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## A long term demand forecasting framework for a network of airports

### Uma estrutura de previsão de demanda de longo prazo para uma rede de aeroportos

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#### ABSTRACT

The study presented in this paper has been developed with the perspective of generating long term development plans for a network of domestic airports. As a first step towards this objective, the problem of generating long term predictions of demand for a network of domestic airports is considered. This is a step towards the objective of producing long term capacity investments plans allowing to manage adequately a network of airports. Then the different demand flows at airports which are relevant to characterize the need for new airport facilities and upgrades in capacity, are analysed and compatibility constraints between these flows introduced. An appraisal is realized about the basic data necessary to perform these network demand forecasts. A sequential scheme is proposed to generate in a coherent way predictions of the different dimensioning networks and airport flows. Passenger, freight and aircraft flows from and to external airports are also considered in this study.

**Keywords:** Air Transport, Airport planning, Networks, Long term demand, Prediction.

#### RESUMO

O estudo apresentado neste artigo foi desenvolvido com a perspectiva de gerar planos de desenvolvimento de longo prazo para uma rede de aeroportos domésticos. Como primeiro passo em direção a este objetivo, é considerado o problema de gerar previsões de longo prazo da demanda para uma rede de aeroportos domésticos. Este é um passo em direção ao objetivo de

produzir planos de investimento em capacidade de longo prazo que permitam administrar de forma adequada uma rede de aeroportos. Em seguida, são analisados os diferentes fluxos de procura nos aeroportos relevantes para caracterizar a necessidade de novas instalações aeroportuárias e upgrades de capacidade e introduzidas as restrições de compatibilidade entre esses fluxos. Uma avaliação é realizada sobre os dados básicos necessários para realizar essas previsões de demanda da rede. Um esquema sequencial é proposto para gerar de forma coerente as previsões das diferentes redes de dimensionamento e fluxos aeroportuários. Os fluxos de passageiros, carga e aeronaves de e para aeroportos externos também são considerados neste estudo.

**Palavras-chave:** Transporte Aéreo, Planejamento Aeroportuário, Redes, Demanda de Longo Prazo, Previsão.

## 1 INTRODUCTION

In this paper is considered the problem of generating long term predictions of demand for a network of domestic airports. This is a step towards the objective of producing long term capacity investments plans allowing to manage adequately this network of airports. Then it appears important to identify the different demand flows at airports which are relevant to characterize the need for new airport capacity and its dimensioning. Any national or regional network of airports is also related to the rest of the world. Then traffic at the considered airports will be dependent of traffic from and to some external airports. So, passenger, freight and aircraft flows from and to these external airports must be considered in such a study. Here is introduced a general network composed of  $N$  airports connected to  $M$  outside airports. In this study it is considered that the concurrent as well as complementary transport modality to air transportation is a generic ground transportation modality.

## 2 THE DEMAND PREDICTION PROBLEM

To distinguish the different flows affecting the different areas of the airports, a new decomposition of airport areas is introduced. Traditionally airports have been decomposed in two closely related subsystems: The landside where passengers and freight evolve in an autonomous way and airside where aircraft loaded with passengers and freight evolve. Each of these subsystems occupies a part of the area of the airport and presents specific operations, facilities and buildings.

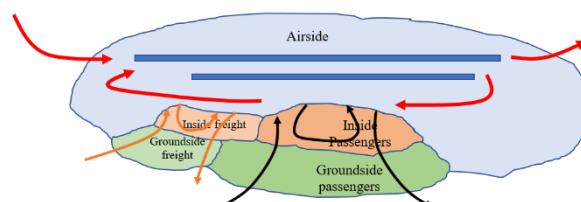
The airside is composed of runways, taxiways and apron-gate areas-on which aircraft and ground handling vehicles operate. The land around the runway up to the limits of the airport as well as approach and departure paths to and from runways are in general considered to be part of the airside. Aircraft traffic at landside is under direct supervision by the airport control tower. The airside may accommodate a large variety of other activities such as general aviation, air freight, maintenance and support, and military. The landside has been defined as those areas and

operations within the airport boundaries, complementary to the airside. Some complementary activities related with air freight, maintenance and support as well as military can take place at landside.

The main visible components of landside are: the ground interface with surrounding area, in general an urban area or an industrial area, or both; the arrival/departure halls for passengers and freight; the registration areas (passenger registration, freight registration and customs); the control areas for passengers and goods; the boarding areas.

