APPRAISING THE BENEFITS OF REGULAR TRAIN TIMETABLES

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Abstract

Regular train timetables in which services depart at the same minutes past every hour throughout the day, preferably at even intervals, are assumed to provide benefits for passengers. They are a feature of some European railways, notably in the Netherlands, Switzerland and Germany, but little research has been conducted into how passengers value these more desirable departure patterns and their impacts on demand.

This study has conducted an SP exercise to estimate the value attached to various aspects of regular timetables, has used these results to enhance a conventional rail demand model estimated to ticket sales data and has applied the demand model to evaluate a regular timetable that has been produced for the East Coast route in Britain. Such a timetable is forecast to deliver considerable benefits that are achievable without significant increases in the resources involved in supplying train services.

Keywords: Railways; Demand forecasting; Regular train timetables; Stated preference
Topic Area: E1 Assessment and Appraisal Method w.r.t. Transport Infrastructure Projects and Transport Activities

1. Introduction and objectives

Some railway administrations, such those in the Netherlands and Switzerland, have adopted regular interval train timetables. These railway authorities regard the benefits of regularity to be self evident and have taken policy decisions without specific empirical evidence in support. Whilst it can hardly be disputed that there are benefits of regularity, there will be instances where its implementation incurs additional train operating costs and thus it is essential that the impacts on demand, for financial appraisal, or on the willingness to pay, for economic appraisal, are firmly established.

Although there has been an enormous amount of research into the valuations and demand impacts of the key timetable related service quality aspects of journey time, service frequency and interchange (Wardman, 2001; ATOC, 2002), and there is also an emerging body of evidence relating to the reliability of service delivery (Bates et al., 2001), there has been very little research into the benefits of introducing a greater degree of regularity into timetable planning. We are aware of only one empirical study in this area. It analysed variations in rail ticket sales data after the introduction of a regular timetable between London and the East Midlands (Rail Operational Research, 1995). Whilst some promising results emerged, the results were inconclusive with regard to the demand impacts.

The aims of the research reported here were to test the hypothesis that regular timetables are valued by travellers, to establish how much they are valued, to determine

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the extent to which these benefits might translate into demand increases and to evaluate the benefits of a regular timetable designed for the East Coast Main Line in Great Britain[2].

2. Background

2.1 Conventional forecasting procedure

It has long been recognised that one of the unattractive features of public transport is that, unlike car travel, cycling or walking, it is not generally possible to travel at the desired time and that the extent to which a journey can be made at the desired time depends upon the frequency of service. Public transport users either have to plan their activities around scheduled departure times, which involves inconvenience and transaction costs along with some amount of wait time, or else turn up at the departure point at random, which avoids the scheduling costs but incurs additional waiting time. Studies demonstrate that individuals are prepared to pay to achieve better frequencies and that changes in frequency impact on rail demand (ATOC, 2002).

The procedure that is widely used within the railway industry in Great Britain to forecast the effect of service quality changes is based around a composite measure of station-to-station journey time (T), service headway (H) and the number of interchanges required (I) which is termed generalise journey time (GJT). It takes the form:

$$GJT = T + aH + bI \tag{1}$$

The parameters a and b are frequency and interchange penalties respectively which convert service headway and interchange into equivalent amounts of time.

A change in service headway between the base (b) and forecast (f) period will influence the volume (V) of rail demand through its effect on GJT as:

$$\frac{V_f}{V_b} = \left(\frac{GJT_f}{GJT_b}\right)^g \tag{2}$$

The effect of changes in service headway on demand will depend upon the GJT elasticity (g) used and the proportion that service headway forms of GJT.

The forecasting procedure outlined above will assign a benefit to a more equal pattern of departures given that this reduces aH through its effect on expected schedule delay, for those with planned station arrivals, or on expected wait time, for those with random station arrivals. However, other desirable aspects of timetables are not accounted for.

2.2 Timetable patterns

Even Interval Departures

Timetables can clearly be planned so that the interval between departures is the same, whereupon the interval is equal to 60 minutes divided by the number of trains per hour. Given a uniform distribution of desired departure times across an hour, an equal interval timetable will minimise the expected waiting time on average amongst those arriving at random and will minimise schedule delay amongst those who plan their journey.

The benefits in terms of schedule delay and expected wait time are already incorporated within the forecasting procedure used in the railway industry in Great Britain and outlined above. However, we might expect additional benefits from even interval timetables. Service frequency is then easy to remember, thereby reducing transaction

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costs, and they also convey an impression of an orderly, well planned and reliable system which instils confidence and thereby encourages its use. This might be particularly important where interchange is concerned, where an even interval of connecting services reduces the risks associated with changing trains.

There are transaction cost and convenience benefits to be obtained from being able to turn up at the station at random, otherwise travellers would always plan where they are able to do so, and these benefits accrue at higher levels of frequency. It may well be that at a given level of frequency an even interval timetable is more likely to encourage the behaviour that allows these benefits to materialise. However, we must recognise that there may be those who prefer departures to be bunched close together to reduce the risks associated with late running or crowded trains.

Clockfaced Departures

This represents the repeating pattern of departures across the day. A perfectly clockfaced timetable involves departures at the same minutes past the hour every hour.

Possibly to a greater extent than with even interval timetables, clockfaced timetables convey the impression of a well planned railway which instils confidence in its efficiency and reliability and encourages use. This can be expected to be particularly important for journeys that involve interchange, and hence a greater degree of risk and uncertainty; what might be perceived to be independently planned services tend to reduce confidence in the system. If only because travellers believe that clockfacedness is a ‘good thing’, there will be some benefit in attracting new travellers and in retaining existing ones.

Clockfaced timetables also allow departures to be more easily memorised. This is not only of use in planning journeys but can also reinforce that a good level of service is offered where this is in fact the case. The memorability aspects of clockfacedness might not be of any great value to regular travellers who depart at the same time, such as commuters, but may be important for inter-urban travellers who make journeys less frequently and of greater value on the return leg of the journey where there tends to be more uncertainty about departure times and when the journey will be made. The memorability benefits may be greater where there are more trains per hour to remember.

