INTERCITY TRAVEL AND THE LONDON MIDLAND ELECTRIFICATION

By Andrew W. Evans

Since 1958 some £290 million has been invested in the road and rail connections between London, the West Midlands and the Northwest. This includes the construction of the London–Rugby section of the M1 and M6 motorways and the electrification of the main line railway from London to Liverpool and Manchester via Birmingham and via the Trent Valley (see Figure 1). Further money is being spent on linking the M1 and the M6 through the Midlands. In addition, the British Railways Board “regard the extension of the Euston main-line electrification from Crewe to Glasgow as necessary to the development of a modern rail system” ([1], para 194). This development would parallel further motorway extensions.

It is not known whether the money spent on either road or rail improvements was wisely invested. The only major study of travel on any part of the route was the cost-benefit study of the M1 [2], which concluded that the M1 would produce a return on capital of 10 to 15 per cent in 1960. There are several reasons for not regarding this figure as reliable. One of the authors, D. J. Reynolds, pointed out in a subsequent paper[3] that the sections of the motorway which bypass towns were much more profitable than the inter-town sections. His conclusion was that, when built, the inter-town sections were not economically worth while. But J. M. Thomson showed in an unpublished paper how the growth in traffic would rapidly increase the annual rate of return.

The railway electrification has cost, in the end, £163 million[4], excluding interest costs during construction. Little capital was available for railway modernization after the war until 1955, with the publication of the Modernization Plan. The Plan proposed railway improvements costing £1.240 million, but it did not consider the details of any individual schemes. It included a proposal for the present London Midland electrification, and also a proposal to electrify the East Coast main line from London to Leeds and York. In 1955 the railways were still making a working surplus, but during the five years to 1960 the surplus of £1.8 million changed to a deficit of £67.7 million. During that period the Modernization Plan rapidly increased in cost, and was repeatedly reassessed. The London Midland electrification was started from the north at Manchester and Liverpool, but the East Coast proposal was dropped. In 1960 the Select Committee on Nationalised Industries investigated British Railways. Their report[5] showed that the economics of the London Midland

1 The cost assumed in the study was £23 million, but the final cost was about £30 million. The road was built to inadequate standards, and the carriageway had subsequently to be rebuilt at a cost of about £8 million. The most important benefit is time saved, notoriously difficult to evaluate.
Figure 1. The Locations of the Motorways and the Electrified Railway
INTERCITY TRAVEL AND THE LM ELECTRIFICATION

Andrew W. Evans

electrification scheme had not been critically examined by the Ministry of Transport, and that, even on the British Transport Commission's calculations, the scheme was only just profitable. The total cost of the scheme was then estimated to be £161 million, of which £113 million was attributable to electrification rather than to work which would be needed in any case. The annual return on the investment was expected to be £5 million in reduced expenses to the Commission and £3 million in increased traffic, a total of £8 million, which is 7 per cent of £113 million. These calculations, however, did not take into account any social benefits not accruing to the B.T.C.: the most obvious such benefit was time savings to passengers. The Select Committee unenthusiastically recommended that the scheme go ahead: "On the evidence given, your Committee are not aware of any considerations which would justify the abandonment of the London Midland electrification at this stage, despite the low rate of return" (para. 393 of their report). The Government was sufficiently doubtful to have work stopped for a short period in late 1960, but eventually allowed it to proceed. Work continued, and electric traction replaced diesel traction as sections of line were completed. The full electric timetable was introduced on the Euston to Liverpool and Manchester routes on 18 April 1966, and on the Birmingham loop and on the Stoke-on-Trent route to Manchester on 6 March 1967.

The electrification work itself greatly interfered with the running of trains. Two major flows of traffic were diverted to alternative routes: passengers from Manchester to London travelled via Derby to St. Pancras, and those from Birmingham to London went via Banbury to Paddington. Since these routes were to be superseded by the electrified route, no major improvements were made to them and they remained fairly slow. The principal reason for the diversion was not so much to provide a faster passenger service as to reduce the number of trains on the main line; but Manchester and Birmingham passengers did not suffer the random delays experienced on the line to Euston. These delays lasted about six years. The result was that before the electrified services were introduced the standard of service available from the Northwest and the Midlands to London was below that from other parts of the country. Air services from Liverpool and Manchester developed rapidly and gained a substantial share of the public transport market. The introduction of the new timetable provided a sudden and dramatic improvement in rail services.

