TIME IS MONEY: THE IMPORTANCE OF HUB TIMETABLE CO-ORDINATION FOR AIRLINE HUB-AND-SPOKE SYSTEMS

Antonio DANESI (University of Bologna, Faculty of Engineering, Viale Risorgimento, 2 – 40136 Bologna - Italy; antonio.danesi@unibo.it; ph. +39-349-5713771)

Abstract

In this paper, alternative schedule proposals for a European airline hub are compared. The analysis mainly focuses on the measure of hub timetable co-ordination and connectivity levels, which are evaluated by means of the "weighted connectivity ratio". The case study demonstrates how a even relatively small hub can offer a huge number of connections, by achieving a satisfactory temporal co-ordination level. Furthermore, the results of the application of specialised software, which has been used for simulating the interaction between air transport demand and supply, seem to confirm that changes in the hub timetable co-ordination level can produce a strong impact on the profitability of the airline network as a whole.

Introduction

An airline that operates a "hub-and-spoke" network offers flights between its one or few "hub" airports and its “spoke” airports. The airline co-ordinates arrivals and departures at its hub in order to minimize delays for passengers continuing through the hub to final destinations on spokes other than the one on which they originated. This strategy targets passengers travelling between origins and destinations for which traffic volume is not sufficient for conveniently frequent non-stop flights.

Effective hubbing requires that flights from the spokes of the network arrive at the hub airport at approximately the same time. The aircraft then wait on the ground simultaneously, in order to facilitate the rapid interchange of passengers and baggage (or freight); afterwards, flights depart in quick succession back out along the spokes. This process, which involves a bank of arrivals followed shortly afterwards by a bank of departures, is described as a “complex” or “wave”. In short, a hub-and-spoke network to be developed requires (Danesi, 2006):

1) spatial concentration of the network structure,
2) temporal co-ordination of the flight schedules at hub airports in “waves”,
3) integration of via-hub sub-services, i.e. the airline has to sell passengers one via-hub fare, from passengers’ point of origin to passengers’ final destinations, and has also to provide automatic baggage transfer at the hub.

1. Evaluating hub timetable co-ordination and connectivity: the “weighted connectivity ratio”

Hub connectivity refers to the number and the quality, in terms of passenger attractivity, of indirect flights available to passengers via an airline hub (Bootsma, 1997). Hub connectivity depends on:

1) the number of markets linked to the hub with direct services,
2) service frequencies,
3) times of arrival and departure of the flights scheduled at the hub.

Large hub airports have a major advantage, because connectivity tends to increase in proportion to the square of the number of flight movements. Nevertheless, smaller airline hubs can try to compensate for this, by offering a higher level of timetable co-ordination, which does not depend on the size of hub operations (Rietveld and Brons, 2001).

Hub timetable co-ordination can be defined as the action and the effect of organising a hub schedule according to an ordered pattern, so that connectivity can be enhanced without increasing the number of flights. Indeed, concentrating flights in complexes is the common approach adopted by airline managers for implementing hub timetable co-ordination.

Hub temporal co-ordination can be measured by using the so-called "weighted connectivity ratio" (Danesi, 2006). Let $i = 1,...,n_a$ be any flight arriving at the airline hub during the time period T , $j = 1,...,n_d$ any flight departing from the hub during the time period T , $t_{a,i}$ the arrival time of flight i , $t_{d,j}$ the departure time of flight j and $TT_k = t_{d,j} - t_{a,i}$, $k = (i, j)$, the transfer time scheduled between flight i and flight j . Furthermore, let

$n_{a,cont}$ be the number of continental flights arriving at the hub and $n_{d,cont}$ the number of continental flights departing from the hub during the time period T. Similarly, let $n_{a,inc}$ and $n_{d,inc}$ be the number of arriving and departing intercontinental flights.