With the exception of an hourly service, a clockfaced timetable need not be even interval, and thus the benefits accruing to memorability and reduced transaction costs are to some extent separate if not entirely independent. Given that there is little sense in an operator offering an even interval but not clockfaced timetable, the first benefit to accrue is that of clockfacedness with a subsequent benefit of even interval given clockfacedness.

Memorable Departures

Both even interval and clockfaced timetables contribute to memorability. However, some departure times are more easily remembered than others. For example, departures at 00, 15, 30 and 45 minutes past the hour may well be more memorable than departures which are on the 5 minutes but do not start on the hour, such as 5, 20, 35, and 50 minutes past the hour, which in turn can be expected to be more memorable than those departure times which are not divisible by 5, such as 8, 23, 38 and 53 minutes past the hour.

It might be argued that memorable departure times are more important as the number of trains per hour, and therefore the number to be remembered, increases. Moreover, individuals may tend to want to depart at memorable times, such as on the hour or half past, rather than uniformly across the hour as is typically assumed in procedures used to determine schedule delay.

2.3 Practical experiences of regular timetables

As a result of the decision making of railway planners and/or politicians, timetables in some European countries, notably Switzerland, the Netherlands and much of Germany, are designed with strong and sensible patterns of regular intervals, good connectivity and departures at the same time each hour. The conviction is that their consistency, memorability and ease of use are critical in creating a favourable image of rail which reaps benefits in terms of increased consumer satisfaction and ultimately increased demand.

The experience in Britain, as in most countries, is somewhat mixed. The Southern Railway introduced clockfaced, even interval timetables on its suburban and inter-urban services which coincided with its extensive electrification programme in the 1920's and 1930's. In the post war years of the nationalised British Railways, regular timetables experienced a patchy existence but were prominent on many suburban networks. Many services had regular departures from principal stations, particularly London, but lost the pattern along the route as a result of varied running times and stopping patterns. A system was perpetuated in which some services had the features of regularity, others strived after them but suffered from extensive variations and others were deliberately planned train by train.

In the immediate aftermath of privatisation, the concept of regular timetables was neglected, with timetable planning characterised by train companies bidding for paths, Railtrack having 'flexing rights' to retime trains by a few minutes in the interests of capacity, and the absence of any champion of regularity, co-ordination and connectivity. However, the weaknesses of the post-privatisation planning system, exacerbated by congestion on the network, have become increasingly apparent. Practical issues involved in developing regular timetables are discussed in detail in Tyler (2003).

3. Method

There is generally a preference amongst behavioural researchers, and particularly economists, for basing analysis on the actual decisions made in real world situations. This has over many years supported an extensive amount of rail demand research in Great Britain (ATOC, 2002). In this context, RP data might be even more preferable. SP is best suited to the analysis of choices based around a specific journey that has recently been made. In contrast, analysis of travellers' preferences towards regular timetables would have to relate to journeys made in general and then to future journeys. This would introduce a greater degree of uncertainty.

Although we do not have before and after rail demand data where there has been the introduction or removal of a regular timetable, it is possible to examine demand on different routes with varying degrees of regular timetable. However, at the outset we recognised that the chances of developing a robust model with significant and plausible estimates of the effects of regular timetables were slim. Thus SP could well have an important contribution to make in isolating the demand impact. In addition, the valuations obtained from an SP exercise would prove invaluable for cost benefit analysis. This would be appropriate in an evaluation of the full benefits of regular timetables, particularly where there was support for them because they are generally a good thing or for 'altruistic' reasons which would not directly affect behaviour.

The SP approach adopted asked rail travellers to rank in order of preference sixteen different scenarios in the context of possible future journeys. Each scenario related to a single variation upon the current situation in terms of either timetable features, journey time or fare.

The timetable scenarios to be ranked are listed in Table 1. To cover the range of timetable features, two different designs were used. They contained nine scenarios, with those based around hourly service frequency and the current timetable common to both. In addition to the nine timetable scenarios, respondents also had to evaluate four journey time reductions of 2, 5, 10 or 15 minutes and three fare reductions of either 50 pence, £1, and £2, or £1, £2.50 and £4.

Table 1: Timetable Scenarios Used In SP Exercise

Scenario	Timetable	Clock	Mem	Design	GJT-H
TT1	4 per hour, even interval, 00 15 30 45	Yes	Yes	1	14.2
TT2	4 per hour, uneven interval, 00 05 30 35	Yes	Maybe	1	18.0
TT3	4 per hour, even interval, 08 23 38 53	Yes	No	2	14.2
TT4	4 per hour, uneven interval, 08 16 40 51	Yes	No	2	15.5
TT5	4 per hour, varies across day	No	No	2	15.2
TT6	2 per hour, even interval, 00 30	Yes	Yes	1	22.6
TT7	2 per hour, uneven interval, 00 10	Yes	Maybe	2	25.4
TT8	2 per hour, even interval, 08 38	Yes	No	1	22.6
TT9	2 per hour, uneven interval, 08 23	Yes	No	2	23.9
TT10	2 per hour, varies across day	No	No	1	22.9
TT11	1 per hour, 08	Yes	No	Both	31.2
TT12	1 per hour, 00	Yes	Yes	Both	31.2
TT13	1 per hour, varies across day	No	No	Both	31.2
TT14	Timetable as now				

Three sets of service frequency of 1, 2 and 4 trains per hour were offered in order to value different levels of frequency per se and also to enable analysis of whether preferences towards clockfacedness, even interval departures and memorability are influenced by the level of frequency.

Starting with the most frequent services, TT1-TT4 all provide clockfaced timetables involving four trains per hour. TT1 represents an even interval, clockfaced and memorable timetable whilst TT3 removes the aspect of memorability. TT2 and TT4 have unequal intervals, with TT2 representing what might be regarded to be a memorable set of departures but less memorable than TT1. TT5 represents four trains an hour but without the clockfaced, memorable or even interval features.

Scenarios TT6-TT10 all relate to two trains per hour, and with the exception of TT10 they are clockfaced. TT6 and TT8 are even interval timetables, with the former having memorable departure times. Of the two uneven interval timetables, it is open to empirical testing whether TT7 possesses any memorability benefits.

Three scenarios cover one train per hour. TT11 and TT12 are both clockfaced but differ in terms of memorability. Given that clockfacedness implies even intervals when there is only one train per hour, the number of scenarios to be considered is here reduced. TT13 varies the departure times of the single train per hour. The final scenario specifies the timetable to be as it is now.