The development of airport security facilities, as the result of airports and air transportation having been many times the target of terrorist attacks, has led to establish inside the airport different control lines, distinguishing in particular local passengers from connecting passengers. Also with the increase of commercial activities inside airports, in general free shops, with the aim to offer a secondary source of profit for airport management, it has been necessary to guarantee access to this commercial areas to a maximum of passengers. This has led in this study to subdivide the landside in two subsystems so that specific flows can be considered: the *groundside* covering the ground interface with surrounding area, arrival/departure halls, registration areas and local controls; the *inside* covering control areas for connecting passengers or goods, free shops areas, waiting areas and boarding areas. These two areas can also be further subdivided by considering passengers and freight processing. Figure 1 provide a general display of such subdivision.

Figure 1: The main traffic areas at airports



There aircraft flows are represented by red arrows, freight flows are represented by orange arrows and passenger flows are represented by black arrows. There the blue area is the airside, the green areas are groundside areas (passengers and freight) and the orange areas are the inside areas (passengers and freight).

### 3 CHARACTERIZING LANDSIDE FLOWS AT AIRPORTS

Here flows of passengers, freight and aircraft must be considered. Prediction of flows of departing/arriving flows of passengers or freight will be useful for the dimensioning of passenger and freight airport terminals in a first step and then in a second step to predict flows of aircraft. To

avoid seasonal effects which should need a detailed prediction of traffic, which does not appear feasible on the long run, passenger and freight demands, as well as other types of demand (aircraft traffic at airports) can be considered on a year basis while peak period factors can be adopted to consider the busiest periods where capacity constraints may be active.

### Passengers flows

It can be considered that a large majority of passenger trips are round trips, so that the quantity  $T_{ij}^{pt}$  represents the flow of passenger trips (a trip may be composed of a succession of connected flights) from airport  $i$  to airport  $j$  and back from airport  $j$  to airport  $i$  during year  $t$ . The passenger flow from an airport  $i$  of the considered network to an external airport  $k$  during period  $t$  is written  $\mathcal{O}_{ik}^{pt}$ . It is also assumed that at urban centers with multiple airports, airports are merged into a unique airport entity for planning purposes. So, the consideration of these passenger flows leads to the definitions of airport dimensioning global quantities such as:

$$O_i^{pt} = \sum_{j=1, j \neq i}^N T_{ij}^{pt} + \sum_{k=1}^M \mathcal{O}_{ik}^{pt} \quad i = 1, \dots, N \quad (1)$$

and

$$D_i^{pt} = \sum_{j=1, j \neq i}^N T_{ji}^{pt} + \sum_{k=1}^M \mathcal{O}_{ki}^{pt} \quad i = 1, \dots, N \quad (2)$$

where  $N$  is the considered number of airports,  $O_i^{pt}$  is the amount of passenger trips generated at airport  $i$  during period  $t$ ,  $D_i^{pt}$  is the amount of passenger trips attracted by airport  $i$  during period  $t$ . Then the total number of *departing and arriving passengers* at airport  $i$  during period  $t$  is twice the primary departing passenger flow, which is given by:

$$PD_i^{pt} = O_i^{pt} + D_i^{pt} \quad i = 1, \dots, N \quad (3)$$

and the primary arriving passenger flow:

$$PA_i^{pt}: PA_i^{pt} = PD_i^{pt} \quad i = 1, \dots, N \quad (4)$$

These passengers will cross and use airport facilities from (or to) the ground side with ground transportation access and parking, to (or from) the airside at boarding to (or deboarding from) an aircraft.

Another important flow of passengers can make use of some airport facilities: *connecting passengers* which will use only a part of airport facilities for deboarding, control, internal transfer, waiting and boarding. The amount of connecting passengers depends not only on generated or attracted passengers flows by airports but also on the structure of the air transport network. While for a point to point network with direct flights, there will be no connecting passengers, for a hub network, the volume of connecting passengers may outcome the volume of primary passengers.

Let  $K_{Ijk}^{pit}$  be at period  $t$  the proportion of passengers which uses airport  $i$  as a network connecting airport during their round trip from airport  $j$  to airport  $k$ , both belonging to the airport network, with:

$$K_{Ijk}^{pit} \geq 0 \quad \forall i, j, k \in \{1, \dots, N\}, i \neq j, i \neq k, j \neq k \quad (5)$$

and if it is assumed to have at most only one connection in an air passenger trip:

$$\tau_{Ijk}^{pt} = \sum_{i=1, i \neq j, i \neq k}^N K_{Ijk}^{pit} \leq 1 \quad \forall k, j \in \{1, \dots, N\}, j \neq k \quad (6)$$

where  $1 - \tau_{Ijk}^{pt}$  is the proportion of passengers performing a direct flight between airports  $j$  and  $k$  of the network.