Now, considering on-line same-day airline hub connections only, let MCT_k be the minimum connect time[1] between i and j, $MACT_k$ be the maximum acceptable connect time for passengers having a viable connection between flight i and j and let define "intermediate connect time" (ICT_k) an intermediate threshold for taking into account the different quality levels, in terms of passenger attractivity, of "rapid connections" ($MCT_k \le TT_k \le ICT_k$) compared to the other viable but less desirable connections ("slow connections", $ICT_k < TT_k \le MACT_k$). In Tab. 1, typical values of MCT_k are listed and possible values of ICT_k and $MACT_k$ are suggested for both continental and intercontinental connections.

The "temporal connectivity matrix" can be defined as the matrix $\underline{\underline{TCM}}$, with n_a rows and n_d columns, such

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[1] Minimum connect time is the minimum time interval that must elapse between a scheduled arrival and a scheduled departure for the two services to be bookable as a connection (Dennis, 1994). Minimum connect time is constrained by the minimum transfer time required to passengers and baggage to be transferred at the hub and by the minimum time to turnaround the aircraft.

CONNECT TIMES (minutes)		MCTk	ICTk	MACTk
CONNECTION TYPE	Continental - Continental	45	90	120
	Continental - Intercont	60	120	180
	Intercont. – Intercont.	60	120	180

Tab. 1 Values of minimum, intermediate and maximum acceptable connect times proposed for the calculation of the weighted connectivity ratio

that, for the generic element τ_{ij} , $i = 1,...,n_a$, $j = 1,...,n_d$, the following holds:

$$\begin{cases} \tau_{ij} = 1 & if \quad MCT_k \le t_{d,j} - t_{a,i} \le ICT_k \\ \tau_{ij} = 0.5 & if \quad ICT_k < t_{d,j} - t_{a,i} \le MACT_k \\ \tau_{ij} = 0 & \quad otherwise \end{cases} \tag{1}$$

Similarly, the "spatial connectivity matrix" can be defined as the matrix $\underline{\underline{SCM}}$, with n_a rows and n_d columns, such that, for the generic element δ_{ij} , $i = 1,...,n_a$, $j = 1,...,n_d$, the following holds:

$$\begin{cases} \delta_{ij} = 1 & if \quad DR_k \le 1.20 \\ \delta_{ij} = 0.5 & if \quad 1.20 < DR_k \le 1.50 \\ \delta_{ij} = 0 & \quad otherwise \end{cases} \tag{2}$$

where

$$DR_k = \frac{ID_k}{DD_k} \tag{3}$$

is the so-called “de-routing index” ($DR_k \geq 1$), with DD_k the great circle distance between the point of origin of flight i and the destination of flight j and ID_k the sum of the great circle distances corresponding to flights i and j.

Furthermore, the “weighted connectivity matrix” can be defined as the matrix $\underline{\underline{WCM}}$, with n_a rows and n_d columns, such that the generic element w_{ij}, $i = 1,...,n_a$, $j = 1,...,n_d$, corresponds to the so-called “weighted connection”

$$w_{ij} = \tau_{ij}\delta_{ij} \tag{4}$$

Now, the “weighted connectivity ratio” can be defined as:

$$WCR = \frac{WN_c}{WN_r} \tag{5}$$

where

$$WN_c = \sum_i \sum_j w_{ij} = \sum_i \sum_j \tau_{ij}\delta_{ij} \tag{6}$$

is the number of weighted connections offered at the airline hub during the time period T and

$$WN_r = \frac{\sum_i \sum_j \delta_{ij}}{n_a n_d} \Big[n_{a,cont} n_{d,cont} \frac{MACT_1 + ICT_1 - 2MCT_1}{2T} + \\ + \left(n_{a,cont} n_{d.inc} + n_{a,inc} n_{d,cont} \right) \frac{MACT_2 + ICT_2 - 2MCT_2}{2T} + \\ + n_{a,inc} n_{d,inc} \frac{MACT_3 + ICT_3 - 2MCT_3}{2T} \Big] \quad (7)$$

the approximate number of weighted connections that would be expected to occur in case of a purely random (uniform) arrival and departure timetable across T (for both continental and intercontinental flights). For practical applications, it is typically assumed that T is one airline operational day, i.e. $T = 15 \div 18$ h.