The particular interest of this improvement is that it was drastic. Since 1955 many train services all over the country have been improved to a similar degree, but the improvements have been gradual, with imperceptible results. Moreover, many other changes have occurred simultaneously with equally great effects on the transport pattern: the enormous increase in motor-car ownership, the construction of motorways, the development of domestic air services and the changing economic situation. It would be difficult to disentangle their effects. The introduction of the electrified train service produced a drastic change in one form of transport, while everything else remained substantially unchanged. The average travel time by train from most places in the Northwest to London was reduced by about 25 per cent. Such a change has never taken place since the war on any other long-distance rail service, and is not likely to occur again in the near future. (Other electrification schemes have produced similar service improvements, but they have all been suburban or outer-suburban in character). This paper describes the method and results of the attempt made at Birmingham University to measure the effects of this radical change.
SCOPE OF THE SURVEYS

As already mentioned, the introduction of the electrified train services was in two stages: those from Manchester and Liverpool to London on 18 April 1966 and those from Stoke and Birmingham on 6 March 1967. The train service from Birmingham was left virtually unaltered in the intervening period, whereas that from Stoke was improved by connection with the first-stage electrified services at Stafford. This situation was convenient for studying. Three surveys were possible: one before the first-stage electrification, one between the two stages, and one after the second. If all the major flows of traffic were considered on each occasion, each pair of successive surveys would include one major flow not affected by service improvements which could be used as a control for the improved flows. That is, for example, between the first and second surveys the services from Birmingham to London would not be altered, and the changes in the traffic pattern on this route between the two surveys could be used as a guide to what would have happened on other routes in the absence of improvement. At the time of writing two surveys have been carried out, and this paper is therefore mainly concerned with the first stage electrification, that from Liverpool and Manchester to London.

Lack of resources made a comprehensive study impossible. All that could be contemplated was to take some representative measurements of major traffic flows and hope that the sampling errors would be small compared with the major changes that took place. The survey aim on each occasion was a complete count of the numbers of people travelling over the routes concerned by each of the main means of transport, i.e., train, plane, scheduled bus and private car. It was expected that the surveys would yield estimates of the proportions of people travelling by each of the transport means, even if they did not produce useful results on the effect of the railway speed-up.

The road traffic survey was expected to produce most of the problems. The most suitable method would have been to interview the drivers of vehicles on the roadside by the variable sampling method used in the M1 study[2]. Unfortunately this was not possible, and the only practicable method was to observe the registration number of every passing vehicle at key points along the route, and then to compare the lists of numbers to identify through vehicles.

The decision to survey the road traffic by the registration number method meant that a large number of observers were required simultaneously. In addition, after discussion with British Railways staff, it was clear that reliable data on rail travel could be obtained only by having interviewers on trains. This further increased the number of people required at the same time. Each survey was restricted to one day only, and it was decided that it should be a "typical" weekday. Unfortunately it was not possible to carry out the two surveys at the same time of year, so the next best alternative of autumn and spring surveys was chosen. The first survey was on Tuesday, 29 March 1966, and the second one on Tuesday, 18 October 1966. The numbers of observers at work on these two dates were 58 and 76 respectively.

Lists of registration numbers of traffic in the same direction complement each other, and the maximum amount of useful information is obtained from a limited number of observers if traffic in one direction only is observed. Observations were made of Southbound travel only on the assumption that traffic in the other direction
would be similar. It was originally hoped to cover traffic from the Northwest to London, from the West Midlands to London, and from the Northwest to the West Midlands. Lack of resources ruled out the last of these flows, but adequate coverage of the first two was possible. The road traffic survey was limited to passenger vehicles (cars and light vans) southbound on the motorways only. There is reason to believe that the major part of the traffic from the Northwest and Birmingham to London does go by the motorways. Other routes almost certainly have longer journey times. Information on rail travel was obtained by having interviewers on trains. The airlines and bus operators on the routes concerned co-operated by kindly providing statistics showing the numbers of southbound passengers on their vehicles on the two dates. No operator refused information.

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Method of Surveying Rail Traffic

Rail traffic was surveyed by train interviewers. The interviewers covered all trains into Euston from Rugby or beyond and into Paddington from Leamington or beyond, and also in March those from Manchester to St. Pancras. Forty-eight trains were involved in the first survey, and 70 in the second. Interviewers travelled up to London working, and then returned by the next available service as ordinary passengers: several interviewers managed three round trips from the West Midlands to London. Every passenger who was travelling to the London area was asked from what station he had come, and only a handful of passengers refused information. A total of 17,000 passengers made relevant journeys in the two surveys, and many others who were not making relevant journeys were on trains which were covered by interviewers. After the second survey, a comparison of the numbers of people interviewed on some trains with the guards' count of the number of people on the trains suggested the possibility that the interviewers were missing people. A check survey was therefore carried out in November 1966, in which passengers on a selection of trains were interviewed as before, but, in addition, the number of passengers was very carefully and independently counted. The results of this check indicate that the numbers of railway passengers reported by the interviewers were below the true figures by only about 1 per cent.

