extraction of the know-how rooted in the experience of relevant actors.
Second, the translation of symbols into mathematical models allows simulation and, hence, rigorous deduction of the consequences of alternative actions and decisions.

5. Results

System dynamic modelling of the airport hub allowed to identify the levers which influence the actual traffic of passengers and to discover feedback loops which constitute engines for growth. On the other hand, by simulating the model and analysing the emerging behaviour it was possible to detect intervening limits to growth as depicted in the s-shaped curve in figure 3.

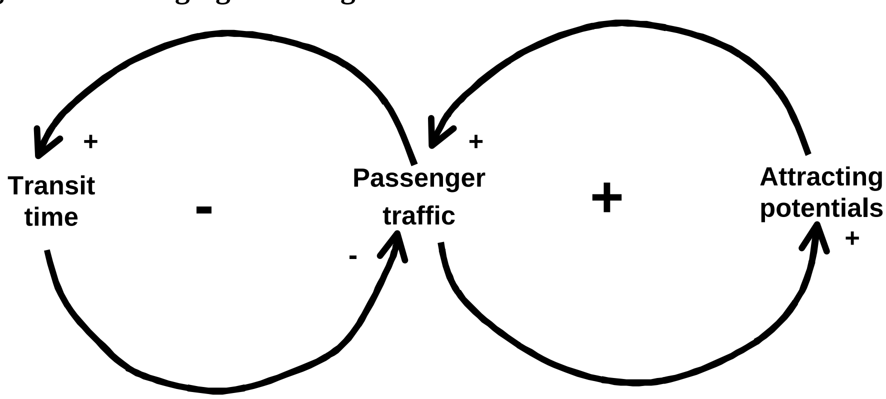
Figure 3 – Simulated growth of passenger traffic



Source: authors' elaboration

As illustrated in figure 3, the intervening limit to growth is the consequence of emerging balancing loops that counteract reinforcing mechanisms. For example, in figure 4, one limit to growth, among those detected, is illustrated.

Figure 4 – Emerging limit to growth

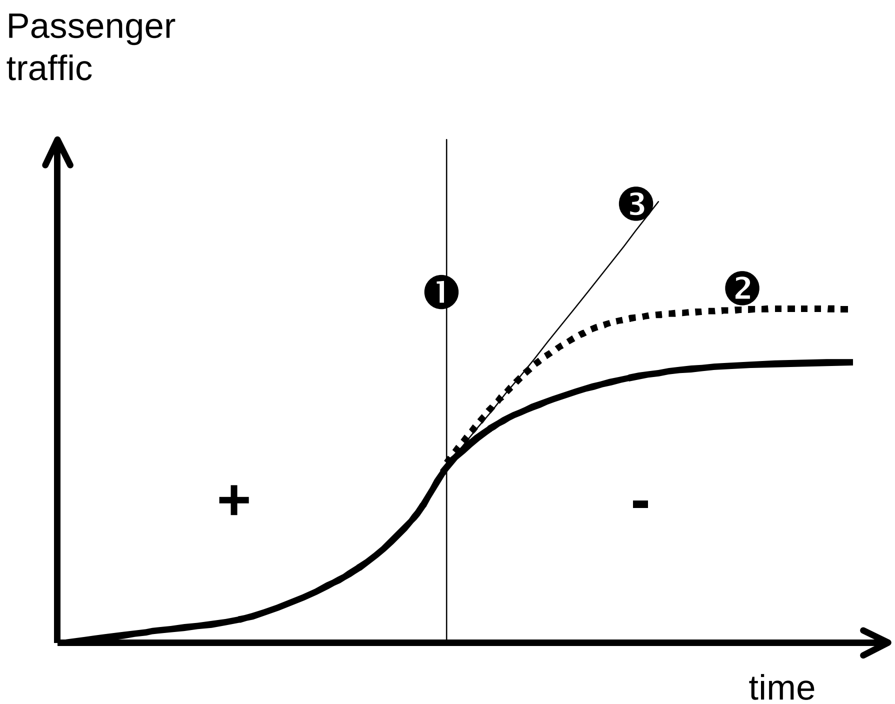


Source: authors' elaboration

In the right-end side of figure 4, a reinforcing loop emerges. As passengers' traffic grows, airport managers are able to increase the number of connections thereby expanding the airport's attracting potential and reinforcing the growth of effective passengers traffic.
In the left-hand side of the figure, however, a balancing feedback emerges. As actual passengers traffic augments, traffic and congestion within the airport is raised, leading to the expansion of time needed for transit, embarking and disembarking. Passengers start to