The weighted connectivity ratio shows if the viable weighted connections are more than purely random. Ideally, WCR should be in the range of 2 to 3 for optimal hub temporal co-ordination, whereas connectivity ratios of 1 or less indicate random or even counterproductive hub schedule co-ordination.

The weighted connectivity ratio classifies viable connections in different quality levels, in terms of passenger attractivity[2], according to their spatial as well

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[2] Generally speaking, the attractivity of any hub connection depends on several factors (Burghouwt and De Wit, 2005; Veldhuis, 1997; Bootsma, 1997). First, the attractivity of connections declines, with increasing hub transfer time. Secondly, the attractivity of connections declines, with increasing backtracking and in-flight time compared alternative. Flight departure and arrival times, service

as temporal characteristics. Indeed, the definition of two quality levels for both spatial and temporal attributes allows any weighted connection to vary between a set of three values other than zero:

$$\begin{cases} w_{ij} = 1 & if \quad \delta_{ij} = \tau_{ij} = 1 \\ w_{ij} = 0.5 & if \quad \delta_{ij} + \tau_{ij} = 1.5 \\ w_{ij} = 0.25 & if \quad \delta_{ij} = \tau_{ij} = 0.5 \\ w_{ij} = 0 & \quad otherwise \end{cases} \tag{8}$$

with $i = 1,...,n_a$, $j = 1,...,n_d$. Moreover, different connect time thresholds can be considered, with respect to the different connection types that may occur and to the particular hub facilities. Indeed, the hub connectivity evaluation procedure, which leads to the computation of WCR, is quite precise and WN_c could be considered itself an acceptable hub connectivity measure.

2. Case study: evaluation of alternative schedule structures for Alitalia hub in Milan Malpensa

In this paragraph alternative proposals for the Winter 2005/2006 schedule of Alitalia hub in Milan Malpensa are compared. The analysis mainly focuses on the measure of hub timetable co-ordination and

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frequency and aircraft type also affect connection passenger attractivity. Moreover, in order to evaluate the attractivity of any connection, the attractivity of the other competitive direct and indirect links available to passengers should be evaluated as well.

connectivity levels, which are evaluated by means of the "weighted connectivity ratio". Moreover, the profitability of the airline network as a whole is simulated by means of specialised software (Sabre Airline Profitability Model).

The first schedule configuration ("MXP-3W") corresponds to Alitalia Winter 2004/2005 schedule. Schedule MXP-3W requires 127 narrow-body aircraft and 19 wide-body aircraft to serve a wide range of continental as well as intercontinental destinations. As a result of schedule MXP-3W, the wave-system structure of Alitalia hub in Milan Malpensa (MXP) is characterised by three waves with centres at 8:55 a.m., 1:50 p.m. and 8:00 p.m (Fig. 1). Since the continental fleet is located at the spokes during the nighttime period and the average hub-repeat cycle is equal to 5h30', the wave-system structure of Alitalia hub in Milan Malpensa can be described by the triple *(3, 5 ½, 1)*[3]. On the other hand, with schedule MXP-3W, the wave-system structure of Alitalia hub in Rome Fiumicino (FCO) is characterised by four waves with centres at about 9:00 a.m., 1:00 p.m., 5:00 p.m., 9:00 p.m. As the continental fleet is stabled at the spokes and the average hub-repeat cycle is equal to four hours, the wave-system structure of Alitalia hub in Rome Fiumicino can be described by the triple *(4, 4, 1)*.

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[3] Let N be the number of waves of a wave-system structure, H the hub-repeat cycle and S a dummy variable, such that: S = 0, if airline continental fleet is stabled at the hub; S = 1, if airline continental fleet is stabled at the spokes; S = 2, if airline continental fleet is stabled both at the hub and at the spokes ("dual stabling" case). Hence, the triple (N, H, S) identifies an airline wave-system structure univocally.