Method of Surveying Road Traffic

The road traffic survey required at the minimum an observation point near the south end of the M1 covering traffic into London, one somewhere east of the West Midlands conurbation and one on the M6 covering traffic travelling from the urban areas of the north-west. It was found that to take registration numbers of cars travelling at speed on the main carriageways of motorways was difficult from any vantage point. This was therefore avoided, and wherever possible roundabouts were chosen as observation sites, as traffic there moves slowly and they are lit at night. The observation points finally adopted were the terminal roundabouts of the M10 and M1 (then near Watford), the roundabout at the east end of the Coventry bypass, Knutsford Service Area on the M6 and several other entrance ramps on the M6 in Lancashire, Cheshire and Staffordshire. There were ten stations altogether. The
times for which observations were made were adjusted to allow for the journey time from the Northwest to London. They were arbitrarily determined to include most of the day’s traffic: 0700–2000 in the North, 0730–2230 in the Midlands and 0830–2400 at the London sites.

Most of the recording was done from cars parked on the verges or (with Ministry of Transport permission) on the hard shoulders of the motorway ramps. Observers at the sites with high volumes of traffic used portable tape recorders. At other sites recording was done by hand on to field sheets. The information required was the complete registration number of each car or light van (except its year letter if any), its time of passing the observation point to the nearest minute, and the number of occupants. Observers were instructed to try to record this information for every car; if this was not possible, a record of the number of vehicles missed was essential. In both surveys together, a total of about 65,000 vehicles passed the observation points. The registration numbers of about 61,000 of these were recorded and 4,000 were missed. The reason for missing vehicles was not so much a flow too high to be recorded as the obscuring of number plates by passing commercial vehicles. The highest flow recorded was about 800 cars per hour, and this gave no trouble.

The method of matching the registration number lists to estimate the amount of traffic between observation points is described briefly in Appendix A. If a flow of traffic could be expected between any pair of observation points, their registration number lists were matched. The distances between points were measured from one-inch ordnance survey maps. The matching process required limits to be placed on acceptable journey times for each pair of points; these were generally set by assuming journey speed limits (usually 65–25 miles/hour, but over short distances the journey time limits were set arbitrarily with reference to road conditions).

Other Traffic

The numbers of air and bus passengers over the routes concerned were provided by the operators. Air services operated to London from airports at Birmingham, Blackpool, Chester, Liverpool and Manchester. Non-scheduled bus travel was not covered; but the observers of road traffic recorded the passage of all buses, scheduled or not. This indicated that the number of private buses was negligible.

RESULTS OF THE RAIL SURVEY

Passengers travelling by rail to London or beyond were classified according to the district whence they came. (The method of classification is described in Appendix B.) Each district has a single main or representative railhead. The starting point of each journey from a particular district is taken to be the district railhead, irrespective of the actual starting point. The district boundaries and railheads are shown in Figure 2. Traffic from outside these districts (Scotland, Ireland) was ignored. The information for each district is summarized in Table 1, which gives the distance of the railhead from London, the district population, and the numbers of passengers by train to London on each of the two survey dates. Table 1 also gives the “mean travel time” to London from district railheads on each of the two survey dates.
Figure 2. Districts of Origin of Rail Passengers
Table 1

Passengers travelling by rail to London

<table>
<thead>
<tr>
<th>Railhead</th>
<th>Distance to London (miles)</th>
<th>No. of Passengers</th>
<th>Mean travel time (mins.)</th>
<th>Population of District (000's)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carlisle</td>
<td>299</td>
<td>242</td>
<td>325</td>
<td>+34.3</td>
</tr>
<tr>
<td>Blackpool</td>
<td>229</td>
<td>141</td>
<td>166</td>
<td>+17.7</td>
</tr>
<tr>
<td>Preston</td>
<td>209</td>
<td>138</td>
<td>202</td>
<td>+46.4</td>
</tr>
<tr>
<td>Wigan</td>
<td>194</td>
<td>120</td>
<td>160</td>
<td>+33.3</td>
</tr>
<tr>
<td>Manchester</td>
<td>189</td>
<td>1,454</td>
<td>1,449</td>
<td>+58.2</td>
</tr>
<tr>
<td>Liverpool</td>
<td>193</td>
<td>916</td>
<td>1,149</td>
<td>+58.2</td>
</tr>
<tr>
<td>Chester</td>
<td>179</td>
<td>142</td>
<td>188</td>
<td>+32.4</td>
</tr>
<tr>
<td>Crewe</td>
<td>158</td>
<td>290</td>
<td>390</td>
<td>+34.5</td>
</tr>
<tr>
<td>Llandudno Junction</td>
<td>223</td>
<td>158</td>
<td>237</td>
<td>+50.0</td>
</tr>
<tr>
<td>Shrewsbury</td>
<td>153</td>
<td>233</td>
<td>233</td>
<td>-4.3</td>
</tr>
<tr>
<td>Stoke-on-Trent</td>
<td>145</td>
<td>114</td>
<td>92</td>
<td>-19.3</td>
</tr>
<tr>
<td>Stafford</td>
<td>133</td>
<td>160</td>
<td>237</td>
<td>+48.1</td>
</tr>
<tr>
<td>Nuneaton</td>
<td>97</td>
<td>106</td>
<td>110</td>
<td>+3.8</td>
</tr>
<tr>
<td>Wolverhampton</td>
<td>123</td>
<td>495</td>
<td>405</td>
<td>-18.2</td>
</tr>
<tr>
<td>Birmingham</td>
<td>110</td>
<td>1,739</td>
<td>1,577</td>
<td>-9.3</td>
</tr>
<tr>
<td>Coventry</td>
<td>94</td>
<td>255</td>
<td>348</td>
<td>+36.5</td>
</tr>
<tr>
<td>Leamington</td>
<td>87</td>
<td>365</td>
<td>313</td>
<td>-14.2</td>
</tr>
<tr>
<td>Rugby</td>
<td>82</td>
<td>200</td>
<td>232</td>
<td>+16.0</td>
</tr>
</tbody>
</table>

