Optimising departure times at a transport interchange to improve connections when services are disrupted

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Abstract

When train services are disrupted, it becomes highly probable that passengers wishing to connect to another service at an interchange miss their connections. Action might be taken to avoid this by means of holding a departing train to maintain the connections. However, if there are already a relatively large number of passengers in the departing train and relatively few transfer passengers, then the benefit of maintaining the connection may be less than the disbenefit of delaying the departure of the particular train.

This paper presents a conceptual demonstration of the automatic optimisation of departure times of trains when one train arrives late at the interchange, using accumulated travel time increase (total passenger-minutes) as the evaluation function to be minimised.

The optimisation process is demonstrated at some example interchanges using simulations built on the passenger flow model using Coloured Petri Nets, which was presented by the authors in COMPRAIL 2002 [1].
Keywords: train control, disruption, re-scheduling.

1 Introduction

When a public transport service arrives late at an interchange, the line controllers may delay departures of services leaving the interchange so that the accumulated disbenefit of passengers on the delayed service, who wish to change to another service, is reduced. However, if there are already a large number of passengers in a departing train and relatively few transfer passengers, then the benefit of

Computers in Railways IX, J. Allan, C. A. Brebbia, R. J. Hill, G. Sciutto & S. Sone (Editors)

maintaining the connection may be less than the disbenefit of delaying the departure of a particular train.

In this paper, the authors present a conceptual demonstration of the computer-based optimisation of departure times when one train arrives late at an interchange, using accumulated travel time increase (total passenger-minutes) as the evaluation function to be minimised.

The calculation requires the knowledge of walking times between different setting down / picking up points in the interchange. The authors have previously developed a passenger flow model using Coloured Petri Nets (CPNs) [1][2]. While the model is simple, it is capable of describing the passenger flows with practicalities such as the variation of walking speeds between passengers and the restricted capacity of features of the interchange infrastructure, such as corridors or staircases, taken into account.

This new paper builds on this model to demonstrate the optimisation process in action at some example interchanges. These are real cases, but inevitably somewhat simplified to enable modelling.

It has been observed that the optimisation results are very sensitive to the O-D (origin-destination) demands that are given as the input data. This shows that, in devising any form of decision support systems for interchange controls like this, the observation or estimation of the O-D demand, preferably in real time, is important. This means that these systems should be closely integrated with systems such as the reservation or fare collection systems.

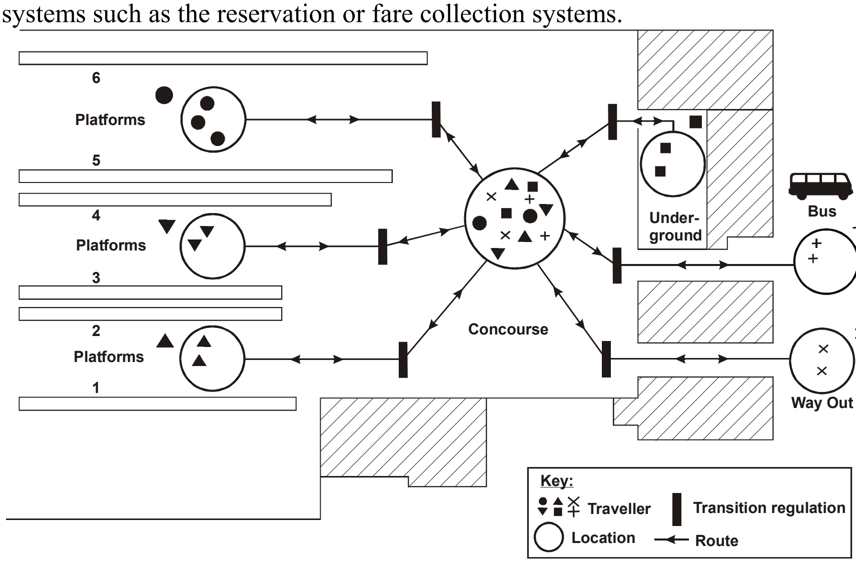

Figure 1: Example CPN model superimposed on a station layout [3].