experience longer time to transfer from one flight to another, prolonged delay in departures and arrivals and low-quality services. Unsatisfaction grows higher motivating passengers to abandon the hub and select alternative routes for their flights.
The negative loop counterbalances the positive one and eventually inhibits the flow of passengers to the airport. Hence, a first implication of the modelling study was that the growth cannot be unlimited; as soon as a number of growth engines are identified, it is important to investigate endogenous (as well as exogenous) limits to the sustainability of growth.
Based on the findings of the simulation study, a number of alternative policies to deal with the airport system were listed. In figure 5, three alternatives policies to manage the system were selected.

Figure 5 – Managing limits to growth



Source: authors' elaboration

The simulation model outlines three alternatives:
1. procrastinate the point of shift of the dominant polarity;
2. increase the equilibrium value for "actual passengers traffic";
3. remove limits to growth.

Following the first alternative, the working of the balancing loop is delayed. In the model, such a result can be obtained by increasing efficiency of airport management in three ways. First, efficiency was increased through improved practices and handling services; second, by increasing labour productivity through better training programmes and, third, by introducing new technologies to shorten luggage transit time.

A second alternative aims at raising the passengers traffic that can be effectively governed in equilibrium. In the model, such an objective may be achieved by expanding the airport's capacity with further investments.

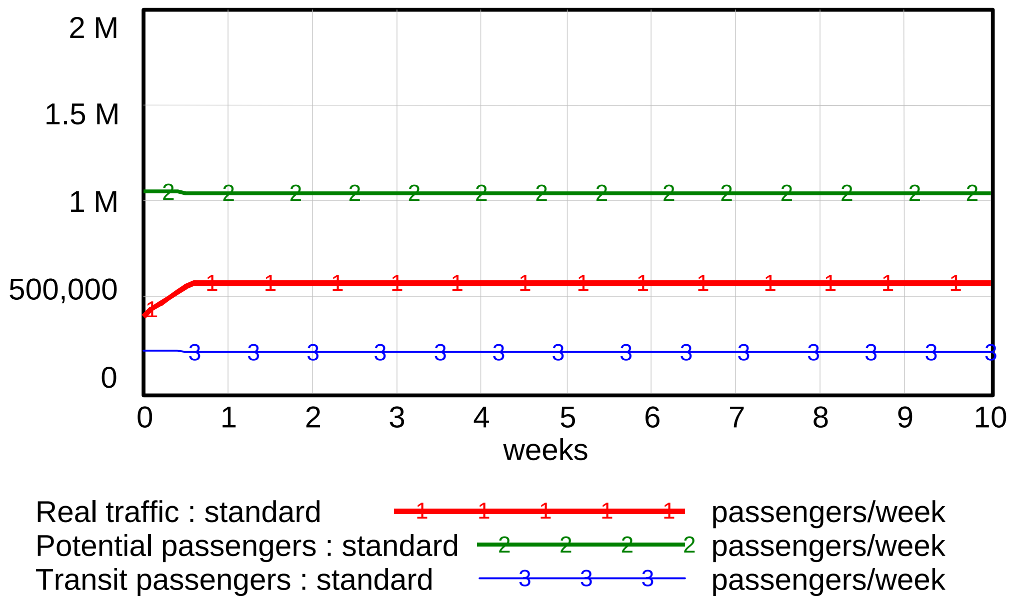
Finally, a third alternative considers the combined use of the levers highlighted in alternative one and two. In other words, for an airport to be able to sustain its growth it is necessary to continuously hone its practices and innovate its technology, on the one hand, and to keep expanding its capacity. Yet, the simulation model vividly highlighted all the difficulties that the implementation of such an ideal course of action would confront. First, the model highlighted how continuous investments in infrastructure, in workforce training and technology may require a considerable amount of financial resources. Second, simulations elucidated how airport expansion very often faces the limits of space available.
In box 1 are presented some of the results produced by model simulations and evidences.

