Borrowing from Behavioural Science: A Novel Method for the Analysis of Indirect Temporal Connectivity at Airport Hubs

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ABSTRACT

We introduce a novel empirical method that quantifies indirect temporal connectivity at airport hubs and overcomes certain limitations of existing methodology.

Employing a pattern recognition algorithm, originally developed for behavioural research, we analysed schedules at Frankfurt and London Stansted airports in 2007.

By employing our model in a comparative analysis, we demonstrate schedule coordination effects.

KEYWORDS

Indirect temporal connectivity
Schedule analysis
Hub
Schedule coordination
Pattern recognition

I. Introduction

Timetable coordination is of crucial importance to network airlines and airline alliances operating hubs.

Previously, the level of timetable coordination has been measured by means of counting the number of flights that fall into a theoretical, ideal departure/arrival wave that is moved over the course of the day (Bootsma, 1997) to determine local maxima and thus the existence and degree of a wave structure or by means of calculating a connectivity ratio (of average de facto viable connections per average of random connections), (Doganis and Dennis, 1989; Dennis, 1994b and 2001; Doganis 2002). For an overview of the different methodologies see Danesi (2006).

Both methods have certain inherent limitations. The Bootsma approach is based on a theoretical model, and describes overall connection quality in terms of relatively rough nominal categories ("excellent", "good", "poor"). It does not control for irrelevant connections and the analysis can not be subdivided by market, i.e. the relevance of connections cannot be taken into account. The other prominent method that has emerged is the "connectivity ratio" that was proposed by Dennis and Doganis (Doganis and Dennis, 1989; Dennis, 1994b and 2001; Doganis 2002). Despite yielding a numerical indicator, Dennis' and Doganis' connectivity ratio is equally faced by imprecision, as it dichotomizes connection quality as "viable" and "not viable" It assumes the existence of an "average number of viable connections per flight arrival" that is descriptive of overall connection quality. The descriptive power of such an indicator must be questioned. In fact, the more pronounced a wave structure of a hub schedule, the less descriptive of overall connection quality will an "average number of connection quality" be, due to the unequal distribution of connections resulting from peaking.

Creating capacity peaks in a hub schedule is, to a large extent, necessary due to the limited number of intercontinental flights. This results in proximity of intercontinental flights to the peak of the wave being a crucial aspect of temporal connectivity. However, an “average number of connections” does not distinguish between continental and intercontinental flights. In fact, a non-peaked schedule would be able to generate the same number of average connections as a highly peaked schedule, thus unjustifiably scoring the same in terms of a connectivity ratio.

However, the objective should be to optimise temporal indirect connectivity by counterbalancing the low frequency of intercontinental flights by increasing their temporal connectivity. The most efficient hub schedule is the one that times arrivals and departures accordingly. Like the Bootsma (1997) model, the analysis can not be subdivided by markets or assessed on a city-pair level when calculating the connectivity ratio, thus limiting its potential use. Neither method takes the weekly frequency of services into account. We consider weekly frequency an important aspect of connection quality that should not be neglected, not least because it is an important factor for airline choice in high-yield business travel markets.