The mean travel time is an average of the journey times of all trains to London, plus an allowance for waiting time related to train frequency (see Appendix C). In the case of a regular-interval service of trains, all with the same journey time, the mean travel time is the journey time plus half the service interval. The best improvement in the electrified services was from Crewe, where the mean travel time to London fell from 224 minutes to 148 minutes for the 158 miles; Crewe benefits from being a compulsory stop where many trains have to change traction. The decrease in mean travel time from Manchester as a result of the new service was from 262 minutes to 195 minutes (189 miles); this is a typical figure.

Effect of Faster Rail Services on Volume of Rail Traffic

Traffic flows between pairs of points generally increase as the travel times between them decrease. A popular simple model for this is the gravity model. We shall use this model to examine the effect of the speed-up in rail services on the volume of rail traffic, ignoring traffic by other means of transport for the time being.

The model proposes that:

$$f_i = \frac{kP_i}{t^a}$$
INTERCITY TRAVEL AND THE LM ELECTRIFICATION

Andrew W. Evans

Where \( f_i \) = no. of passengers from place \( i \) to London
\( k \) = constant
\( P_i \) = measure of size of place \( i \) (e.g., population)
\( t_i \) = mean travel time of place \( i \) to London
\( n \) = constant.

We allow \( k \) to have different values on the two survey dates to take into account any general changes in levels of traffic between the two surveys. These may be seasonal changes or just general daily fluctuations. We write the suffix \( 1 \) for March, and \( 2 \) for October.

\[
\frac{f_{2i}}{f_{1i}} = \frac{k_2}{k_1} \left( \frac{t_{1i}}{t_{2i}} \right)^n
\]
and
\[
\log \left( \frac{f_{2i}}{f_{1i}} \right) = \log k' + n \log \left( \frac{t_{1i}}{t_{2i}} \right)
\]
where \( k' = \frac{k_2}{k_1} \).

Thus \( \log \left( \frac{f_{2i}}{f_{1i}} \right) \) is a linear function of \( \log \left( \frac{t_{1i}}{t_{2i}} \right) \) and we can estimate \( \log k' \) and \( n \) by linear regression. If \( n \) is significantly non-zero, it will show that traffic levels were affected by electrification. It does not matter what \( P_i \) is, since it cancels out: it should be the population which uses railheads in district \( i \). This is not necessarily the same as the population of district \( i \). We assume that the \( P_i \)'s were the same for both surveys. This will be true if no district gained at the expense of another, or in other words if people did not change their railheads as a result of electrification. It does not matter if people changed their railheads within a district: they all count the same in any case. (This includes people who changed from one station to another in the same town.) However, it is possible that a few people changed the district from which they travelled. The weighting of the point \( \log \left( \frac{f_{2i}}{f_{1i}} \right) \) in the regression is \( f_{1i} f_{2i} / (f_{1i} + f_{2i}) \).

The points and the regression line are shown in Figure 3. The figure against each point is its relative weight. The estimated regression line when put back into gravity model form is

\[
\frac{f_2}{f_1} = 0.92 \left( \frac{t_1}{t_2} \right)^{1.30}
\]

This equation suggests that traffic on the October survey day from places unaffected by electrification was at about 92 per cent of its March level. The exponent gives an indication of the effect of shortening the mean travel time if other conditions remain unaltered. There is no question that this exponent, 1.30, is non-zero: its standard error is 0.24. This means that electrification certainly had an effect. The equation suggests that, for small changes in mean travel time, a 1 per cent reduction would, on average, cause a 1.30 per cent increase in passengers; a 25 per cent reduction in mean travel time would cause, on average, an increase of 45 per cent in passengers. This figure must be considered cautiously because it has a comparatively large standard error, and the points in Figure 3 are fairly widely scattered about the regression line.