Box 1 – The results of the model
Dynamic social systems behaviour is the result of the complex interaction between variables and interconnected processes. Because of actors bounded rationality quite often policies regarding social systems strikes with the difficulty to understand in depth decisions consequences. Frequently decision and rational actions cause counterintuitive consequences.
Analysing social systems through computer simulation it's and effective tool to highlight mechanisms relating decisions and emerging dynamic phenomena.

In the following part of the box are presented some simulations selected to illustrate simulation logic of airport hub and to explore the effectiveness of some managerial policies. In particular we selected the most meaningful simulations in order to illustrate simulations usefulness and to understand the cause of counterintuitive results.

Table 1 shows the functioning of the simulated model. The first simulation presented (standard) reproduces the behaviours of a hub in the first weeks of life analysing the equilibrium level of the system if we hypothesise that the airport is operating in normal and standard conditions. It is possible to observe that, if potential traffic the airport could attract is rather high, effective traffic growth reach a limit, reasonably because of organisational and infrastructure constraints characterising an airport.

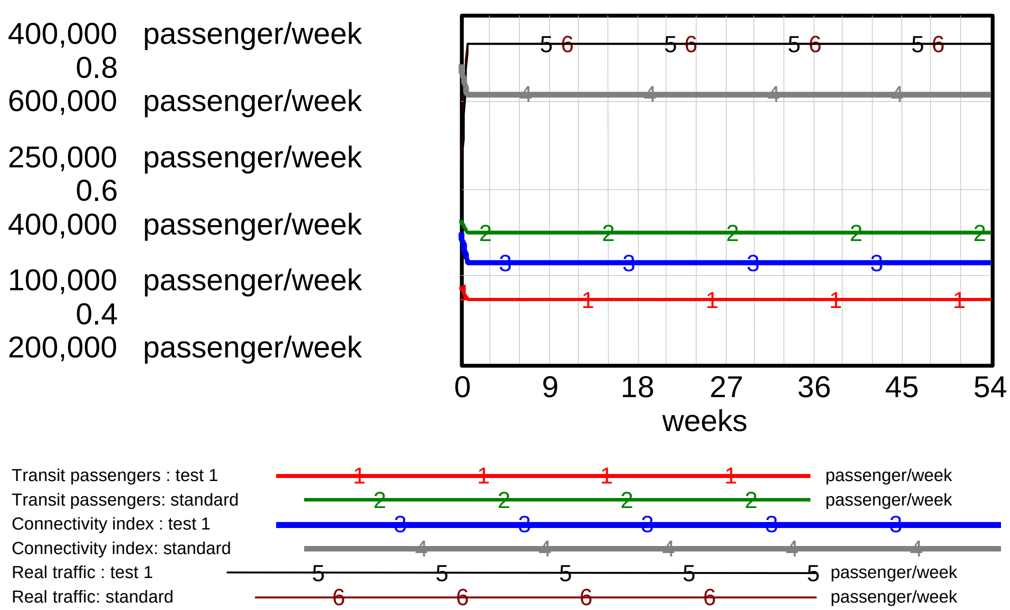
Table 1 – Standard operating conditions



In the second simulation (test 1), it has been analysed the consequence of a worsening of airport connectivity, in the hypotheses to decrease connection frequency offered by the airport reducing them from 3000 to 600 every week. A reduction in connection frequency should substantially worsen airport connectivity level and, consequently, reducing airport potential traffic and a stabilisation of maximum passenger traffic to a lower level than in the initial situation. This should happen because connection reduction limits airport attractiveness for terminal passengers and particularly for transit passengers, independently from real airport receptiveness.

Results showed in table 2 do not fully match with forecasts. Obviously, transit passengers decrease notwithstanding the effect on effective traffic it is not relevant. This result, apparently counterintuitive, is the product of two factors. First of all, effective traffic is highly influenced by airport catchment area. Therefore, unless airport develops in a real hub, the effect of a worsening in the connectivity index doe not heavily effect airport effective traffic. Secondly, in the development phase, the effective traffic is limited to existing infrastructures (for example runaways). Airport is operating at its potentials limits and consequently possible traffic reductions are non "visible" unless these reductions bring effective traffic below traffic level the airport can manage.