II. Aim of this paper

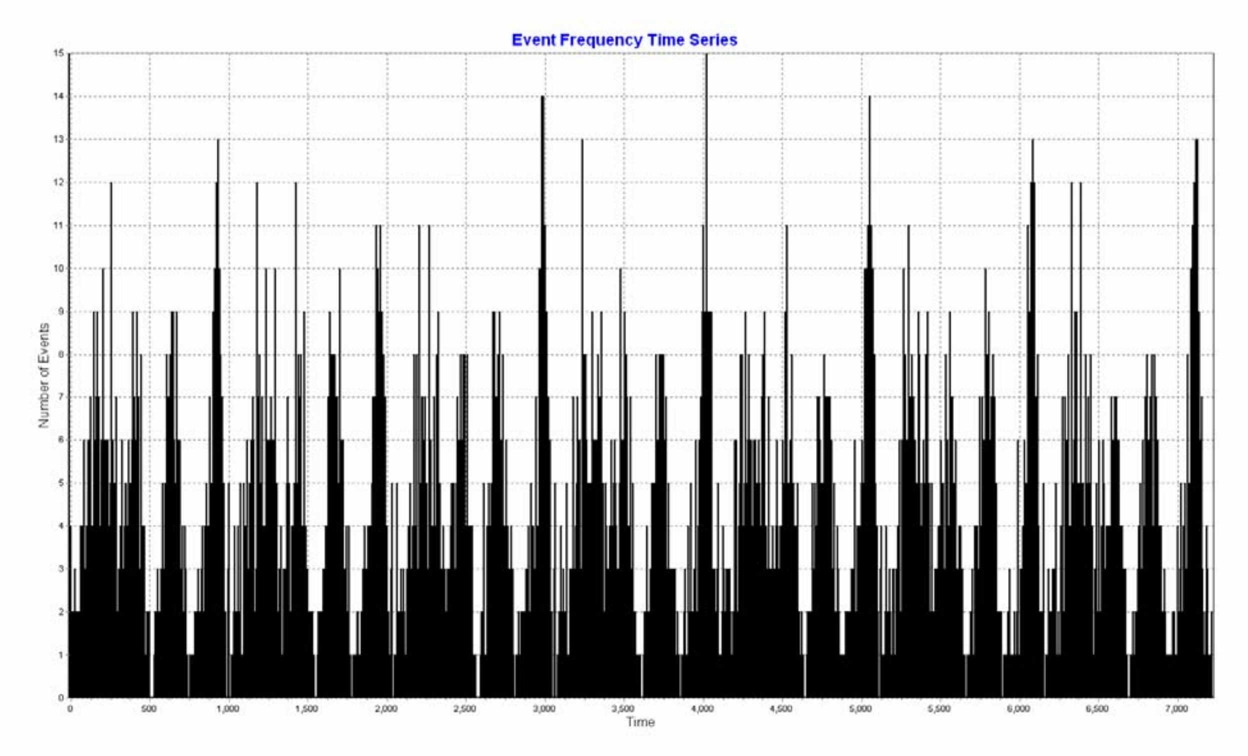
“Hub timetable coordination can be defined as the action and the effect of organising a hub schedule according to an ordered pattern, so that connectivity can be enhanced without increasing the number of flights” (Danesi, 2006). To this end, we employed a pattern recognition software tool (“Theme”) that has originally been developed for behavioural research. The method was originally conceived by Magnus Magnusson, a psychologist, to recognise patterns in the occurrence of events.

We aim to both introduce a novel method that overcomes some of the limitations of existing methodology for schedule analysis and we hypothesise that by employing our model we are able to demonstrate schedule coordination effects, specifically on the temporal connectivity of intercontinental services. In an exemplary manner, we analyse temporal connectivity of the Lufthansa schedule at Frankfurt and all scheduled flights at London Stansted.