Let  $K_{Ejk}^{pit}$  be at period  $t$  the proportion of passengers which uses airport  $i$  as a network connecting airport during their round trip from network airport  $j$  to external airport  $k$ , with

$$K_{Ejk}^{pit} \geq 0 \quad \forall i, j \in \{1, \dots, N\}, i \neq j, k \in \{1, \dots, M\} \quad (7)$$

and if it is assumed to have at most only one connection in an air passenger trip:

$$\tau_{Ejk}^{pt} = \sum_{i=1, i \neq j}^N K_{Ejk}^{pit} \leq 1 \quad \forall j \in \{1, \dots, N\}, \forall k \in \{1, \dots, M\} \quad (8)$$

where  $1 - \tau_{Ejk}^{pt}$  is the proportion of passengers performing a direct flight between network airport  $j$  and external airport  $k$ .

It will be assumed that the same connecting airport is used in mean on the return trip. Then the volume of connecting passengers, or secondary passengers at airport  $i$ , either arriving or departing, will be given by:

$$SA_i^{pt} = SD_i^{pt} = 2 \left( \sum_{j=1, j \neq i}^N \sum_{k=1, k \neq i, k \neq j}^N K_{ijk}^{pit} T_{jk}^{pt} + \sum_{j=1, j \neq i}^N \sum_{k=1}^M K_{Ejk}^{pit} \Theta_{jk}^{pt} \right) \quad (9)$$

where the coefficient 2 refers to round trips with connection.

Finally, the amounts of secondary passengers which can use partially (inside and airside) the airport facilities and of primary passengers which can use fully (groundside, inside and airside) the airport facilities, are given in the following table:

Table 1: Passengers flows identification

Passenger operation	Passenger location	Primary passenger flow	Secondary passenger flow	Total
arrival	groundside	$PA_i^{pt}$	—	$PA_i^{pt}$
arrival	inside	$PA_i^{pt}$	$SA_i^{pt}$	$PA_i^{pt} + SA_i^{pt}$
arrival	airside	$PA_i^{pt}$	$SA_i^{pt}$	$PA_i^{pt} + SA_i^{pt}$
departure	groundside	$PD_i^{pt}$	—	$PD_i^{pt}$
departure	inside	$PD_i^{pt}$	$SD_i^{pt}$	$PD_i^{pt} + SD_i^{pt}$
departure	airside	$PD_i^{pt}$	$SD_i^{pt}$	$PD_i^{pt} + SD_i^{pt}$

Then, in Table 2, the dimensioning passenger flows for the different airport components are listed.

Table 2. Passenger flow and airport components interaction

	Primary passenger flows	Secondary passenger flows
Ground side components influenced by passenger flows	Ground Airport Access Check-in area Security control area Control passport (departure) Control passport (Entrance) Baggage area Custom control Rest rooms	Passport control Security control area
Inside Components influenced by passenger flows	Boarding gate Duty free area Rest rooms Waiting rooms and lounges	Passport control Security control area Boarding gate Duty free area Rest rooms Waiting rooms and lounges

### Freight flows

In the case of air freight transportation, the flows considered are supposed to be measured in tons, and freight is under a process of transfer from one place to another without return (no round trip), so that the quantity  $T_{ij}^{ft}$  represents the flow of freight in tons from airport  $i$  to airport  $j$  during year  $t$ . The freight flow from an airport  $i$  of the considered network to an external airport  $k$  during period  $t$  is written  $\Theta_{ik}^{ft}$ . So, the consideration of these freight flows leads to the definitions of airport dimensioning global quantities such as:

$$O_i^{ft} = \sum_{j=1, j \neq i}^N T_{ij}^{ft} + \sum_{k=1}^M \Theta_{ik}^{ft} \quad i = 1, \dots, N \quad (10)$$

and

$$D_i^{ft} = \sum_{j=1, j \neq i}^N T_{ji}^{ft} + \sum_{k=1}^M \Theta_{ki}^{ft} \quad i = 1, \dots, N \quad (11)$$

where  $O_i^{ft}$  is the amount of freight *generated* (departing) at airport  $i$  during period  $t$ ,  $D_i^{ft}$  is the amount of freight *attracted* (arriving) by airport  $i$  during period  $t$ .