The districts of Figure 3 can be divided into two groups according to whether or not their train services were affected by electrification. From all the places unaffected by electrification (the West Midlands) there was less rail traffic in the October survey than in the March one. From all the places affected by electrification (the
one exception is Stoke-on-Trent, and for this there is a simple explanation\(^2\) there was an increase in traffic, but there is no evidence that the increase was related to the time saved. Thus the significance of the regression line rests almost wholly on the comparison of the West Midlands results with the rest. In other words, we assume that what happened to traffic from the West Midlands would have happened to traffic from other places without electrification. An attempt was made to obtain train passenger levels on other unaffected lines on the two dates, to give support to the West Midlands results, but no adequate data could be obtained. There is no reason, however, to suppose that the West Midlands results are misleading.

A number of reasons can be suggested to explain why the points of the places

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\(^2\)Stoke-on-Trent is an anomalous point in Figure 3, because, although its mean travel time to London was reduced by the first stage of the electrification, there was apparently no increase in traffic. The number of passengers from Stoke was very low in both surveys. After the introduction of the first-stage service, there were no through trains at all from Stoke to London. All required a change at Stafford. The service from Stafford to London was improved with the first stage of the electrification, but the line between Stoke and Stafford remained unimproved until the second stage, when Stoke was provided with its own service direct to London. Before either stage many Stoke people had become accustomed to using Stafford as their railhead for London, and there was no reason to stop doing so after the first stage. The combined Stoke and Stafford results gave a quite normal increase in traffic.
affecting travel should be scattered. The first is that the numbers of passengers from some of them are small, and so chance fluctuations will be large. Next, places affected by electrification do not all have the same range of alternative methods of transport. In particular, air services are available from the Northwest of England to London, but not from places further south, such as Crewe and Stoke-on-Trent. The increase in rail passengers from the Northwest includes passengers transferred from air, but the increase from other places does not. In a later section of this article the point will be considered in greater detail, and traffic from the Northwest will be considered separately from that from other places.

Another reason for the scatter of the points in Figure 3 is that the inauguration of the electrified train services coincided with a change in fare structure. Although the standard fares were not altered, average fares were generally reduced by the widespread introduction of “cheap day” and “cheap period” return tickets. With the data from these surveys it is impossible to separate the effects of the fare changes from the effects of the time changes; it would not be easy with any data, since the present fare structure is complicated. The fare changes could have made an important contribution to the increase in traffic. The new “cheap” tickets applied to all places affected by electrification, but not to the West Midlands. Their effects would vary according to the previous fare arrangements: some places previously sold “cheap” tickets to London, while others did not. The places previously selling “cheap day” tickets to London included Manchester but not Liverpool. From Liverpool, 58 per cent more people travelled to London by train on the October survey day than on the March day; from Manchester, the increase was only 27 per cent. The time saving from the two places was very much the same. Although these figures by themselves are not an adequate guide to the relative effect of the new service on the two cities, they do suggest that in the long run there was more extra traffic from Liverpool than from Manchester. If this is so, the explanation could be that Liverpool received some fare reductions which had already been in operation for some time from Manchester.

ROAD TRAFFIC RESULTS

Traffic Flows
A disadvantage of registration number surveys is that the origins and destinations of vehicles are indicated only within very wide areas. In this survey, the origins of the road journeys could reasonably be divided into just three areas for comparison with traffic by other modes, the three areas being the Northwest, the North Midlands, and the West Midlands.\(^3\)

\(^3\)The railway district combinations (see Figure 2) which correspond to each of these three groups are:

*The Northwest*: Carlisle, Blackpool, Preston, Wigan, Manchester, Liverpool, Chester, Llandudno Junction.

*The North Midlands*: Crewe, Stoke-on-Trent, Stafford.

*The West Midlands*: Birmingham, Wolverhampton, Shrewsbury.

Because of inadequate data, no estimate was made of road traffic from other places covered by the rail survey.
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JOURNAL OF TRANSPORT ECONOMICS AND POLICY

Table 2 gives estimates of the numbers of people travelling by private car on the motorways from each of the origin areas to London or beyond.

**Table 2**

*Estimated Numbers of People travelling to London by Car on the Motorways*

<table>
<thead>
<tr>
<th>From</th>
<th>29 March 1966</th>
<th>18 October 1966</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Northwest</td>
<td>800</td>
<td>921</td>
</tr>
<tr>
<td>North Midlands</td>
<td>466</td>
<td>500</td>
</tr>
<tr>
<td>West Midlands</td>
<td>1,665</td>
<td>1,827</td>
</tr>
</tbody>
</table>

The results of Table 2 agree broadly with the external cordon survey results in the London Traffic Survey[6]. From this survey it can be estimated that about three-quarters of private car traffic from the Midlands and Northwest comes via the M1.