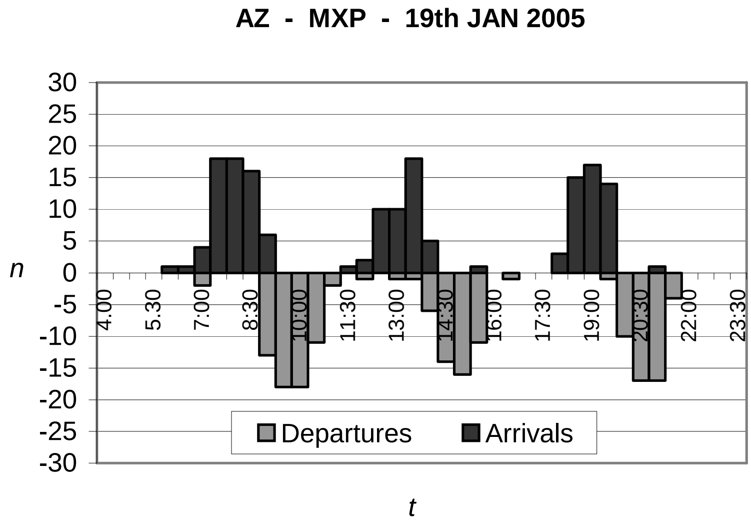

Fig. 1 Schedule structure of Alitalia hub in Milan Malpensa, on Wednesday 19th January 2005 (Alitalia schedule MXP-3W)

Tab. 2 reports the results of the temporal co-ordination and connectivity analysis, which has been performed for Alitalia hubs and other major European hubs, with reference to Wednesday 19th January 2005 OAG data. Both the weighted number of connections (WN_c) and the weighted connectivity ratio (*WCR*) have been calculated, in order to estimate hub connectivity and hub temporal co-ordination respectively. The results of the analysis demonstrate how even relatively small airline hubs can offer a huge number of weighted connections, through a satisfactory timetable co-ordination level, that is by achieving a high value of the weighted connectivity ratio.

AIRLINE (CODE)	**AIRPORT (CODE)**	**na**	**WNc**	**WCR**
Air France (AF)	Paris (CDG)	380	7285	1,42
Iberia (IB)	Madrid (MAD)	320	3967	1,32
British A. (BA)	London H. (LHR)	280	3788	1,23
KLM (KL)	Amsterdam (AMS)	247	4526	1,75
Alitalia (AZ)	Rome (FCO)	203	1983	1,53
Alitalia (AZ)	Milan (MXP)	163	2942	2,48

Tab. 2 Daily number of arriving flights (n_a), number of weighted connections (WN_c) and weighted connectivity ratio (WCR) for selected European hubs, with reference to Wednesday 19th January 2005 OAG data (T = 18 h for CDG, LHR and MAD; T = 16 h for AMS, T = 15 h for FCO and MXP)

Alitalia hub in Milan Malpensa shows a very high degree of temporal co-ordination (2,48), which can be considered “ideal”, according to the classification proposed (Par. 1). Indeed, Alitalia is able to offer as many as 2942 weighted connections, by scheduling only 163 daily arriving flights at Milan Malpensa hub. Alitalia hub in Rome Fiumicino exhibits a quite high degree of temporal co-ordination and connectivity as well: with 200 daily arriving flights and a weighted connectivity ratio equal to 1,53, almost 2000 daily weighted connections are available to passengers.

Fig. 5 illustrates the timetable structure of Alitalia hub in Milan Malpensa, which results from the implementation of schedule MXP-4W. MXP-4W serves more or less the same destinations and requires the same fleet that is necessary to operate schedule MXP-3W. In schedule MXP-4W, the wave-system structure of Alitalia hub in Milan Malpensa (MXP) can be described by the triple *(4, 4, 1)* and it is characterised by four waves with centres at about 9:00 a.m., 1:00 p.m., 5:00 p.m., and 9:00 p.m. The triple *(4, 4, 1)* can describe also the wave-system structure of Alitalia hub in Rome Fiumicino (FCO), which undergoes only minor modifications switching from MXP-3W to MXP-4W schedule.