Table 2 – Worsening of connection quality



In the third simulation (test 2) we checked if a variation in offered flight prices from and to the airport can influence the attractiveness of the airport, both for terminal traffic and for transit traffic. In table 3 it is showed the effect in terms of traffic increase of a reduction to half of airport tariffs in comparison with main competitors (for practical reasons it has been selected only the average total price).

Expected result is the increase of real traffic while table 3 shows that real traffic do not vary in comparison to standard simulation. In fact, it is clear that real traffic growth is limited by infrastructures. In order to check if, once eliminated growth limits, price variations can influence real traffic, we tried to simulate again the model (test 3) doubling the number of runways. Table 4 illustrates that, removing infrastructure limit to growth real traffic increases effectively even if, in a later time, it stabilised below the maximum level obtained with two runways only (test 2 in table 4).

Table 3 – The relevance of price

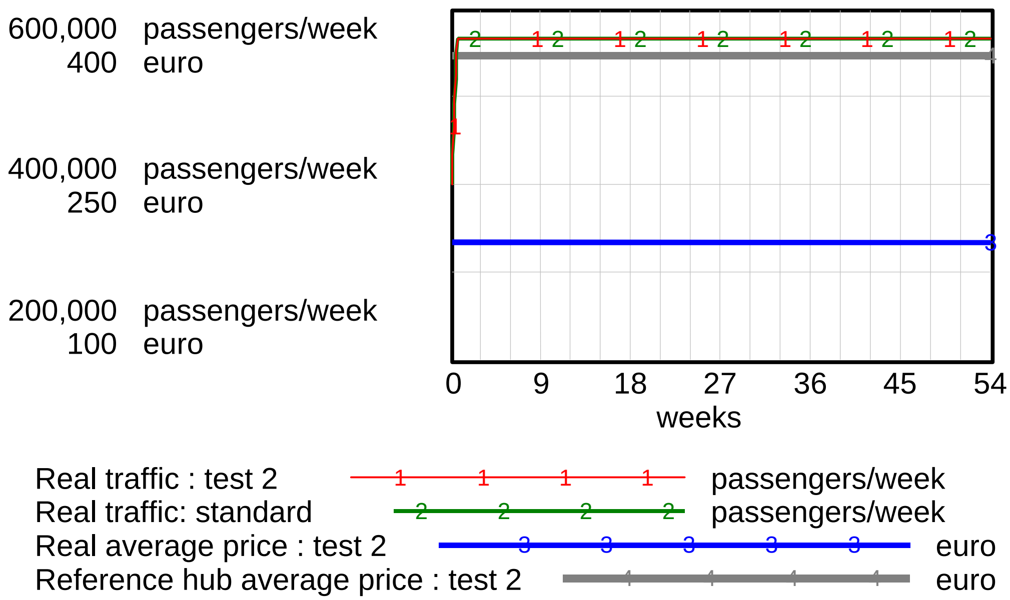
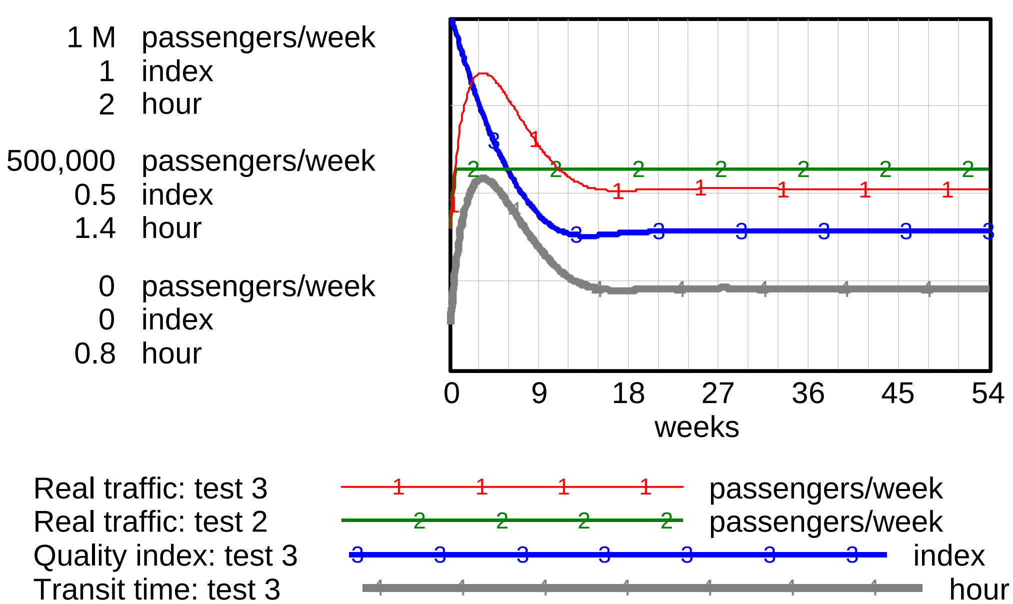
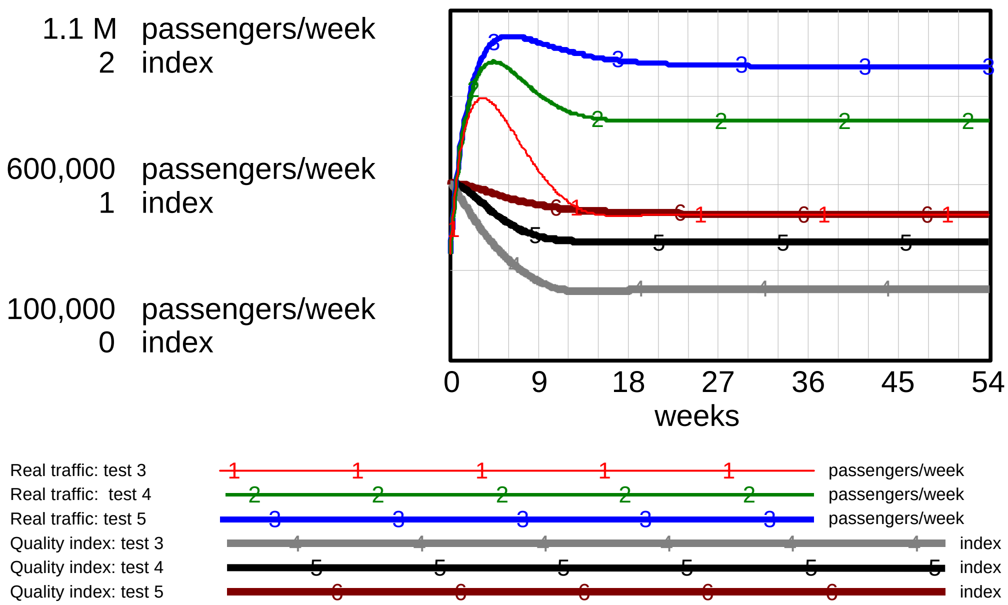


Table 4 – Price reduction and increase in runways number



The emerging problem is related to the fact that, though increasing runways numbers, traffic increase causes airport congestion that causes higher transit times and a airport quality reduction. Such a worsening, if persistent, discourage airport use.
Simulating the model trying to understand the system resistance points, it has been highlighted a second important limit to growth represented by workers dedicated to baggage handling. In table 5 are showed the results of two simulations (test 4 e test 5) where handling workers have been increased from 50 in standard simulation to 100 and 150. The results of the simulations, compared with test 3 simulations (table 5), describe how it is possible to shift gradually the equilibrium point of the system to higher real traffic values by increasing the number of workers, diminishing, consequently, transit times and bringing them to acceptable quality levels.

Table 5 – Price reduction, increase in runways number and increase in workers number



The suggestions deriving from the model cannot push us further. In fact, we analysed simulations where the increase in runways number and workers number is not subjected to time delays. In other simulations we have reproduced more realistic situations where the building of new runways and workers request time. The effect of this variation causes only a limited time delay. These simulations show the difficulty to manage a airport and highlights criticality, decision content and decision timing.