**Relationship Between Mean Journey Time and Distance**

The mean journey times, distances, and numbers of observations for journeys between 17 main pairs of survey points are plotted in Figure 4. The number against each point is the number of observations of which the journey time is the mean. The journeys in Figure 4 are all entirely on motorways, except those that include the non-motorway section between the M6 and the M1. All the journeys include the whole non-motorway link, except those from the Coventry survey point to the London ends of the M1 and M10 motorways; these journeys include none of it.

We now set up a simple journey time model. We suppose that, for travel on the motorways, mean journey time is proportional to distance. Journey times on the non-motorway M6-M1 link will be greater than if the link were motorway, as speeds will be lower. So for journeys which include this link a constant is added to the mean time.

Thus it is assumed that:

\[
\text{mean journey time} = \alpha \times \text{distance} + \beta \quad \text{(if journey includes M6–M1 link)}
\]

where \(\alpha\) and \(\beta\) are to be estimated, \(\alpha\) is the number of minutes per mile on motorways and \(\beta\) is the time which would be saved over the M6–M1 link if a motorway replaced the present roads.

We now consider the standard error of the mean journey times plotted in Figure 4. During the registration number matching process (see Appendix A) it was necessary to specify journey time limits for each pair of observation points; the traffic flow estimates include only those vehicles whose journey times were between these limits. For most journeys, the range of acceptable journey times was taken as proportional to the distance. The standard error of a single journey time observation is assumed also to be proportional to the distance, and so the standard error of a mean journey

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4Results used for this section are based on the exact matches only (see Appendix A).

5The 7-mile section along the A45 from the observation point at the east end of the Coventry bypass to the beginning of the M45, a spur to the M1, is counted as a motorway. It was at the time a derestricted dual-carriageway trunk road. (It now has a 60 miles/hour speed limit.)

80
time is proportional to the distance and inversely proportional to the square root of the number of observations.\(^6\)

The complete journey time model is:

\[
t_i = \alpha d_i + \beta m_i + \frac{d_i}{\sqrt{n_i}} \sigma \varepsilon_i
\]

where

- \(t_i\) = mean journey time for journey \(i\)
- \(d_i\) = distance
- \(m_i\) = \{ 1 if journey \(i\) includes inter-motorway link \(\setminus 0\) otherwise\)
- \(n_i\) = number of observations of journey \(i\)
- \(\varepsilon_i\) = random normally-distributed error, mean 0, variance 1.
- \(\sigma\) = constant standard error of a single observation, per unit distance.

\(^6\)This differs from the result given in the M1 cost-benefit study\(^2\) that the standard error of a single journey time observation is approximately proportional to the square root of the journey time. The difference arises because the result mentioned in the M1 study and that used here are concerned with different kinds of journey time variation. The former was based on non-stop journeys on ordinary roads, and the time variation was caused by traffic conditions. By contrast, the journey times on the motorways considered here would hardly be affected by traffic conditions; the variation is due to driver choice.
The estimated line is

\[ t = 1.274 \, d + 19.6 \, m \]

where \( t \) is in minutes and \( d \) is in miles.

The estimate of the mean journey time for car travel on motorways is 1.274 minutes per mile, with standard error 0.013. The constant speed which would result in this journey time is 47.1 miles per hour. The estimate of the time on each journey which would be saved by building a motorway between the M6 and the M1 is 19.6 minutes, with standard error 1.9 minutes.

**Distribution of Journey Speeds along M1**

There were enough journey time observations between Coventry by-pass and the terminal points of the M1 and M10 to make it worth while to look at their distribution. A curious feature of these journeys is that, although the route to both terminal points is the same except for the last mile or two, the mean journey speeds differed significantly by about 3\frac{1}{4} per cent. Drivers who took the M1 route into London drove faster than those who took the M10 route.

An interesting histogram was obtained when the journey times for the 71-mile journey from Coventry to the Watford terminal of the M1 were converted into average journey speeds. Journey speed distributions are less skew than journey time distributions. The histogram is shown in Figure 5. The distribution is quite clearly bimodal, with modes at about 44 m.p.h. and 64 m.p.h. A possible explanation is that the two parts of the distribution can be identified with the two sets of journeys: one set is made non-stop and the other set is made with a stop at a service area. On this hypothesis, roughly 40 per cent of the journeys are non-stop. This is in agreement with other results.

**Numbers of People in Road Vehicles**

The average occupancy of vehicles travelling from all survey points to London was 1.652. The mean spot occupancy over all survey points was 1.487. The difference is

![Figure 5. Distribution of Journey Speeds Along the M1 Motorway](image-url)
INTERCITY TRAVEL AND THE LM ELECTRIFICATION

Andrew W. Evans

statistically very significant. On the other hand, there was no evidence in this data that occupancies tended to be higher on longer journeys. The occupancies would probably be very different at weekend or holiday periods.