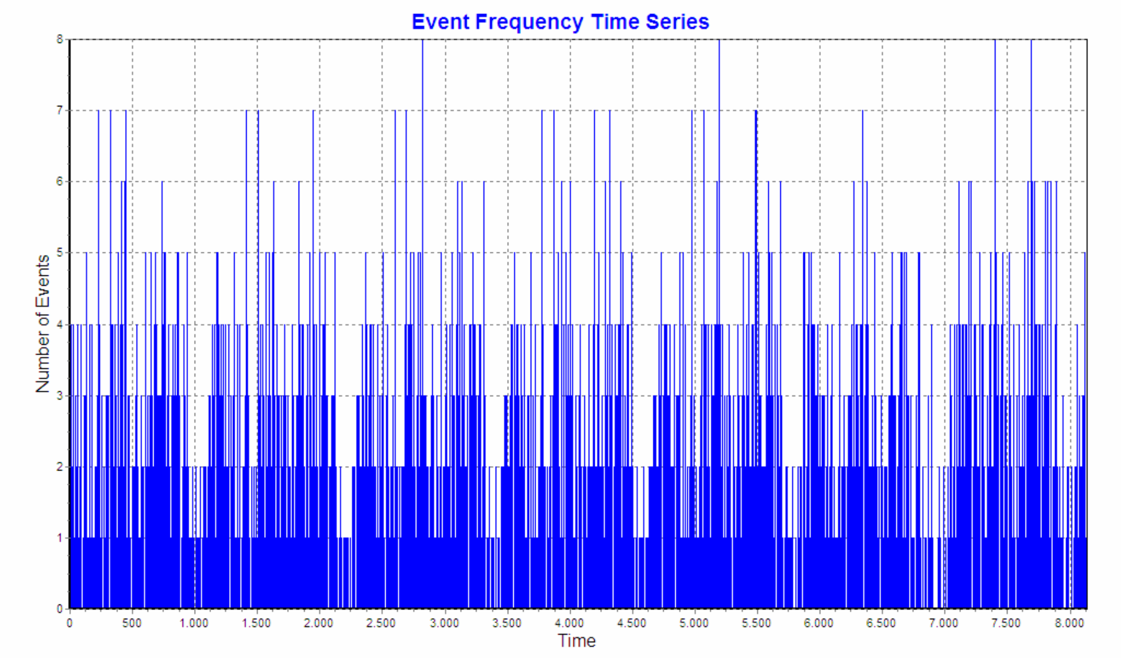
III. Scope of this paper

We restrict our analysis to temporal connectivity. We define the connectivity of an indirect connection by its frequency per week and the connection time. The higher the weekly (and daily) frequency of a connection and the shorter the connecting time, the better we consider the connection. The best connection is the one with the highest frequency and the shortest average connection time. The best coordinated timetable is the one that most efficiently counterbalances low frequency with high temporal connectivity.

Schedule structure of Lufthansa at FRA



Schedule structure at STN



IV. Methodology

The program is based on the following principle. If two events occur in succession, (event A followed by B) and do so at least twice within a given timeframe, the program tests the null hypothesis that these events are distributed independently (by chance) and have a constant probability per time unit NB/T (where NB = the number of points of B and T = the observation period in time units). Obviously, in case of hub schedules, events (departures and arrivals) will rarely be distributed by chance and significance levels will have to be set accordingly high.

After setting a significance level, the software finds the interval within which event A is followed significantly more often by event B than can be expected by chance. This interval is termed a critical interval and its outer limit is termed d2.

Whenever an event A is followed by event B within a critical interval at least twice within the given timeframe, a pattern (AB) is found.

Arrivals and departures can be conceptualised as events. A high quality indirect connection can be conceptualised as a pattern because it consists of two events that occur repeatedly and in close temporal proximity. The inclusion of a flight in a departure/arrival pattern we term pattern participation. An efficiently designed hub schedule will generate a maximum of high quality indirect connections (patterns) out of a minimum of arrivals and departures (events). A highly connective flight will have a high degree of pattern participation.

The basic principle

The concept is thus based on measuring the quality of schedule coordination by determining the ability of the timetable to generate arrival / departure patterns.

V. Data preparation and search parameter settings

We conducted a pattern search, using timetable data for Lufthansa passenger flights at Frankfurt airport in the week from June 11 to June 17, 2007 (as published on the Lufthansa Cargo website on May 17, 2007) and for the week of February 12 to February 18, 2007 at London Stansted (OAG data). Flights were classified by:

1) their direction (arrival/departure), (both airports)
2) their continental or intercontinental origin or destination, (FRA only)
3) the region of their origin or destination (Africa, Asia, Europe, North America, South America), (FRA only)
4) the country of their origin or destination, (FRA only)
5) the airport code of their origin or destination and (both airports)
6) their flight number (both airports).

The analysis was conducted on a flight number level. Departure and arrival times were converted to minutes and in Frankfurt 45 minutes were subtracted from each departure time to account for a uniform minimum connection time of 45 minutes (with the exception of Tel Aviv, where we deducted 120 minutes to account for a longer MCT). In Stansted we used an MCT of 120 minutes. Arrival dates of overnight flights were adjusted accordingly. We set the significance level at $p = 0.000001$ and the minimum occurrences requirement of the software tool to the minimum of 2, to allow for all flights with twice weekly frequency or more to potentially be detected.