Here also, another important flow of air freight can make use of some airport facilities: *connecting freight flows* which will use only the airside airport facilities for deboarding, control and board air freight while the primary freight flows use also the ground access to airport i.e. its landside. The amount of connecting freight flows depends here also not only on generated or attracted freight flows by airports but also on the structure of the air transport network. While for a point to point network with direct flights, there will be no connecting freight, for a hub network,



the volume of connecting freight may outcome the volume of direct freight directed from or to the airport hub. Let  $K_{Ijk}^{fit}$  be at period  $t$  the proportion of freight which uses airport  $i$  as a network connecting airport during their round trip from airport  $j$  to airport  $k$ , both belonging to the airport network, with

$$K_{Ijk}^{fit} \geq 0 \quad \forall i, j, k \in \{1, \dots, N\}, i \neq j, i \neq k, j \neq k \quad (12)$$

and if it is assumed to have at most only one connection in an air passenger trip:

$$\tau_{Ijk}^{ft} = \sum_{i=1, i \neq j, i \neq k}^N K_{Ijk}^{fit} \leq 1 \quad \forall k, j \in \{1, \dots, N\}, j \neq k \quad (13)$$

where  $1 - \tau_{Ijk}^{ft}$  is the proportion of freight performing a direct flight between airports  $j$  and  $k$  of the network.

Let  $K_{Ejk}^{fit}$  be at period  $t$  the proportion of passengers which uses airport  $i$  as a network connecting airport during their round trip from network airport  $j$  to external airport  $k$ , with

$$K_{Ejk}^{fit} \geq 0 \quad \forall i, j \in \{1, \dots, N\}, i \neq j, k \in \{1, \dots, M\} \quad (14)$$

and if it is assumed to have at most only one connection in an air passenger trip:

$$\tau_{Ejk}^{ft} = \sum_{i=1, i \neq j}^N K_{Ejk}^{fit} \leq 1 \quad \forall j \in \{1, \dots, N\}, \forall k \in \{1, \dots, M\} \quad (15)$$

where  $1 - \tau_{Ejk}^{ft}$  is the proportion of passengers performing a direct flight between network airport  $j$  and external airport  $k$ . Then the volume of connecting freight, or secondary freight at airport  $i$ , either arriving or departing, will be given by:

$$SA_i^{ft} = SD_i^{ft} = \sum_{j=1, j \neq i}^N \sum_{k=1, k \neq i, k \neq j}^N K_{Ijk}^{fit} T_{jk}^{ft} + \sum_{j=1, j \neq i}^N \sum_{k=1}^M K_{Ejk}^{fit} \Theta_{jk}^{ft} \quad (16)$$

Finally, the amounts of secondary freight which can use partially (inside and airside) the airport facilities and of primary passengers

which can use fully (groundside, inside and airside) the airport facilities, are given in the following table:

Table 3: Freight flows identification

Freight operation	Freight location	Primary freight flow	Secondary freight flow	Total
arrival	groundside	$PA_i^{ft}$	—	$PA_i^{ft}$
arrival	airside	$PA_i^{ft}$	$SA_i^{ft}$	$PA_i^{ft} + SA_i^{ft}$
departure	groundside	$PD_i^{ft}$	—	$PD_i^{ft}$
departure	airside	$PD_i^{ft}$	$SD_i^{ft}$	$PD_i^{ft} + SD_i^{ft}$

Then, in Table 4, the dimensioning freight flows for the different airport components are listed.

Table 4: Freight flow and airport Components interaction

	Primary Freight flow	Secondary freight flow
Ground side Components influenced by Flow	Ground Airport Access Check-in area Baggage area Security Control (Departure) Custom control (Entrance)	Baggage area Security Control area Custom control
Inside Components influenced by Flow	-	-

#### 4 AIRCRAFT FLOWS CHARACTERIZATION

Considering round trips and transfers, passengers flow from airport  $i$  to airport  $j$  of the network is given by:

$$\begin{aligned}
 F_{ij}^{pt} &= T_{ij}^{pt} + T_{ji}^{pt} + \\
 &\left( \sum_{k=1, k \neq i, k \neq j}^N K_{I_{kj}}^{pit} T_{kj}^{pt} + \sum_{k=1, k \neq i, k \neq j}^N K_{I_{jk}}^{pit} T_{jk}^{pt} \right) \\
 &\quad + \\
 &\left( \sum_{k=1}^M K_{E_{kj}}^{pit} \Theta_{kj}^{pt} + \sum_{k=1}^M K_{E_{jk}}^{pit} \Theta_{jk}^{pt} \right) \\
 &\quad (17) \\
 &\quad \forall i, j \in \{1, \dots, N\}, i \neq j
 \end{aligned}$$

Considering direct trips and transfers, freight flow from airport  $i$  to airport  $j$  is given by:

$$F_{ij}^{ft} = T_{ij}^f + \sum_{k=1, k \neq i, k \neq j}^N K_{I_{kj}}^{fit} T_{kj}^{pt} + \sum_{k=1}^M K_{E_{kj}}^{fit} \Theta_{kj}^{ft} \quad \forall i, j \in \{1, \dots, N\}, i \neq j \quad (18)$$