Whether the scenario is clockfaced, memorable or even interval is indicated in Table 1. In addition, the final column indicates the penalty in time units (GJT-H) assigned to each timetable as part of the GJT term within the demand forecasting procedure widely used in the rail industry in Britain (ATOC, 2002). This figure is determined by the amount of schedule delay and a planning penalty for those with planned arrivals and the expected waiting time, valued at twice in-vehicle time, for those with random arrivals. The proportion arriving at random varies with the level of frequency. It can be seen that the penalty is lower when the timetable is even interval, as well as when the service is more frequent, but that there is no difference according to the other timetable features.

The inclusion of this time penalty (GJT-H) allows us to identify whether there are any benefits to even interval services over and above those attributed using the standard procedure alongside the estimation of the additional benefits of clockfacedness and memorability.

There are obviously many different degrees of non-clockfacedness and ideally more detail on the precise timetable involved should be given when the timetable varies across the day. However, the survey process, strongly influenced by resource constraints, meant that the latter was not a practical option. Additionally, a range of other timetables with specific features could have been examined. For example, we could have specified: clockfacedness for varying parts of the day or as a subset of all departures; bunching of services, which might be attractive to risk averse travellers; more extensive forms of memorability; the inclusion of prima donna services and peak supplements; different frequencies by time of day and varying running times across departures. Our view was that it was sufficiently challenging within the survey method to be used to examine the range of relatively straightforward timetables set out in Table 1, and that examination of these would in any event constitute a substantial contribution to understanding in this area.

4. Stated preference results

Given resource limitations, the SP exercise was administered as a self completion questionnaire amongst rail travellers. Surveys were conducted on GNER's services between York and London and between Leeds and London, and also on Virgin Cross Country services between Leeds and Birmingham. The survey was piloted on 29th November 2002 and, after some modifications, the main survey was conducted in early December 2002. In total 2490 questionnaires were distributed and 2223 (89%) were returned which contained some information. For SP modelling purposes, 1368 (55%) had at least part completed the SP exercise with 1168 (47%) providing a complete ranking.

The exploded logit model has been used to estimate the importance attached to each attribute from the rank orderings supplied (Chapman and Staelin, 1982). This treats the first ranked alternative as a choice for that alternative from the full set of sixteen, the second ranked alternative as a choice for that alternative from amongst the remaining set of fifteen, and so on until the ranking is exhausted.

The repeat sampling jack-knife procedure (Cirillo et al., 2000) has been used within the ALOGIT software package (Hague Consulting Group, 2000) to correct the standard errors of estimated coefficients to allow for error correlation amongst the multiple choice observations per person.

We have developed models that account for the frequency component of GJT, which is reported in the final column of Table 1 (GJT-H), and which specify variables to denote the additional benefits of whether the timetable is clockfaced (*CLOCK*) and memorable (*MEM*) and to discern any unaccounted for benefits of even interval (*EVEN*).

Models for business travel are reported in Table 2. All the coefficients are of the correct sign and are significant at the usual 5% level. The term Cost-In is an incremental effect for those who were asked to consider the timetable features for the inbound journey. It seems that they have not considered cost to the same extent as those who evaluated the timetable features for the outward journey. This may be because typically return tickets are used and these would have been purchased prior to the return journey whereupon the cost variations could have been neglected. Surprisingly, there were no other clearcut differences in parameters according to whether the outward or return leg had been considered.

The GJT-H variable expresses the frequency penalty in equivalent units of time and therefore its coefficient ought to be broadly similar to the time coefficient. It is encouraging that the two coefficients are not very dissimilar: unless the SP responses were of at least reasonable quality, there is no reason why the two coefficients should be remotely similar. No significant coefficients were estimated for frequency over and above the effect assigned by GJT-H.

The even interval hourly departure is the same as an hourly clockfaced timetable and hence additional terms were specified to determine whether there were any benefits of even interval over and above those covered by GJT-H. The coefficients estimated to even interval departures for two and four trains an hour were very similar and hence combined into a single term (*Even2_4*). This indicates a relatively strong additional benefit from even interval timetables.

Table 2: Business Models

	Model I		Model II	
	Coeff (t)	Value (t)	Coeff (t)	Value (t)
GJT-H	-0.073 (9.3)	1.35 (8.5)	-0.082 (10.8)	1.52 (9.6)
Time	-0.054 (21.1)	38.6 (3.3)	-0.054 (21.4)	38.57 (3.6)
EVEN2_4	0.416 (6.9)	7.70 (6.6)	-	-
CLOCK1	0.268 (3.5)	4.96 (3.5)	0.291 (3.7)	5.39 (3.6)
CLOCK2	0.373 (7.0)	6.91 (6.6)	0.538 (12.1)	9.96 (10.5)
CLOCK4	0.555 (9.5)	10.28 (8.7)	0.634 (11.3)	11.74 (10.0)
MEM1	0.109 (2.2)	2.02 (2.2)	0.109 (2.2)	2.02 (2.2)
MEM2_4	0.357 (6.0)	6.61 (5.8)	0.309 (5.3)	5.72 (5.1)
Cost	-0.0014 (3.5)	-	-0.0014 (3.6)	-
Cost-In	0.0010 (1.9)	-	0.0010 (2.0)	-
ρ^2	0.113		0.111	

Note: Values are in equivalent units of time, except for time which is a monetary value

The value of clockfaced timetables depends upon whether there is one (*CLOCK1*), two (*CLOCK2*) or four (*CLOCK4*) trains per hour with a monotonic increasing effect. As for memorability, there was a significant value for a single train per hour (*MEM1*) and higher but insignificantly different values for two and four trains per hour (*MEM2_4*).

Model II examined the impact of removing the allowance for the even interval effect on the grounds that it could be argued that GJT-H ought to discern the majority of this effect. Not surprisingly given that there is a degree of association, the result is that the even interval benefit is transferred to the clockfaced variables whose coefficients experience some relatively large increases. There is also an impact on the GJT-H coefficient of the expected form.