The program also permits searching for higher order patterns, i.e. once patterns are found, it determines whether pattern relationships exist between these patterns. We, however, restricted the search to the first level, as we did not consider higher order patterns of interest in this investigation.

The program treats events that occur at exactly the same time as redundant and considers them as one event. This function is useful for the analysis of behaviour, where several events that take place at the same time can be conceived as components of one and the same behaviour. However, it seriously hampers schedule analysis, as it results in limiting the search to arrivals and departures that take place at different points in time. To prevent this “blindness” for simultaneous events, we multiplied all arrival and departure times by the factor ten and by subsequently deducting 1 time unit for each simultaneous arrival and adding one time unit for each simultaneous departure in a stepwise fashion. This procedure ensured that each event was assigned a discrete time unit. It enabled detection, while keeping distortion of the original data at an acceptable, sub-minute, level. For instance, departures of LH 438 to Detroit/Wayne and LH 4726 to London Heathrow are both scheduled at 10:05 h, corresponding to 605 minutes. From these 605 minutes, 45 are deducted for minimum connecting time, resulting in 560 time units. After multiplying with the factor 10, the departure to LHR is assigned time unit 5600 and the departure to DTW time unit 5601 (ten seconds later than scheduled). When interpreting the results, all time unit data then has to be divided by the factor ten to obtain the value in minutes.

VI. Results

Overall connectivity parameters FRA / STN

A total of 9393 arrival/departure patterns per 4305 events (arrivals/departures) were found, corresponding to an overall pattern/event rate of 2.18. In line with our expectations, the Stansted schedule generated a much lower pattern/event rate of 0.68 (2279 pattern per 3349 events).

The length of the maximum outer limit of the critical interval was d2= 155.80 minutes (STN: 170.60), the longest connecting time was thus 205.80 minutes (d2 max plus MCT) in Frankfurt and 290.60 minutes in Stansted, . A mean d2 of 80.04 minutes (Stansted: 61.62) and a mode of 35.00 minutes (Stansted: 4) were calculated, indicating that, at this significance level, the average connection time was 125.04 minutes in Frankfurt and 181.62 minutes in Stansted and the most common connection time 80 minutes for FRA and 124 for STN (d2 mean plus MCT and d2 mode plus MCT, respectively). The standard deviation of d2 in FRA and STN was determined at 39.28 minutes and 11.51 minutes, respectively.