Then, introducing a medium size  $S_{ij}^{pt}$  for passengers aircraft operating between network airports  $i$  and  $j$  during period  $t$ , as well as a medium expected passengers load factor  $\alpha_{ij}^{pt}$  with  $0 \leq \alpha_{ij}^{pt} \leq 1$ , it is possible to compute the necessary mean flow of aircrafts  $F_{ij}^{at}$  from airports  $i$  to  $j$  to cover the expected passengers demand  $F_{ij}^{pt}$ ,  $\forall i, j \in \{1, \dots, N\}, i \neq j$ :

$$F_{ij}^{apt} = \lfloor F_{ij}^{pt} / (\alpha_{ij}^{pt} \cdot S_{ij}^{pt}) \rfloor \quad (19)$$

The size of the operated passenger aircraft between two airports is, when passengers demand is relevant, mainly related with the distance between the airports and their runways characteristics (length). Then, introducing a medium size  $S_{Eij}^{pt}$  for passengers aircraft operating between network airport  $i$  and external airport  $j$  during period  $t$ , as well as a medium expected passengers load factor  $\alpha_{Eij}^{pt}$  with  $0 \leq \alpha_{Eij}^{pt} \leq 1$ , it is possible to compute the necessary mean flow of aircrafts  $F_{Eij}^{at}$  from airports  $i$  to  $j$  to cover the expected passengers demand  $F_{Eij}^{pt}$ ,  $\forall i \in \{1, \dots, N\}, j \in \{1, \dots, M\}$ :

$$F_{Eij}^{apt} = \lfloor F_{Eij}^{pt} / (\alpha_{Eij}^{pt} \cdot S_{Eij}^{pt}) \rfloor \quad (20)$$

Then, the arriving and departing flows of passenger aircrafts at network airport  $i$  are given by:

$$\Phi A_i^{apt} = \Phi D_i^{apt} = \sum_{j=1, j \neq i}^N F_{ij}^{apt} + \sum_{j=1}^M F_{Eij}^{apt} \quad (21)$$

Passengers aircraft in the considered network offers a transportation freight capacity in their hold. Let for a passenger aircraft of medium size  $S_{lij}^{pt}$ ,  $H_{lij}^{pt}$  be its freight capacity measured in tons and let  $\beta_{lij}^{pt}$ , with  $0 \leq \beta_{lij}^{pt} \leq 1$ , be the expected percentage of effective use of it, then, the mean offered freight capacity offered by passenger aircrafts between airports  $i$  and  $j$  is given by  $F_{lij}^{apt} \cdot H_{lij}^{pt} \cdot \beta_{lij}^{pt}$  and if :

$$F_{lij}^{ft} \leq F_{lij}^{apt} \cdot H_{lij}^{pt} \cdot \beta_{lij}^{pt} \quad (22)$$

no need of freight aircraft is present from airport  $i$  to airport  $j$ . Otherwise,  $H_{lij}^{ft}$  being the mean freight capacity of freight aircrafts between network airports  $i$  and  $j$ , and  $\alpha_{lij}^{ft}$  with  $0 \leq \alpha_{lij}^{ft} \leq 1$  being the mean load factor, the necessary number of freight aircraft is then given by:

$$F_{lij}^{aft} = \lfloor (F_{lij}^{ft} - F_{lij}^{apt} \cdot H_{lij}^{pt} \cdot \beta_{lij}^{pt}) / (H_{lij}^{ft} \cdot \alpha_{lij}^{ft}) \rfloor \quad (23)$$

$$\forall i, j \in \{1, \dots, N\}, i \neq j$$

Passenger aircrafts operating in the links between network airports and the exterior airports offer a transportation freight capacity in their hold. Let for a passenger aircraft of medium size  $S_{Eij}^{pt}$ ,  $H_{Eij}^{pt}$  be its freight capacity measured in tons and let  $\beta_{Eij}^{pt}$ , with  $0 \leq \beta_{Eij}^{pt} \leq 1$ , be the expected percentage of effective use of it, then, the mean offered freight capacity offered by passenger aircrafts between network airport  $i$  and external airport  $j$  is given by  $F_{Eij}^{apt} \cdot H_{Eij}^{pt} \cdot \beta_{Eij}^{pt}$  and if :

$$F_{Eij}^{ft} \leq F_{Eij}^{apt} \cdot H_{Eij}^{pt} \cdot \beta_{Eij}^{pt} \quad (24)$$

no need of freight aircraft is present from airport  $i$  to airport  $j$ . Otherwise,  $H_{Eij}^{ft}$  being the mean freight capacity of freight aircrafts between network airport  $i$  and external airport  $j$ , and  $\alpha_{Eij}^{ft}$  with  $0 \leq \alpha_{Eij}^{ft} \leq 1$  being the mean load factor, the necessary number of freight aircrafts is then given by:

$$F_{Eij}^{aft} = \lfloor (F_{Eij}^{ft} - F_{Eij}^{apt} \cdot H_{Eij}^{pt} \cdot \beta_{Eij}^{pt}) / (H_{Eij}^{ft} \cdot \alpha_{Eij}^{ft}) \rfloor \quad (25)$$

$$\forall i \in \{1, \dots, N\}, j \in \{1, \dots, M\}$$

The arriving and departing flows of freight aircrafts at airport  $i$  are then given respectively for  $i \in \{1, \dots, N\}$  by:

$$\Phi A_i^{aft} = \sum_{j=1, j \neq i}^N F_{Iji}^{aft} + \sum_{k=1}^M F_{Eki}^{aft} \quad (26)$$

and

$$\Phi D_i^{aft} = \sum_{j=1, j \neq i}^N F_{Iij}^{aft} + \sum_{k=1}^M F_{Eik}^{aft} \quad (27)$$

Observe that if  $\Phi A_i^{aft} \geq \Phi D_i^{aft}$ , some freight aircraft will leave airport  $i$  with no freight or with a reduced freight with respect to the mean load factor since anyway aircraft flow balance at each airport must be satisfied over a period such as a year.

Then, in Table 5, the dimensioning aircraft flows for the different airside components are listed.

Table 5. Aircraft flows and airport components interaction

	Passenger aircraft flows	Freight aircraft flows
Landside components influenced by aircraft flows	Runway Taxiways Aircraft stands Aircraft parking areas Hangars Maintenance Air navigation building and facilities Ground handling facilities	Runway Taxiways Aircraft stands Aircraft parking areas Hangars Maintenance Air navigation building and facilities Ground handling facilities

## 5 DATA FOR AIRPORT DIMENSIONING

According to the above analysis, the following input data appears sufficient to be able to estimate the different dimensioning flows in a network of airports,:

- Basic passenger and freight demand distributions given by :

$$[T_{ij}^{pt}] \text{ and } [T_{ij}^{ft}] \quad i, j \in \{1, \dots, N\}, i \neq j, \quad (28)$$

$$[\phi_{ki}^{pt}] [\phi_{ik}^{pt}] \text{ and } [\phi_{ki}^{ft}], [\phi_{ik}^{ft}] \quad i \in \{1, \dots, N\}, k \in \{1, \dots, M\}$$

- Networks parameters:

$$\begin{aligned} \text{Passengers: } & K_{I_{jk}}^{pit} \quad i, j, k \in \\ & \{1, \dots, N\}, i \neq j \neq k \\ & K_{E_{kj}}^{pit} \quad i, j \in \{1, \dots, N\}, i \neq j, k \in \\ & \{1, \dots, M\}. \quad (29) \end{aligned}$$

$$\begin{aligned} \text{Freight: } & K_{I_{jk}}^{fit} \quad i, j, k \in \{1, \dots, N\}, i \neq \\ & j \neq k \quad (30) \\ & K_{E_{kj}}^{pit} \quad i, j \in \{1, \dots, N\}, i \neq j, k \in \\ & \{1, \dots, M\} \end{aligned}$$

- Load factors:

$$\begin{aligned} \text{Passenger load factors: } & \alpha_{I_{ij}}^{pt} \quad i, j \in \\ & \{1, \dots, N\}, i \neq j, \alpha_{E_{ik}}^{pt} \quad i \in \\ & \{1, \dots, N\}, k \in \{1, \dots, M\} \quad (31) \end{aligned}$$

Freight hold load factors:

$$\begin{aligned} & \beta_{I_{ij}}^{ft} \quad i, j \in \{1, \dots, N\}, i \neq j \\ & \beta_{E_{ik}}^{ft} \quad i \in \{1, \dots, N\}, k \in \{1, \dots, M\} \\ & \quad (32) \end{aligned}$$

Freighters load factors:

$$\begin{aligned} & \alpha_{I_{ij}}^{ft} \quad i, j \in \{1, \dots, N\}, i \neq j \\ & \alpha_{E_{ik}}^{ft} \quad i \in \{1, \dots, N\}, k \in \{1, \dots, M\} \\ & \quad (33) \end{aligned}$$

The demand prediction resulting in the distribution of flows of passengers and freight between airports will be conducted from an adaptation of the sequential approach for transport demand prediction. This will be described in the next paragraph.