2 CPN-based passenger flow model

The authors have proposed a novel passenger flow model [1][2]. It is a simplified model using Coloured Petri Nets [3], a variant of Petri Nets which offer the possibility of a standardised representation of a concurrent dynamic system. Such a representation consists of a network formed by "places" which are linked together by "arcs" and "transitions", and "tokens" which move around in this network. In theory, the model can handle any complexity of interchange layout, including variability of passenger performance and infrastructure capacity limits. An example model of a realistic station layout using CPN is shown in Figure 1. For the sake of brevity, each of the routes is represented by one bi-directional link. In reality, each direction would need to be modelled by its own Petri Net, which would, in any case, often be representing physically different infrastructure features. Each transition in Figure 1 (represented by black rectangles) hides these features behind it. Each in fact represents a "subnet", which in itself can be fairly complex.

3 The parameters of the interchange

Figure 2 shows the outline of the interchange used. It is modelled on the Highbury & Islington Station north of London. The North London Line (NLL) runs east-west, and the East Coast Line (ECL) from Moorgate in central London runs north-south, and the Victoria Line (VL) crosses underground.

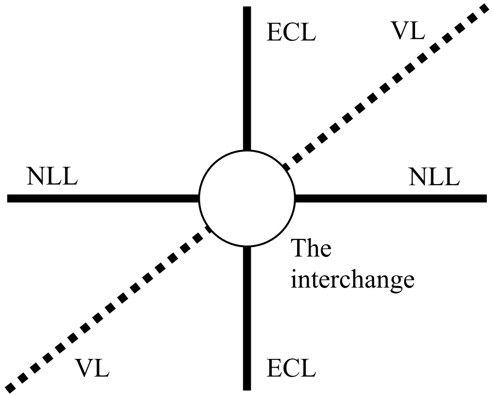

Figure 2: Outline of the interchange used in the optimisation.

The train times are assumed to be as follows (arrivals past each hour):

a. NLL Eastbound (EB): 09 / 24 / 39 / 54
b. NLL Westbound (WB): 08 / 23 / 38 / 53
c. ECL Northbound (NB): 09 / 19 / 29 / 39 / 49 / 59
d. ECL Southbound (SB): 00 / 10 / 20 / 30 / 40 / 50
e. VL: each direction every 6 minutes

The minimum, and scheduled, dwell time at the interchange is 30 seconds for every train.

Computers in Railways IX, J. Allan, C. A. Brebbia, R. J. Hill, G. Sciutto & S. Sone (Editors)

Table 1: Supposed Origin-Destination passenger flow matrices at the interchange, in passengers per hour.

Case 1:

from \ to		NLL EB	NLL WB	ECL NB	ECL SB	VL	way out
NLL	EB	1000	0	120	240	960	240
NLL	WB	0	1000	120	240	960	240
ECL	NB	240	240	1500	0	120	360
ECL	SB	120	120	0	1500	120	180
VL		960	960	120	120	5000	900
way in		240	240	180	360	900	

Case 2:

from \ to		NLL EB	NLL WB	ECL NB	ECL SB	VL	way out
NLL	EB	280	0	360	720	960	240
NLL	WB	0	280	360	720	960	240
ECL	NB	720	720	540	0	120	360
ECL	SB	360	360	0	540	120	180
VL		960	960	120	120	5000	900
way in		240	240	180	360	900	

Two different Origin-Destination passenger flow matrices were supposed, which are shown in Table 1.

The figures are shown in passengers per hour. For arriving trains, these passengers are evenly distributed to trains arriving at the interchange. For example, in case 1, because there are four NLL EB trains per hour, every NLL EB train arriving at the interchange will have 250 passengers who would not change to any other service here, 30 who are changing to ECL NB, 60 to ECL SB, 240 to VL, and 60 who are terminating their train journey here and walking out of the station. For the passengers starting the journey (shown in the "way in" horizontal row), it is assumed that the rate of showing up at the interchange will be even throughout the whole hour, i.e. 4 passengers per minute for passengers starting journey on NLL EB & WB trains, 3 for ECL NB, 6 for ECL SB and 15 for VL. The number of passengers on the departing trains will be subject to the result of calculation.