TRAFFIC BY ALL MODES

Table 3 gives the numbers of passengers to London by each mode of transport from the three origin areas introduced above.

**Table 3**

*Numbers and Percentages of Passengers to London from each Origin Area by Method of Transport*

<table>
<thead>
<tr>
<th>Mode</th>
<th>Train</th>
<th>Bus</th>
<th>Plane</th>
<th>Car</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td>The Northwest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 March</td>
<td>3,111</td>
<td>220</td>
<td>1,855</td>
<td>800</td>
<td>5,586</td>
</tr>
<tr>
<td>18 October</td>
<td>4,572</td>
<td>311</td>
<td>730</td>
<td>921</td>
<td>6,534</td>
</tr>
<tr>
<td>The North Midlands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 March</td>
<td>564</td>
<td>29</td>
<td>0</td>
<td>466</td>
<td>1,059</td>
</tr>
<tr>
<td>18 October</td>
<td>719</td>
<td>17</td>
<td>0</td>
<td>500</td>
<td>1,236</td>
</tr>
<tr>
<td>The West Midlands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 March</td>
<td>2,467</td>
<td>203</td>
<td>58</td>
<td>1,605</td>
<td>4,393</td>
</tr>
<tr>
<td>18 October</td>
<td>2,205</td>
<td>207</td>
<td>89</td>
<td>1,827</td>
<td>4,328</td>
</tr>
</tbody>
</table>

The traffic from the West Midlands was unaffected by train service alterations between the two surveys, and we shall use the West Midlands results to estimate the likely traffic from the Northwest if the improved train service had not been introduced.

Car traffic from the West Midlands was 9.7 per cent higher in the October survey than in the March survey. If car traffic from the Northwest had increased in the same proportion, there would have been 878 car travellers in October. If car travellers had changed to rail as a result of electrification, the actual number of car travellers in October would probably have been less than this expected number; in fact, the estimated actual number was 921. There is therefore no evidence that car travellers from the Northwest changed to rail. A similar calculation shows no evidence of a swing from bus to rail, but the numbers of passengers are too small for any conclusion about this. Bus traffic is of greater importance at weekends and in holiday periods, about which these weekday figures give little information.

The comparison of the numbers of passengers by train from the Northwest with those from the West Midlands suggests that rail traffic from the Northwest went up by a little over 50 per cent. This is a slightly greater increase than would be expected from the formula derived in the section on the rail results alone. That formula was based on the results from all places affected by electrification, but rail traffic from
the Northwest generally increased by relatively more than from other places. On the evidence of the previous paragraph, none of these extra rail passengers came from private car or bus. It remains to estimate how many of them came from air, and how many did not travel at all before electrification.

There were very few air passengers from the West Midlands to London in either survey, and most of them would fly on elsewhere from London Airport, so it is not possible to use the West Midlands results to estimate how many air passengers there would have been from the Northwest in October without electrification. This has been done here by combining the rail and air results, and using the combined West Midlands results to estimate what would have happened to both rail and air traffic from the Northwest. Thus the combined rail and air traffic from the West Midlands fell by 8.0 per cent from the March survey to the October survey, and this percentage fall would have given 3,008 rail and 1,140 air passengers in October from the Northwest. The actual figures were 4,572 and 730 respectively. On this basis, the estimated increase in rail traffic is 52 per cent, of which 14 per cent come from air and 38 per cent is generated. Thirty-six per cent of the former air passengers changed to rail. This estimating procedure assumes that the seasonal and daily fluctuations in the West Midlands rail traffic are the same as those in the traffic from the Northwest by air as well as rail. The estimate of the total increase in rail traffic does not depend on this assumption, but the estimate of the number of passengers transferring from air to rail does. Figures from the airlines suggest that the figure obtained here is about right. For example, the B.E.A. Annual Report[7] shows that London–Manchester air traffic was 25 per cent lower in the year ending 31 March 1967 than in the previous year, and this decline is to be compared with increases of 11 per cent and 5 per cent in the two previous years. (The new rail services were introduced on 18 April 1966).

The official British Railways Board statement of the results of electrification is to be found in the 1966 Annual Report[1], paras 12 and 61. Para 12: “The opening of the London Midland Electrification scheme from Euston was accompanied by . . . an upsurge of 50 per cent in passenger receipts and 65 per cent in passenger journeys, some of which were recaptured from air”. Para 61: “Significant increases were made in loadings and revenue, much new business being generated by the accelerated timings and a large number of travellers being won from road and more particularly from air”.