6. Discussion and managerial implications

A number of managerial implications arises from a system dynamics model of an hub, which is a common organisational form for an airport.
In general, a system dynamic model of an hub provides an effective symbolic language to represent and communicate the causal structure underpinning such a complex system. The friendly software interface for computer simulation allows to play out the unfolding of

behaviour generated by the causal structure and provides a nice environment to discover recurring pitfalls, faulted management policies and sensitive levers for intervention.

The simulation model is useful for, at least, three groups of actors: airport authorities, carriers and handling service providers.

Concerning the ***airport authority***, after calibration of clients and competitive arena characteristics, the model may be used to design an airport plans for growth.

In this respect the model helps to define sustainable trajectories for growth, to test alternative policies and understand the contribution of different actors in this sense. For example, the model explores the role of a geographical area's infrastructures in defining the optimal size of the airport. Playing with the characteristics of the web of roads and train connections in which the airport is embedded, and with their relative costs, it is possible to explore different trajectories of growth in terms of number and type of users. Is, thus, possible to develop different growth strategies and different target markets (for example, leisure or business travellers).

In the perspective of a ***carrier***, the model provides a tool to select a location to create an hub, to evaluate size and timing of investments in capacity and to plan decisions concerning frequency of connections, number of destinations available and harmonisation of connections. In defining investment policy, given scarce resources available and magnitude of average size of investments required to carries, the model provides a support to select alternative policies. For example, in decisions concerning expansion policy, the model might help to understand whether the addition of a new destination is better pursued by purchasing a further aircraft or by reducing the waiting time between two interconnected flights. Of course, the two alternatives have different impact on the cost and organisational structure of the company and generate different expectations concerning potential attractiveness of an airport.

In addition, the simulation model allows testing consequences of different levels of quality and effectiveness in providing airport services. In this vein, the model provides a tool to re-design activities and practices. Furthermore, the simulation model is a flight-simulator in which long term consequences of infrastructure expansion can be assessed and easily communicated and constitutes a field of interaction wherein carrier and airport managing companies may jointly evaluate and plan further investments.

Finally, in the angle of a ***handling service provider***, the simulation model helps to outline effective organisational structure and practices to better meet clients needs and optimise the relationships with carriers and airport managers.

Concluding, managing an airport hub entail to understand the complex interplay of different actors embedded in a web of interconnected activities. In this light, a system dynamics model may provide an effective tool to represent, communicate and effectively rationalise airports' operating mechanisms and the complex interplay among different actors.

Notes

Albeit the presented work is the result of joint effort of the two authors, the content of section 1, 2 and 3 is the result of research work conducted by Elisabetta Marafioti. Ideas, concepts and opinions in the remaining parts of the article are, however, to be attributed to both authors who are fully responsible for them.

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[1] In this paper we will refer exclusively to the passenger traffic, without taking into consideration the freight traffic.

[2] Some authors (Butler e Huston, 1989) define a hub as and airport where the major part of the arriving and departing flights are co-ordinated in order to create numerous potential connections.

[3] The multiplying effect is determined by the possibility to offer, with a limited number of direct flights, indirect connections with one stop; they differ from the direct ones because they are the results of a combination of direct flights.

[4] The origin and destination passengers, also defined as terminal passengers, are those leaving from or arriving to the airport catchment area. Generally, in as hub they represent less than half of the passengers.

[5] The alternative is represented by the *point-to-point* connections through which an airline connect city pairs without concentrating the connections in a single airport.

[6] The liberalisation of the airport services, completed in 1996, has abolished the monopoly in the management of the handling services by the airport authorities.

[7] The London airports can be considered rich and convenient shopping areas by the population living in the London suburban area.

[8] ANAS is the State owned company in charge of the management and construction of the widest past of Italian highways, national and regional roads.

[9] The centrality in the transit traffic is measured in terms of weighted average of the distances (in Km) of the connections actually offered by the airport.

[10] A slot is a period of time, generally of a five minutes length, during which an airline has the authorisation for the take-off or landing in an airport. The assignation of a slot allows to define the schedule of the various airlines.

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