Table 3 reports the models estimated to leisure travellers. All the reported coefficients in Model I are right sign and only the memorability coefficient for one train per hour (*MEM1*) was not statistically significant and was therefore removed. The benefits of clockfaced timetables for 2 and 4 trains per hour were very similar and insignificantly different and hence the two terms have been combined (*CLOCK2_4*). The same is true of memorability (*MEM2_4*).

We again observe that there is a tendency for the benefits of even interval timetables, clockfacedness and memorability to increase as the service frequency increases and in this instance there is a very close correspondence of the GJT-H and time coefficients.

Model II additional specifies terms for whether there were two (*FREQ2*) or four (*FREQ4*) trains per hour. According to a likelihood ratio test, the estimated χ^2 of 12.6 is far greater than the tabulated value for two degrees of freedom. Nonetheless, we are inclined to prefer Model I since the inclusion of the two frequency term has dramatically impacted upon the GJT-H coefficient and the latter is consistent with the time coefficient in Model I, as it should be, but somewhat different and indeed not statistically significant in Model II. Model III again removes the even interval variables, and again the clockfacedness variables discern some of the effect previously attributed to them.

Table 3: Leisure Models

	Model I		Model II		Model III	
	Coeff (t)	Value (t)	Coeff (t)	Value (t)	Coeff (t)	Value (t)
GJT-H	-0.047 (7.5)	0.96 (7.1)	-0.019 (1.5)	0.39 (1.5)	-0.052 (9.3)	1.06 (8.6)
Time	-0.049 (21.7)	9.07 (10.4)	-0.049 (22.0)	9.07 (10.3)	-0.049 (21.8)	9.07 (10.1)
EVEN2	0.227 (3.2)	4.63 (3.2)	0.294 (3.5)	6.00 (3.5)	-	-
EVEN4	0.422 (6.4)	8.61 (6.1)	0.478 (6.4)	9.76 (6.1)	-	-
CLOCK1	0.145 (3.2)	2.96 (3.2)	0.146 (2.9)	2.97 (2.9)	0.168 (3.7)	3.43 (3.6)
CLOCK2_4	0.339 (5.9)	6.92 (5.7)	0.275 (4.2)	5.61 (4.1)	0.438 (9.1)	8.94 (8.4)
MEM2_4	0.127 (2.4)	2.59 (2.4)	0.097 (2.0)	1.98 (2.0)	0.107 (2.2)	2.18 (2.2)
FREQ2	-	-	0.246 (2.5)	5.02 (2.5)	-	
FREQ4	-	-	0.499 (2.6)	10.18 (2.6)	-	
Cost	-0.0054 (11.3)	-	-0.0054 (11.6)	-	-0.0054 (11.4)	
Cost-In	0.0022 (3.6)	-	0.0021 (3.6)	-	0.0022 (3.6)	
ρ^2	0.099		0.099		0.097	

Note: Values are in equivalent units of time, except for time which is a monetary value

Overall, the results that have been obtained are reasonable and precisely estimated; we would not expect to obtain high values for timetable related features. The estimated values of time are plausible and there is an encouraging degree of similarity between the time and GJT-H coefficients.

The most striking feature of the results is that the even interval, clockfaced and memorability benefits increase as the number of trains per hour increases. This does not seem to be the discernment of the benefits of improved frequency since the correlations between the coefficient estimates relating to timetable features and the frequency coefficients when the latter were entered were not high. Indeed, the inclusion of the frequency variables had little impact on the coefficient estimates other than GJT-H.

For both business and leisure travel, a slightly better fit was obtained when scenarios TT2 and TT7 were defined as memorable. Thus memorability here covers all timetables that have departure times divisible by 5. The value increases with the number of departures, presumably because it is more difficult to remember departure times as the number of departures increases. Additionally, respondents may simply feel that as more trains per hour are offered it increasingly makes sense to provide them at memorable times. There is also the issue that individuals do not want to depart at times uniformly distributed across the hour but instead want to depart at the more memorable times. Therefore the more departures that are offered at memorable times then the more the coincidence between actual and desired departure times and the lower is scheduled delay.

The increasing value of clockfaced and even interval timetables as frequency improves may also stem from the greater difficulty of otherwise remembering more departure times. Again, there may also be a feeling that it makes increasingly more sense to have clockfaced and even interval timetables as frequencies are improved. The argument that clockfacedness reinforces that a good level of service is offered might also contribute to the larger benefits at higher frequency.

As far as even interval timetables are concerned, the benefits could increase with frequency since the benefits that can be obtained from random arrivals at stations that accrue to high frequencies may be stimulated more if the departures are even interval. To the extent that the current GJT formulation understates the benefits to even interval timetables as frequency increases, there will be a compensating effect of the form observed in Table 3. If the GJT approach understates the values of schedule delay or wait time, it could also explain why, at least in the leisure model, significant frequency benefits over and above those attributed by GJT-H were estimated.

5. Modelling effect on rail demand

We have developed cross-sectional models of rail demand to ticket sales data for the financial year 1999/2000. The data covers 10324 inter-urban flows of over 40 kilometres. In addition to variables representing the generating potential of origin stations, the attracting potential of destination stations and the attractiveness of the rail services between stations, terms were specified to represent the clockfacedness and memorability of the timetable.

A clockfaced index (CI) was specified as a function of the rounded up integer value of paths per hour (PPH) and the number of different departure times (NDDT):

$$CI = \frac{PPH}{NDDT} \tag{3}$$

where:

$$PPH = \frac{NT - 1}{SS} \tag{4}$$

NT is the number of trains and SS is the service span in hours. The purpose of subtracting one is to make the index less sensitive to the inclusion of a prima donna service which strictly speaking breaks a clockfaced pattern.

CI will be 1 for a perfect clockfaced timetable or one where there is a single departure deviation from it. Its minimum value is driven by the service span. For an 18 hour service span and the maximum of 60 different departure times provided by the minimum of 60 departures gives a CI index of 0.066. The memorability index (MI) was simply specified as the ratio of the total number of memorable departures, however defined, and the total number of departures, and ranges between 0 and 1.