With respect to the network parameters, either for passengers or freight, first it is to say that the majority of them are expected to be equal to zero since in general few alternate path to a direct path are considered by airlines. In some specific cases these coefficients can be obtained exactly:

- In a network with point to point flights, all these coefficients will be equal to zero.
- In the case of a network organized around a unique hub (airport 1), these proportion coefficients will be such as:

$$\begin{aligned} K_{I_{jk}}^{p1t} &= 1 \quad \forall j, k \in \{1, \dots, N\}, j \neq k, \\ K_{I_{1k}}^{pit} &= 0 \quad \forall i, k \in \{1, \dots, N\}, i \neq k, \\ K_{I_{j1}}^{pit} &= 0 \quad \forall i, j \in \{1, \dots, N\}, i \neq j \end{aligned} \quad (34)$$

The demand prediction resulting in the distribution of flows of passengers and freight between airports will be conducted from an adaptation of the sequential approach for transport demand prediction. This will be described in the next paragraph.

With respect to the network parameters, either for passengers or freight, first it is to say that the majority of them are expected to be equal to zero since in general few alternate path to a direct path are considered by airlines. In some specific cases these coefficients can be obtained exactly:

- In a network with point to point flights, all these coefficients will be equal to zero.
- In the case of a network organized around a unique hub (airport 1), these proportion coefficients will be such as:

$$\begin{aligned} K_{I_{jk}}^{p1t} &= 1 \quad \forall j, k \in \{1, \dots, N\}, j \neq k, \\ K_{I_{1k}}^{pit} &= 0 \quad \forall i, k \in \{1, \dots, N\}, i \neq k, \\ K_{I_{j1}}^{pit} &= 0 \quad \forall i, j \in \{1, \dots, N\}, i \neq j \end{aligned} \quad (34)$$

- In more general cases, a way to get an estimation of the values of these coefficients will be through the resolution of an assignment problem.

With respect to the prediction of load factors for passenger aircraft (cabin and hold) and for freight aircraft, different approaches can be adopted and mixed according to the available data and the stage considered in the planning horizon: historical data can be extrapolated, goal values for air carriers can be adopted and sets of scenari can be produced.

## 6 THE PROPOSED PREDICTION FRAMEWORK

The proposed prediction framework describes the different processing steps to get the predicted dimensioning flows for each airport.

A different treatment must be done to flows between two network airports and flows between a network airport and an external airport.

Either for passengers as for freight transportation, starting from a multimodal (ground and air transportation) generation-attraction study for network airports and from a prediction of end to

end air flows between network airports and external airports (matrices  $[\mathcal{O}_{ik}^{pt}]$  and  $[\mathcal{O}_{ik}^{ft}]$ ), a multimodal distribution of flows between network airports can be performed, then for each network connection, modal assignment of flows can be realized. This leads to the computation of matrices  $[T_{ij}^{pt}]$  and  $[T_{ij}^{ft}]$ . Then, adopting values for the network parameters and the different mean load factors, all the dimensioning flows of the network airports can be computed using expressions of the previous section.

The whole process is represented in Figure 2 where for  $i \in \{1, \dots, N\}$ :

$$\tilde{O}_{li}^{pt} = O_{li}^{pt} - \sum_{k=1}^M \mathcal{O}_{ik}^{pt}, \tilde{D}_{li}^{pt} = D_{li}^{pt} - \sum_{k=1}^M \mathcal{O}_{ki}^{pt} \quad (35)$$

$$\tilde{O}_{li}^{ft} = O_{li}^{ft} - \sum_{k=1}^M \mathcal{O}_{ik}^{ft}, \tilde{D}_{li}^{ft} = D_{li}^{ft} - \sum_{k=1}^M \mathcal{O}_{ki}^{ft} \quad (36)$$

$$\text{and} \quad T_{ij}^{mpt} = T_{ij}^{pt} + T_{ij}^{gpt} \quad T_{ij}^{mft} = T_{ij}^{ft} + T_{ij}^{gft} \quad (37)$$

where  $T_{ij}^{gpt}$  and  $T_{ij}^{gft}$  are respectively the ground passenger and freight flows between network airports  $i$  and  $j$ .