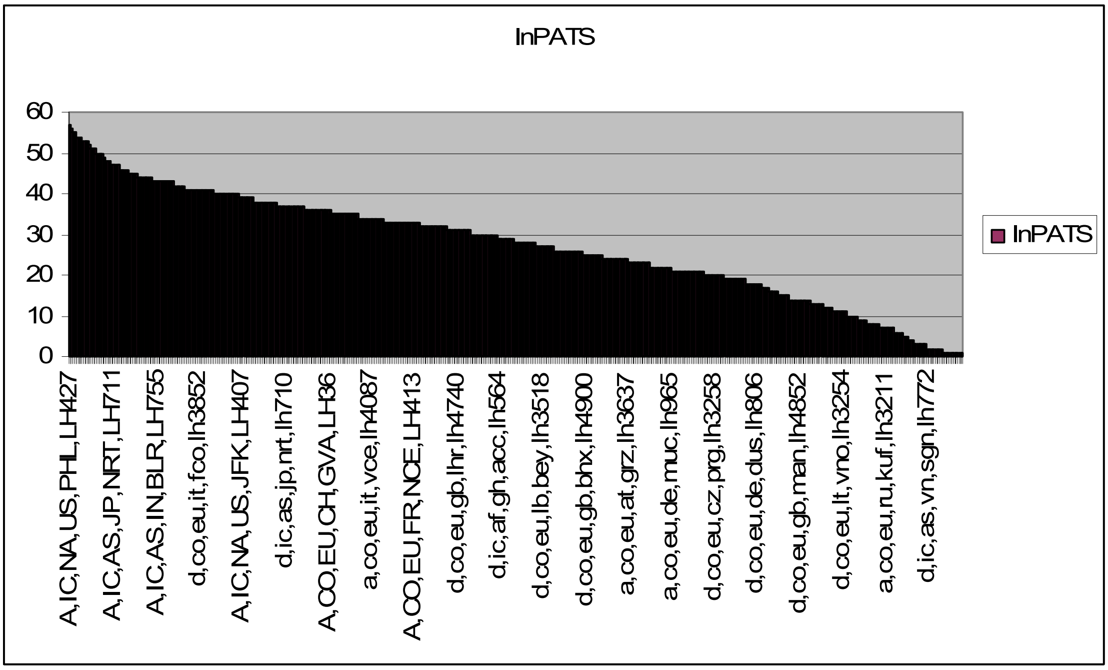
The data for the Lufthansa schedule in Frankfurt was additionally classified by continental/intercontinental origin/destination. Overall, the average number of patterns per arrival/departure was 28.99 for intercontinental flights and 27.92 for continental flights. Out of the pool of 930 intercontinental arrivals/departures during the observation period, 2232 patterns were formed, corresponding to a pattern/event rate of 2.4. The 3375 continental arrivals/departures contributed to the formation of 7161 patterns, which amounts to a pattern/event rate of 2.12. Intercontinental flights account for only 22% of all events (arrivals/departures), but participated in 24% of patterns and had a higher average pattern participation rate. We attribute this finding to an effect of overall better timetable coordination of intercontinental flights compared to continental flights.
However, one has to bear in mind that overall connectivity parameters, all possible connections are included and relevance is not controlled for.

Continental/intercontinental connections FRA

To control for irrelevant connections and to assess pattern participation in the market benefiting most from timetable coordination, we selectively studied connection patterns containing both a continental and an intercontinental leg. 3544 such patterns were found (accounting for over a third of all patterns). A mean d2 of 89.52 minutes and a mode of 55.00 minutes were calculated, indicating that for continental/intercontinental connections at this significance level, the most common connection time was 100 minutes. The pattern/event rate was 3.8 for intercontinental and 1.05 for continental flights. Intercontinental flights connected on average to 23.32 continental flights (ranging from 1 to 53, with a median of 24) and continental flights to 14.16 intercontinental flights (ranging from 1 to 24, with a median of 6). These results, and in particular the high pattern/event rate of intercontinental flights, are in accordance with our predictions and we interpret the steep connectivity gradient in continental/intercontinental pairs as evidence of a schedule coordination effect.

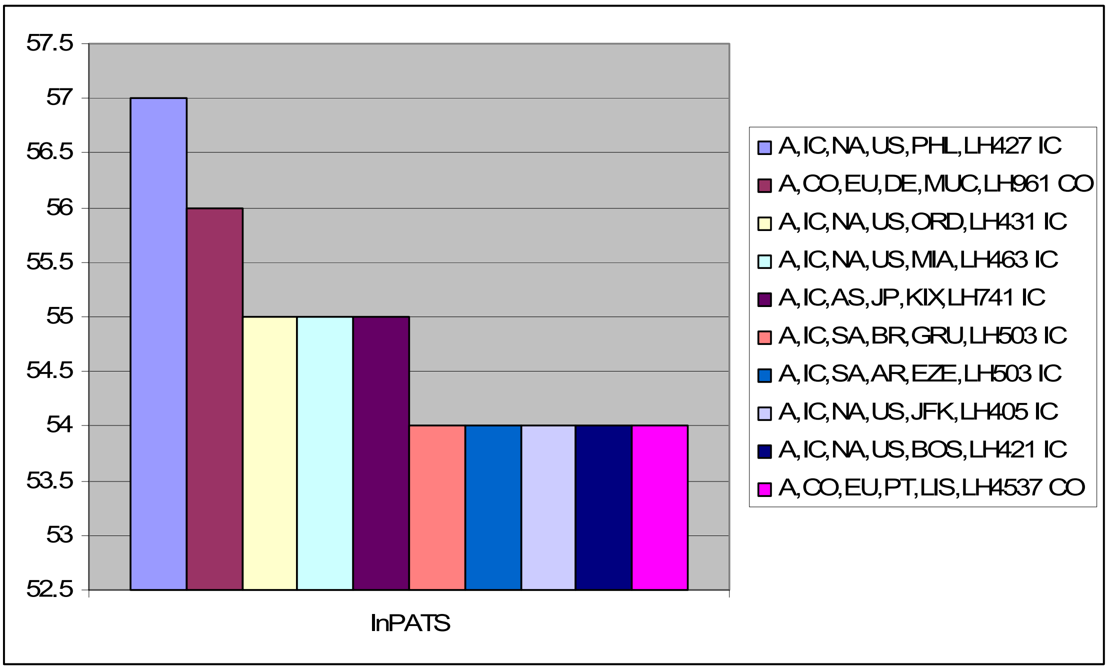
Overall distribution of pattern participation