The key issue with cross-sectional models is the adequate specification of the station catchment areas since these fundamentally influence the magnitude of trips between stations around which there is variation due to changes in the attractiveness of rail. We have done this by specifying dummy variables to represent the trip generating potential of origin stations and the trip attracting potential of destination stations. This model expresses the volume of rail demand between two stations (i and j) as:

$$V_{ij} = \mu e^{\sum_{i=1}^{p-1}\gamma_i O_i \sum_{j=1}^{q-1}\delta_j D_j} GC_{ij}^{\omega} \qquad (5)$$

The O_i and D_j are dummy variables for all but one of the p origin stations and all but one of the q destination stations respectively, and GC_{ij} denotes the generalised cost of rail travel between i and j. Whilst this model tells us little of the factors which generate and attract trips, this need not concern us here. Although the results are not readily transferable to forecast demand at stations for which generation and attraction terms have not been specified, these are not problems if we are concerned primarily with the elasticities to the other elements of the demand model such as timetable features or, as here, if our origin and destination variables cover all the stations to be included at the appraisal stage.

A composite generalised cost (GC) is specified because of the high correlation between generalised journey time (GJT) as defined in equation 1 and fare (F). GC is here defined as:

$$GC_{ij} = F_{ij} + \upsilon(GJT_{ij} - \varphi CI_{ij} - \phi MI_{ij}) \qquad (6)$$

GJT has here effectively been extended to cover the timetable related factors of clockfacedness and memorability, each weighted by their time valuation obtained from the SP exercise. The parameter υ is the value of time and converts the service quality elements which are expressed in units of time into equivalent monetary amounts. There is no reason in principle why CI and MI cannot be removed from the GC term and separate coefficients estimated to them.

GJT for each flow was obtained from the MOIRA system and provided to us by ATOC. The values of time used were obtained from a large scale review reported in Wardman (2001) with appropriate weighting on London and Non-London flows to allow for the different mixes of business and leisure travel. The same purpose weightings were applied to the values of clockfacedness and memorability estimated for business and leisure travel. These were taken from Model I of Table 2 for business and Model I of Table 3 for leisure. We have not included any additional benefits for even interval timetables over and above that which would be attributed by GJT.

The estimated models are reported in Table 4 both with and without the timetable feature indices. The inclusion of CI and MI reduces the GC elasticity although only slightly. The impact is slight because the proportion of GC accounted for by CI and MI is very small, on average less than 1%.

The GC elasticity is around -1.6 which is reasonable given fare and GJT elasticities are both typically found to be around -0.9 on these routes (ATOC, 2002). The models which include CI and MI provide a slightly better fit than the models which do not contain them. Although the improvement is very small, this is hardly surprising given that the CI and MI terms form such a small proportion of GC, whilst any improvement in fit is certainly preferable to a deterioration.

Table 4: Ticket Sales Demand Models

	Without CI/MI	With CI/MI
GC	-1.615 (145.3)	-1.605 (145.4)
Adj R^2	0.7992	0.7993

Some experimentation with free estimation of elasticities to CI and MI has also been undertaken. This revealed, as with the SP analysis, that the best definition of memorability was that where departure times were divisible by 5 minutes. We also experimented with different specifications of clockfacedness, including the creation of dummy variables to denote whether a timetable was clockfaced or not depending upon threshold values of CI of 0.5 or 0.95, but the use of the continuous variable provided the best fit.

The situation on London flows is not straightforward, since these are the largest flows and also tend to have clockfaced and memorable departures. Analysis was therefore conducted on Non London flows. Using the dummy variable model, this obtained a coefficient for CI which was not far removed from significant (t=1.8) and which marginally improved the fit. It estimated that a perfect clockfaced timetable would increase demand by around 12% compared to an essentially random set of departures. Whilst this figure is on the high side, these initial results indicate that further analysis might prove fruitful.

6. Illustrative demand impacts

Table 5 uses the results of the model reported in Table 4 to illustrate the demand increases that would be forecast to result from various timetable improvements. These improvements are based around the scenarios contained in Table 1 which were used in the SP exercise. For one, two and four trains per hour, the impact of clockfaced, even interval and memorable timetables are forecast. The clockfaced and memorability benefits are those estimated by our SP models whilst the benefits of even interval timetables are those which are attributed by GJT. We have not used any of the SP evidence relating to even interval timetables.

Forecasts are produced for a range of different journeys since the impact of the timetable improvement will depend on the proportion it forms of GC. For one and two trains an hour, the journey times are one, two and three hours. For four trains per hour, the journey times are half an hour and an hour since it is only usually on shorter distance flows where frequencies are so high.

The initial scenario is where there is no particular pattern to the timetable. This determines a base level of GC given the headway penalty outlined in Table 1, the time and fare specified, and the value of time. The initial improvement is to provide a clockfaced timetable, followed by an even interval clockfaced timetable and finally adding memorability.

The impact on the demand forecasts of the proportion that the change in GC forms of the level of GC is quite clear. In general, the timetable improvements have relatively small impacts on demand, but they can be large where the fare and journey time are low. However, should the benefits of regular timetables be included in evaluation, particularly those associated with clockfacedness, they would provide worthwhile additional benefits

The impact of clockfaced departures far exceeds that of memorability. This is to be expected given the difference in the valuations of these two aspects of timetables. However, what is noticeable is the small impact from even interval timetables, somewhat smaller even than memorability. This raises the question of whether in fact the results in Tables 2 and 3 for even interval are in fact discerning a benefit that is not being covered by GJT.

Table 5: Illustrative Demand Forecasts

Time	Head	Fare	GC	Clock	GC	%ΔV	Even	GC	%ΔV	Mem	GC	%ΔV
60 120 180	31.2 31.2 31.2	1000 2000 3000	2368 4570 7013	08	231 4 450 9 694 5	3.8% 2.2% 1.6%	00	2314 4509 6945	0.0% 0.0% 0.0%	00	230 5 449 9 693 3	0.6% 0.4% 0.3%
60 120 180	22.9 22.9 22.9	1000 2000 3000	2243 4429 6855	08 23	213 9 431 1 670 4	7.8% 4.4% 3.6%	08 38	2119 4289 6680	1.5% 0.8% 0.6%	00 30	206 2 422 4 660 7	4.5% 2.5% 1.8%
30 60	15.2 15.2	500 1000	1133 2128	08 16 40 51	102 2 200 9	18.0% 9.7%	08 23 38 53	1003 1989	3.1% 1.6%	00 15 30 45	949 193 2	9.2% 4.8%

Note: The value of time used depends on distance and values corresponding reasonably to the journey time have here been used. These are averages across business and leisure travel and were 14, 15, 17 and 19 pence per minute for the four journey times used of 30, 60, 120 and 180 minutes. A split of 30% business travel and 70% leisure travel is assumed.