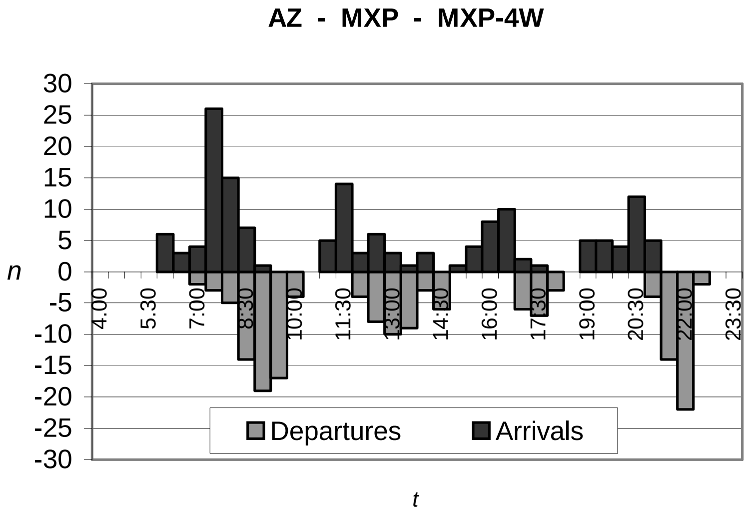

Fig. 5 MXP-4W design schedule structure of Alitalia hub in Milan Malpensa

About the temporal co-ordination and connectivity of Alitalia hub in Milan Malpensa (Tab.3), it can be noted that schedule MXP-4W leads to 2211 weighted connections instead of 2942, with a reduction of 731 weighted connections (-24,85%). This can be easily explained, by considering that the re-distribution of the same amount of flight frequencies in four waves instead of three makes the weighted connectivity ratio drop from 2,48 to 1,96 (-20,97%).

Schedule	**WNc (MXP)**	**WCR (MXP)**
MXP-3W	2942	2,48
MXP-4W	2211	1,96
Difference	-24,85%	-20,97%

Tab. 3 Comparative analysis of schedule MXP-3W and schedule MXP-4W: number of weighted connections (WN_c); score of the weighted connectivity ratio (with T = 15h) for Alitalia hub in Milan Malpensa (WCR)

Schedule	**LF (%)**	**NP (euro/week)**
MXP-3W	67,27	Confidential
MXP-4W	64,09	Confidential
Difference	-3,18	P <<0

Tab. 4 Output of Alitalia network simulation: average load factor (LF) and network profitability (NP) for schedule MXP-3W and schedule MXP-4W

A simulation has been performed using Sabre Airline Profitability model, in order to forecast the effect that would produce on Alitalia network profitability the implementation of schedule MXP-4W and schedule MXP-3W, in Winter 2005/2006. According to the outputs of the simulation, which are summarised in Tab.

4, the adoption of schedule MXP-4W would lead to a diminution both in the average load factor (*LF*) and in the network profitability of Alitalia, compared to the use of MXP-3W schedule. Indeed, the passenger demand assignment completed by means of APM software does estimate a drop in *LF* equal to 3,18%, in case of the introduction of schedule MXP-4W instead of schedule MXP-3W. This would result in a decrease by several euros per week in Alitalia network profitability.

Therefore, it can be concluded that the implementation of a 4-wave-system structure in Milan Malpensa hub could seriously threaten Alitalia network profitability, at least until the number of fleet and flight frequencies were not increased. In particular, both the connectivity analysis and the network simulation completed by means of APM software recommend to adopt MXP-3W schedule and not MXP-4W schedule in Winter 2005/2006.

Conclusions

The case study, which corresponds to the evaluation of two alternative schedule structures for Alitalia hub in Milan Malpensa, demonstrates how a relatively small hub can offer a huge number of connections, by achieving a satisfactory timetable co-ordination level. Furthermore, the results of the application of specialised software, which has been used for simulating the interaction between air transport demand and supply, seem to confirm that the profitability of the airline network as a whole can be strongly affected by changes in the hub temporal co-ordination level. Indeed, the degree of temporal co-ordination of an airline hub appears to be strictly related to the profitability of the network. Thus, hub timetable co-ordination and connectivity indexes are important performance measures for airlines that operate hub-and-spoke networks; airline managers may apply the “weighted connectivity ratio” as a helpful and straightforward pre-analysis tool for the evaluation of new schedule proposals.

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