FRA



Overall pattern participation Top Ten

FRA



Europe – North America FRA

We further narrowed down our search to the Europe-North America market and found a total of 1564 patterns. The mean outer limit of the critical interval (d2) was determined at 97.52 minutes and the mode was 55.00 minutes. While average connection time was thus somewhat longer, compared to continental/intercontinental connections in general, the modal value was the same. On average, a flight with origin or destination North America participated in 30.07 patterns with European flights, while the European flights on average connected with 4.78 North American flights. We interpret the fact that this connectivity gradient is even steeper than for continental-intercontinental connections at large, as further evidence of schedule coordination, presumably due to the relevance of the market for connecting traffic.

VII. Analysis on an individual connection level

The model is of additional value for the analysis on a single connection level:

- For each connection, a p-value is calculated that describes how “solid” a pattern is.
- Conditional probability forward / conditional probability backward: the predictive value of an event for the occurrence of another event – how does an arrival predict the departure / how does a departure predict a previous arrival?
- Mean, minimum and maximum connection times are displayed, as well as the actual connection times

VIII. Discussion

The results of our analysis of the Lufthansa schedule at Frankfurt airport and the schedules at London Stansted and airports indicate that the proposed method lends itself to quantifying indirect temporal connectivity. The model was able to detect and quantify indirect temporal connectivity of the two hubs compared to “spontaneous hubbing” at Stansted.

We consider that the method possesses distinct advantages with respect to existing methodology. The pattern/event rate yielded is an exact numerical indicator of indirect temporal connectivity on a continuous scale and weekly frequency is an integral component of the model. The empirical evaluation of all feasible pairs of connecting flights individually permits an in-depth analysis of connectivity. By restricting the pattern search, irrelevant connections can be left out in the analysis. A multitude of connectivity indicators can be calculated from the data. We consider the intercontinental pattern/event rate the single most important parameter that describes schedule coordination.

The greatest value of the model lies in its empirical evaluation of all possible connections and the calculation of connectivity parameters for each connection individually.

While dichotomizing connections to some degree (by dividing them into those that are detected as patterns and those that are not), connections that are found can be rated on a continuous scale based on their p-value or their conditional probability forward or backward. The sensitivity of detection can be adjusted by setting the p-value accordingly.

If the data is classified accordingly, the model permits analysis on different levels (e.g. overall or on a region, country and city-pair level or alliance/airline) and any combination of these different levels is possible. This feature of the method makes it particularly suitable for assessing the temporal connectivity of connections between geographical markets of interest or for determining the effects for alliance formation on indirect temporal connectivity.

Somewhat limiting is that the model's control for irrelevant connections is restricted to making a positive selection and that it requires a uniform minimum connecting time. After having conducted comprehensive external validation (e.g. comparisons of hub airports, historical effects on temporal connectivity), we can envisage employing the method for airport benchmarking, impact assessment of airline mergers, alliance formation or code-share agreements on temporal connectivity. The model might also present a useful addition to the Netscan connectivity evaluation model.

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