7. Appraisal results

The final part of this study was to develop a regular timetable for the East Coast route and connecting services and to evaluate the benefits of introducing such a timetable. A more detailed discussion of the appraisal can be found in Shires et al. (2003).

The East Coast Main Line [ECML] runs from Edinburgh Waverley through Newcastle upon Tyne, York, Doncaster and Peterborough to London Kings Cross. At Doncaster it is joined by the line from Leeds. The ECML itself is electrified throughout, but it is also used by many diesel-operated services. These include the High Speed Trains [HSTs] built in the late 1970s and providing through services between the north of Scotland and London, and modern sets on the cross-country route that shares the ECML north of York and then diverges to serve Sheffield, Birmingham and western and southern England. There are associated local services in North East England and Yorkshire and regional trains sharing and crossing the route, and at the southern end an intensive service of electric multiple-units operates in the London suburbs.

The present timetable has been developed incrementally over many years, and it is generally accepted that it does not make optimal use of paths or rolling stock and that it does not represent the best possible service-offer for customers. Occupation of some two-track sections and a number of junctions is close to their capacity, but engineering solutions will mostly be expensive and take time to build. The route was therefore an obvious choice for the case-study of a different approach to timetabling that could yield useful benefits in the immediate future.

The exercise was based on the Swiss *Taktfahrplan* concept. Its key features are:

- the hierarchy of services (eg. long-distance inter-urban / regional / local) and their respective stopping patterns are designed from first principles in accordance with evidence of demand;
- the construction of the timetable emphasises connectivity between all the component services rather than each being planned on a largely self-contained basis - this is achieved by arranging as far as possible for trains to arrive at key

interchanges in a logical sequence from the local to the principal and to depart in the reverse order;

- the timetable in one direction is the mirror-image of the timetable in the other;
- frequencies are as high as can be justified for each service and where two or more share a route they are spaced at as even an interval as is possible;
- the standard pattern developed in this way repeats itself through every hour of the day (in some cases with additional peak-hour trains).

The test timetable was constructed with the aid of the Swiss *Viriato* timetabling software, which was purpose-designed for this approach and which is used extensively by the Swiss Railways and a number of other administrations in Europe. It is effectively a decision-support tool that enables the planner to seek the best practicable arrangement of services relative to each other (see Figure 1).

The objective of a *Taktfahrplan* is to so arrange the timings of trains (by good planning and engineering) that their closeness to the ideal at each node is in proportion to the importance of the connections there. Note that each pair of minutes-past-the-hour times sums to 60 in a perfectly symmetrical scheme.

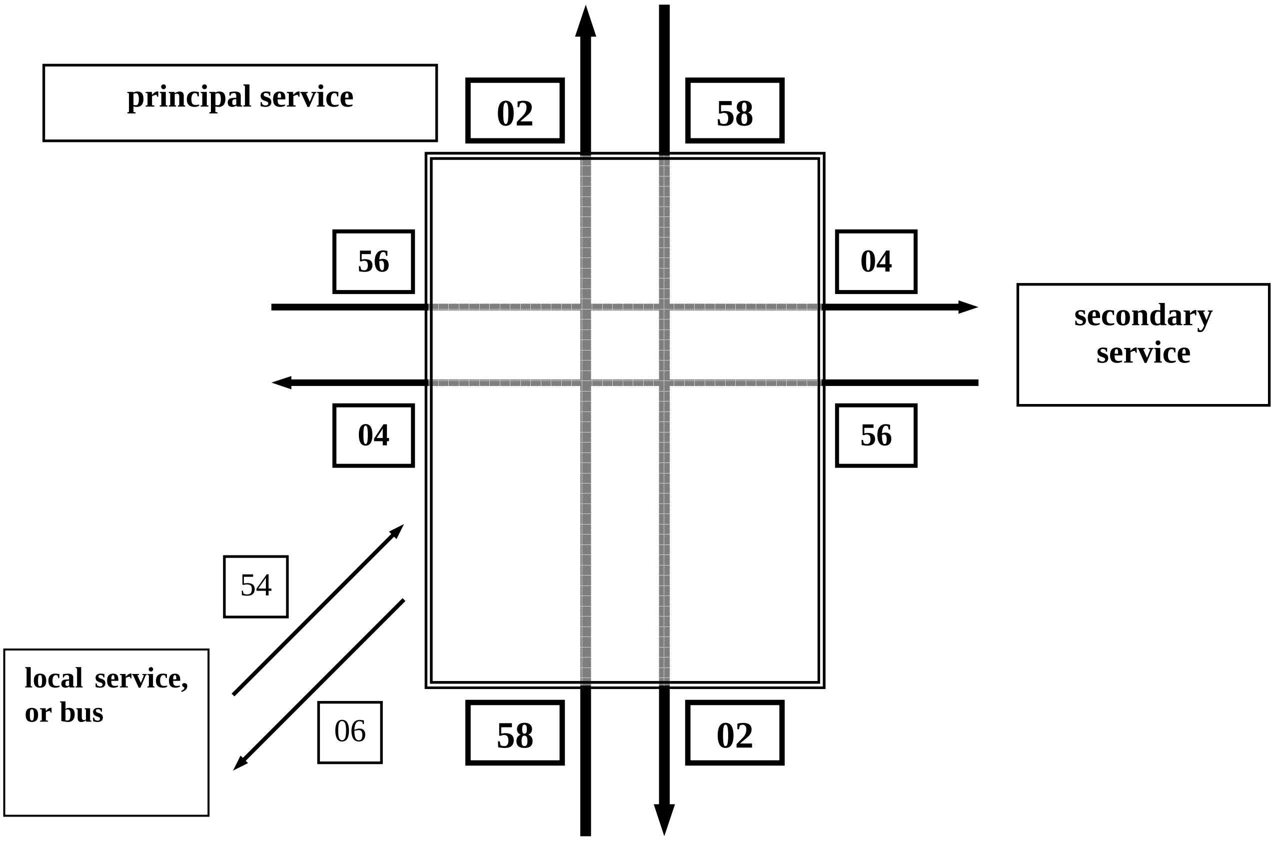

Figure 1: The Ideal Pattern of Service at a Key Node

Unlike the present timetable, which suffers from an almost complete lack of pattern, the *Taktfahrplan* is strongly patterned, with a system of standard and operationally-robust paths and well-organised connections between services. The result is that for almost all relations (station-pairs) a simple repeating cycle of well-spaced opportunities to travel would replace a timetable that has irregular intervals, differs every hour and is unmemorable. Some long-distance relations might have a slightly longer mean journey time because a mix of 'prima donna' extra-fast trains and rather slower trains would be replaced by a more consistent scheme, but it was found that many shorter relations on the main line and nearly all relations requiring interchange between ECML trains and regional and local services would benefit from faster mean journey times, enhanced frequencies (without extra rolling stock being needed), better interchange arrangements and a more attractive and more marketable offer.