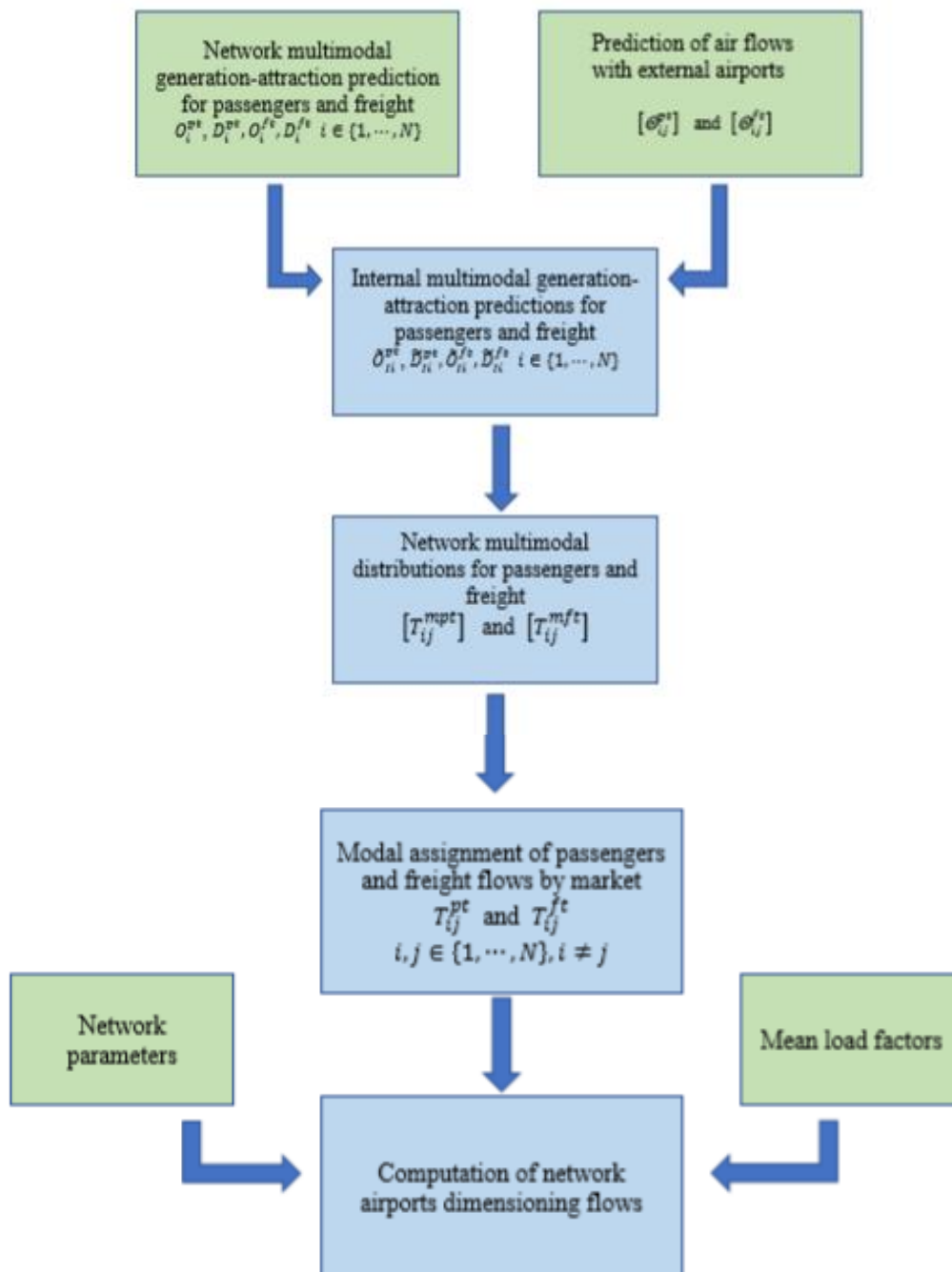
It is important to emphasize that at this stage, no specific models or techniques need to be proposed to solve the sequence of problems composing the developed framework (generation-attraction, spatial distribution and mode choice). A large range of techniques has already been referred in the previous chapter and the choice of specific predictive models and techniques appears to be strongly related with the characteristics (network size and structure, historical perspective, quality and quantity available data, previous studies and length of prediction horizon, ...) of each airport network planning case study.

In this approach, the drivers of the prediction are the generation and attraction levels of the network airports and the air flows with external airports for which an estimation must be provided at each stage of the planning process. Since these drivers depend on observed flows (initial stage) and on predictions of economic and demographic variables on the following stages, their degree of uncertainty increases with the stage in the planning process. This reverberates on the accuracy of the prediction of the dimensioning flows at airport. Different scenarios with respect to the



increasing uncertainty of these drivers can be generated and tested so that the range of the possible outcomes for the dimensioning flows of the network airports can be explored.

Figure 2: The proposed framework for the estimation of dimensioning flows



## 7 CONCLUSION

This study has introduced a framework to generate long term predictions of demand for airport capacity over a network of airports. After identifying dimensioning flows for airports, their interdependence at the network level has been analyzed and compatibility constraints have

been established. Then, starting from the prediction of a limited number of data drivers, the different steps of the framework can be developed. This should produce coherent predictions of the dimensioning flows of each network airport.

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