Compared with case 1, in case 2 considerably more passengers get on, get off or change at the interchange and fewer go through it. Because the actual statistical data was not available, passenger flows are artificially supposed, with

Computers in Railways IX, J. Allan, C. A. Brebbia, R. J. Hill, G. Sciutto & S. Sone (Editors)

a certain symmetry; for example, the total number of passengers going from the interchange to NLL EB is the same as that to NLL WB.

Transfer times between the lines are:

- NLL – ECL: average 5 minutes (minimum 3 ~ 7 maximum).
- NLL – VL: average 10 minutes (minimum 6 ~ 14 maximum).
- ECL – VL: average 10 minutes (minimum 6 ~ 14 maximum).

It is assumed that the distribution of passengers' transfer times will be binomial.

Figure 3 shows the passenger flow into one of the platforms of the NLL, calculated by the CPN-based model. In the figure, "Delay 0" shows the case when all trains arrive and depart on time, and "Delay 3" when one particular train, xx19 ECL NB, is delayed for 3 minutes. Because of the symmetry assumed in the passenger flows, the calculation results for NLL EB and NLL WB are the same.

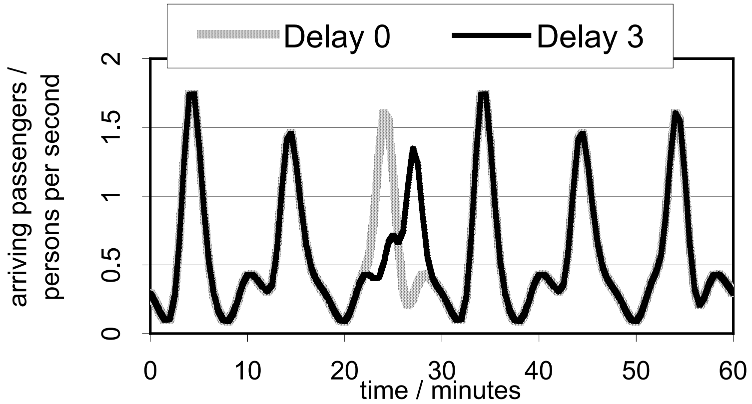

Figure 3: Calculated arrival rate of passengers at the platform for the NLL using the CPN-based model.

4 Optimisation

It is assumed that xx19 train of the ECL NB service is delayed. The following two cases of optimisation in response to this delay are considered:

(a) Adjusting the departure of NLL and ECL trains leaving the interchange after the arrival of the delayed train; and
(b) Adjusting the departure of ECL NB trains leaving the interchange before / after the arrival of the delayed train.

For both of the cases (a) and (b) above, the two passenger flows, cases 1 and 2, are to be considered, which constitutes 4 cases in total, namely cases 1(a), 1(b), 2(a) and 2(b).

Computers in Railways IX, J. Allan, C. A. Brebbia, R. J. Hill, G. Sciutto & S. Sone (Editors)

Accumulated passenger transfer times, which is the sum of walking times and waiting times of all passengers, are used as the evaluation function. Because there are frequent trains on the VL, their departure times are not adjusted in the optimisation, although their times are included in calculating the evaluation function. The optimisation algorithm used is the multidimensional downhill simplex method [4].

5 Results

Cases 1(a) and 1(b) produce results that suggest "no holding", i.e. trains should depart as scheduled, for any value of delay, because passenger numbers changing trains at this interchange are relatively limited; this means that, in the passenger flow of case 1, the accumulated disbenefit of transfer passengers missing a train because of the delay is always less than the benefit of passengers already on board being able to start faster.

The optimisation result for case 2(a) is shown in Figure 4. In this figure, the xx23 NLL WB train and the xx24 NLL EB train are the trains connecting to the delayed xx19 ECL NB train. The result suggests that:

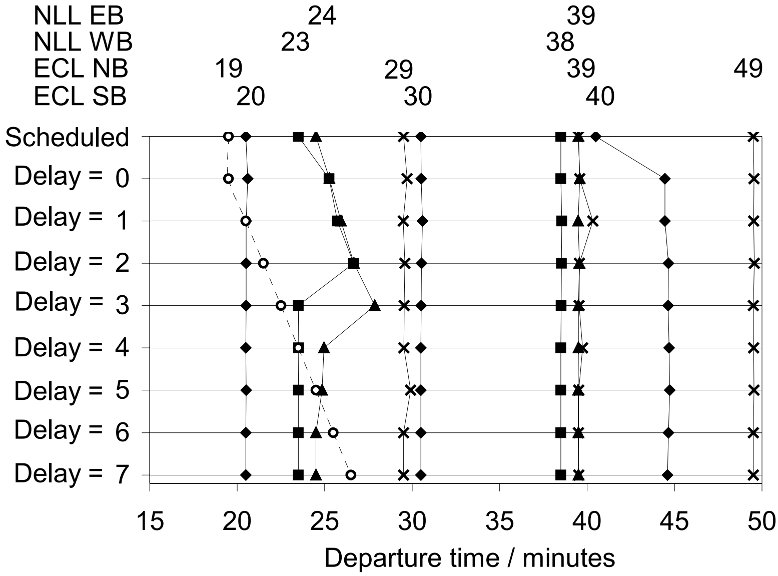

Figure 4: Optimisation result for case 2(a).

1. The trains should be held to wait for passengers wishing to connect even if there is no delayed arrival. This implies that, if passenger flow case 2 is assumed, the schedule itself is not optimal.

2. When the delay of the ECL NB train is up to 2 minutes, the amount of time that the connecting NLL trains should be held increases as the delay increases. However, when the delay is more than 4 minutes, the holding time reduces to zero, since the disbenefit of passengers already on board outweighs the benefit of connecting passengers beyond this point.

The optimisation result for case 2(b) is shown in Figure 5. The result suggests that the xx09 train should be held for nearly 4 minutes, which again implies that, if passenger flow case 2 is assumed, the schedule itself is not optimal. The xx19 train in this figure is the delayed train itself, and the result naturally suggests that the delayed train should depart as soon as possible.

For metro services, it is normally recommended to equalise the departure interval between trains. However, in this case, the result suggests no such operations; this is because:

1) The evaluation function does not include congestion inside a train, and
2) The assumption of the case is such that transfer passengers between trains outnumber those using the station locally; therefore the passenger flow into any of the platform will have high peaks, as shown in Figure 3.

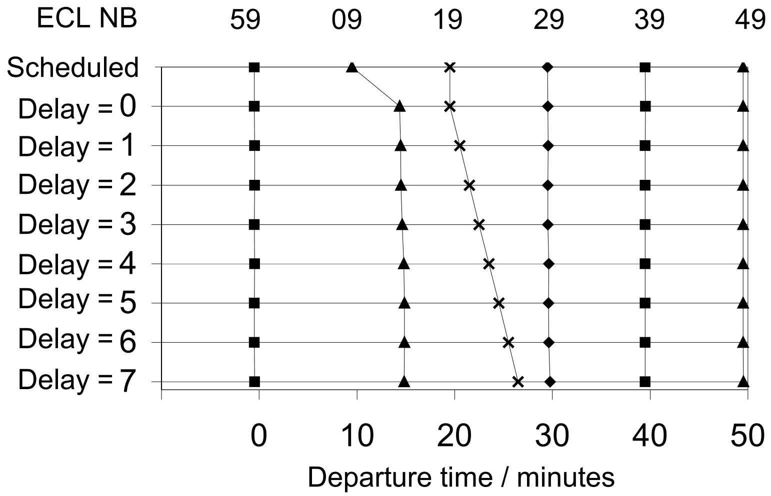

Figure 5: Optimisation result for case 2(b).

6 Conclusion

The comparison of cases 1 and 2 suggests that accurate passenger flow data is crucial in devising any sort of interchange optimisation, since relatively small differences in supposed passenger flows result in fairly large differences in the optimal solutions. In addition, the evaluation function should be modified to include congestion in the train, which can be of significant importance in disrupted conditions. Variations in dwell time should also be taken into account. These modifications should come together with a more robust optimisation algorithm that can deal with less well-behaved evaluation functions.

In practical applications, to get better optimisation results it is generally better for the line controllers to get information on the delayed arrivals of trains as quickly as possible. At such interchange stations where transfer passengers between trains outnumber those using the station locally, the options will be either “holding” or “no holding” as seen in the optimisation results of case 2(a) presented in Figure 4; in such circumstances, it will be beneficial if such information is available even before the delayed train actually arrives at the interchange.

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