The appraisal results are outlined in Tables 7 to 8 using disaggregate UK values. The appraisal differentiates between the type of road where traffic is being diverted from or to, and also uses specific bus cost and revenue data per bus kilometre to work out the change in bus costs and revenues. The external costs for these road types were obtained from a previous study (Sansom et al 2001). This appraisal approach is very data intensive and has therefore been undertaken only for the top ten London flows and the top ten Non London flows according to passenger volume. These flows are listed in Table 6. In estimating the overall benefits of the new timetable, average non-use values per passenger kilometre based upon the route level analysis have been calculated and added to the change in use benefits (change in rail consumer surplus) and the change in financial impacts (change in rail revenue) to complete the aggregate appraisal.

Table 6: Routes Selected for Appraisal (in order of passenger flow)

London Routes	**Non-London Routes**
Leeds-London	York-Leeds
Newcastle-London	Leeds-York
London-Edinburgh	Newcastle-Edinburgh
London-Leeds	Newcastle-York
London-Newcastle	Darlington-Newcastle
York-London	Edinburgh-Newcastle
Edinburgh-London	Doncaster-Leeds
London-York	Scarborough-York
Doncaster-London	Hull-Leeds
Darlington-London	York-Edinburgh

It is interesting to note that in terms of the change in rail passenger trips the move towards a *Taktfahrplan* appears to be very beneficial for ten largest non-London flows (9 of the 10 routes experience an increase in passenger trips) and less beneficial for the ten largest London flows (6 of the 10 routes experience a reduction in passenger trips). This may reflect the greater variability of current regional flows and that the *Taktfahrplan* tends to reduce the number of services for certain London based flows compared with current levels. In particular, the long distance London based flows seem to be particularly adversely affected (Edinburgh and Newcastle) compared to those under 200 miles (Leeds, Doncaster and Peterborough). This is because on average trains on these very long distance routes have more stops.

The impact of environmental benefits tends to be overshadowed by the impacts arising from congestion and rail user benefits. Within the latter the three major impacts are the changes to rail passenger consumer surplus, car congestion and rail revenues. In two of the London flows very large positive changes in consumer surplus have compensated for the fall in passengers to return a positive overall total.

Changes to rail revenue and car congestion are particularly influential for the appraisal of London based flows where fares are higher and journeys longer.

Table 7: Appraisal Results for Non-London Flows

Impact	York-Edinburgh	Hull – Leeds	Scarborough-York	Doncaster-Leeds	Edinburgh-Newcastle	Darlington-Newcastle	Newcastle-York	Newcastle-Edinburgh	Leeds-York	York-Leeds
Change in Rail Passenger Trips	-1,870	17,221	12,440	21,724	12,432	23,953	16,501	20,221	70,518	76,992
1. The Environment										
1.1 Noise	-66	45	94	52	240	54	185	393	344	376
1.2 LAQ	-1,062	1,475	1,518	1,209	3,874	1,402	3,433	6,339	5,595	6,109
1.3 Greenhouse Gases	-376	1,050	538	695	1,373	880	1,532	2,246	2,015	2,200
Safety	-4,130	3,042	5,901	3,339	15,063	3,495	11,736	24,647	21,587	23,569
Total	-5,634	5,611	8,050	5,295	20,551	5,831	16,886	33,625	29,542	32,255
2. Modal Shift & The Economy										
2.1 User Benefits										
Rail – GC	108,590	158,510	66,175	173,971	140,628	184,433	179,642	327,315	304,067	367,980
Car – Congestion	-33,281	23,785	47,553	26,541	121,391	27,636	94,140	198,619	173,919	189,886
Bus – Congestion	-2,376	3,139	3,395	2,624	8,666	3,021	7,584	14,179	12,506	13,654
2.2 Private Transport Providers										
Rail Revenues	-21,961	52,026	27,188	35,725	93,183	44,397	68,271	136,989	128,625	137,315
Rail Costs	0	0	0	0	0	0	0	0	0	0
Rail Profits	-21,961	52,026	27,188	35,725	93,183	44,397	68,271	136,989	128,625	137,315
Coach Revenue	6,701	-16,739	-12,848	-21,116	-33,230	-20,372	-35,085	-54,051	-59,976	-65,482
Coach Costs	-8,537	24,407	12,198	16,068	31,138	20,401	35,113	50,948	45,758	49,959
Coach Profits	-1,836	7,668	-650	-5,048	-2,092	29	28	-3,103	-14,218	-15,523
2.3 Government										
Indirect Tax	11,029	-31,533	-15,759	-20,758	-40,228	-26,357	-45,364	-65,822	-59,118	-64,545
Rail Subsidy	0	0	0	0	0	0	0	0	0	0
Total	60,166	213,596	127,902	213,055	321,546	233,160	304,302	608,176	545,782	628,768
Overall Total	54,532	219,207	135,953	218,349	342,096	238,990	321,188	641,800	575,324	661,023

Table 8: Appraisal Results for London Flows

Impact	Doncaster-London	Darlington-London	London-York	Edinburgh-London	York-London	London-Newcastle	London-Leeds	London-Edinburgh	Newcastle-London	Leeds-London
Change in Rail Passenger Trips	34,794	11,067	-3,592	-29,874	-5,370	-13,923	55,319	-49,096	-4,456	72,463
1. The Environment										
1.4 Noise	113	128	-111	-356	-166	-511	149	-581	-229	2,660
1.5 LAQ	7,040	4,082	-1,914	-15,734	-2,861	-9,303	12,138	-2,5804	-3,696	48,416
1.6 Greenhouse Gases	6,190	2,878	-768	-12,668	-1,148	-4,053	11,209	-20,799	-1,309	21,096
Safety	8,492	8,559	-6,983	-24,941	-10,441	-32,303	11,901	-40,777	-14,370	168,115
Total	21,835	15,647	-9,775	-53,698	-14,616	-46,170	35,397	-87,961	-19,604	240,286
2. Modal Shift & The Economy										
2.1 User Benefits										
Rail – GC	522,047	251,879	-77,035	-728,378	263,135	-360,647	1,284,256	-1,514,559	169,636	1,273,108
Car – Congestion	63,350	6,707	-56,152	-191,228	-83,958	-259,272	86,402	-312,568	-115,800	1,349,350
Bus – Congestion	14,628	8,698	-4,253	-33,048	-6,360	-20,580	25,060	-54,190	-8,267	107,106
2.2 Private Transport Providers										
Rail Revenues	501,840	174,932	-57,657	-428,037	-89,676	-229,772	967,465	-738,700	-67,180	1,177,272
Rail Costs	0	0	0	0	0	0	0	0	0	0
Rail Profits	501,840	722,481	-57,657	-428,037	-89,676	-229,772	967,465	-738,700	-67,180	1,177,272
Coach Revenue	-95,119	-45,046	12,873	130,669	19,247	56,672	-151,227	214,746	18,137	-198,096
Coach Costs	144,612	66,908	-17,515	-295,417	-26,188	-92,815	262,120	-485,061	-29,704	483,044
Coach Profits	49,493	13,408	-4,642	-164,748	-6,941	-36,143	110,893	-270,315	-11,567	284,948
2.3 Government										
Indirect Tax	-186,832	-86,441	22,628	381,663	33,833	119,912	-338,645	626,673	38,376	-624,067
Rail Subsidy	0	0	0	0	0	0	0	0	0	0
Total	964,527	437,938	-177,111	-1,163,775	110,034	-786,501	2,135,431	-2,263,659	5,198	3,567,716
Overall Total	986,362	453,585	-186,886	-1,217,474	95,418	-832,671	2,170,828	-2,351,620	-14,406	3,808,003

A less data intensive appraisal was then carried out for all the 360 flows using average UK values. The results from the forecasting work show that in the majority of cases the introduction of a Taktfahrplan would result in an increase in passenger volumes on both the London (76%) and non-London flows (77%). This is reflected in the aggregate appraisal which finds a positive outcome for 85% of the London flows and 82% of the non-London flows

The aggregate appraisal results are presented in Table 9. They indicate that the introduction of a *Taktfahrplan* would result in overall benefits of £15.6 million for non-London services and £7.2 million for London based services. In each case positive changes were found for user benefits, revenue and non-user benefits. For London flows the increase in revenue was equivalent to 2% of the current base revenue and for non-London flows the increase in revenue was 10% of the current base revenue.

Table 9: Aggregate Appraisal Results (£'s)

Route Type (number of Services)	User Benefits	Revenue	Non-User Benefits	Total
Non-London (314)	8,607,328	3,357,246	3,619,836	15,584,408
London (46)	3,746,527	3,052,665	416,917	7,216,109

In order to see the impact on rail demand from a simple operations point of view following the introduction of a *Taktfahrplan*, the demand model was re-run but with the 'Takt' indices relating to clockfacedness and memorability set to zero. In Table 10, the demand and revenue for the 'with Takt' and 'without Takt' models are presented for the top 10 London and Non London flows. As expected, the removal of the Takt benefits reduces the demand forecasts. Demand falls by 43% on Non London routes whilst revenues are reduced by 48%. For London services the equivalent figures are considerably larger at 105% and 92% respectively. Nonetheless, the introduction of the *Taktfahrplan* still results in demand and revenue growth on both sets of flow.

Table 10: Top 10 London and Non-London Flows With and Without Takt Values

	'With Takt Values' Change In		'Without Takt Values' Change In		Difference 'With Takt – Without Takt'	
	Demand	Revenue	Demand	Revenue	Demand	Revenue
Non London	270,132	701,758	153,221	362,552	116,891	339,206
London	67,332	1,210,487	-3,320	99,045	70,652	1,111,442

8. Conclusions

Although the research reported here was ambitious in nature, and has dealt with quality improvements that are inherently difficult to represent and value, some interesting results have emerged from a novel application of SP methods. The valuations of clockfacedness and memorability produced by the SP exercise seem reasonable, whilst the results obtained for even interval timetables suggest that the current procedure used in Britain may be underestimating this benefit.

The SP values have been used to enhance the conventional form of rail demand model used in Britain and in turn this has been used to forecast the effect on demand of more regular timetables for a range of situations. Not surprisingly, the demand impacts will generally be relatively small, although they would be welcome additional benefits in the evaluation of a regular timetable. However, there remains an urgent need to determine through closely controlled monitoring the effect on demand of the actual introduction of regular timetables.

A regular timetable has been produced for the East Coast Main Line and connecting services in Great Britain. Patronage and revenue forecasts have been made for 360 O/D pairs. The results show that in the vast majority of cases the introduction of a *Taktfahrplan* has resulted in an increase in passenger flows on both the London (76%) and non-London flows (77%). An aggregate appraisal found that the introduction of a *Taktfahrplan* would result in overall benefits of £15.6 million for non-London services and £7.2 million for London based services. In each case positive changes were found for user benefits, revenue and non-user benefits, with an improvement of revenue of the order of £3m per annum for each type of flow corresponding to an increase in the existing revenue of 2% and 10% respectively for London and non-London flows. Given that train frequencies are comparable to the present, it was assumed that operating costs would be unchanged.

Even after ignoring the benefits of clockfacedness and memorability estimated by the SP exercise, the *Taktfahrplan* has a positive impact on demand as a result of the greater connectivity of services and the more regular pattern of departures, both of which are covered by the current forecasting procedure. This demand increase occurs even though there are some longer journey times in the revised timetable. It would thus appear that the introduction of a *Taktfahrplan* would be very beneficial for both non-London and London flows.

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