The suggestion that a large number of road travellers changed to rail is not supported by the results of this survey, but this conclusion may apply to journeys other than those from the Northwest to London. No details of the Board’s findings have been published, so no comparison can be made with the results of these surveys. The results on traffic from the Northwest to London are in broad agreement with estimates, both of the proportion by each means of transport and of the effect of electrification, given by H. C. Johnson in his paper to the Institute of Transport[9]. But Johnson’s estimate of the proportion of road traffic from the Midlands is well above that found here.

**Traffic Flows related to Journey Times**

The gravity model has been used in an earlier section to examine the results from the rail surveys by themselves. It will now be used to relate the total traffic flow to
London from various areas by all methods of transport to the travel time. Three main difficulties arise in the application of this model to the data available from these surveys.

(i) The first difficulty is that some passengers cannot easily be allocated to the right area of origin. It can be seen from Table 1 that there are very wide variations in the ratio of the number of rail passengers from a district to the size of its population, even for districts about the same distance from London. Thus, for example, in October there were apparently 2.1 journeys to London per 1,000 population from Stafford, but only 0.2 from Stoke-on-Trent. Again, there were 2.0 journeys per 1,000 population from Leamington, but only 1.0 from Coventry. One reason is that people cross district boundaries on their way to the railhead. Many of the passengers travelling from Stafford Station in fact live in Stoke. A way round this difficulty is to combine the districts into larger areas which include any boundaries likely to be crossed by passengers en route to their railhead. Seven areas are used in this section; they are shown in Table 4. These seven areas together cover all the districts shown in Figure 2, except Nuneaton, Coventry, Rugby and Leamington. To form them, one of the districts was split, the two parts contributing to different areas.

(ii) The number of cars from each of the areas in Table 4 is not known, but only the numbers from the larger areas in Table 2. However, the number of rail passengers from each of the areas of Table 4 is known. To estimate the total traffic from each area, we increase each rail figure by the ratio of total traffic to rail traffic of the appropriate large area. Thus from the Northwest as a whole in March 59.3 per cent of all traffic was by rail. To estimate the total traffic from, say, Manchester, we multiply the Manchester March rail figure by $\frac{100}{59.3}$. The effect of this is to distribute the non-rail traffic from each of the three major areas among the areas of Table 4 in the same proportion as the rail traffic.

(iii) There is no single figure for the journey time to London from an area. The areas are extensive, so there are large journey time variations even by the same means of transport. In addition, the time of a journey by public transport is very sensitive

### Table 4

**Numbers of Passengers to London and Mean Travel Times by all Methods of Transport**

<table>
<thead>
<tr>
<th>From</th>
<th>Population (000's)</th>
<th>Passengers/000 Pop%</th>
<th>Mean Travel Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>29 March</td>
<td>18 October</td>
</tr>
<tr>
<td>The North (Blackpool)</td>
<td>1,153</td>
<td>0.72</td>
<td>0.81</td>
</tr>
<tr>
<td>Manchester</td>
<td>3,014</td>
<td>0.83</td>
<td>0.89</td>
</tr>
<tr>
<td>Liverpool</td>
<td>2,775</td>
<td>0.89</td>
<td>1.13</td>
</tr>
<tr>
<td>North Wales (Llandudno)</td>
<td>384</td>
<td>0.69</td>
<td>0.88</td>
</tr>
<tr>
<td>Shrewsbury</td>
<td>492</td>
<td>0.85</td>
<td>0.89</td>
</tr>
<tr>
<td>Stoke-on-Trent</td>
<td>487</td>
<td>1.06</td>
<td>1.16</td>
</tr>
<tr>
<td>West Midlands (Birmingham)</td>
<td>4,449</td>
<td>1.62</td>
<td>1.59</td>
</tr>
</tbody>
</table>
to its exact origin and destination: the journey time from central Birmingham to central London by public transport is very different from that from, say, Selly Oak to Croydon. A representative place has therefore been chosen for each area, and a representative journey time has been calculated by averaging the centre-to-centre journey times by all modes weighted by the number of passengers using each. Bus journey times have not, however, been included in this averaging, and air journey times only from Manchester and Liverpool. For rail journey times, the mean travel time from the representative town has been taken. The car journey times are calculated as follows. Two minutes per mile (30 miles/hour) are allowed for the journey from the centre of the origin city to the nearest motorway access point. Then 1.274 minutes per mile are allowed as far as the end of the M1. There is an addition of 20 minutes if the journey includes the non-motorway section from the M6 to the M1 (see Figure 4). Finally 45 minutes are allowed from the end of the M1 (then near Watford) into London. Times worked out on this basis could certainly be bettered on occasion but should be representative of normal driving, typically with a stop en route. There is a further difficulty in giving the time for the air journey from Manchester and Liverpool to London. There were several flights in the morning and evening peak business travel periods, but few at other times. It would be unrealistic to give the "mean travel time" for the air journey in the same way as it was calculated for the train service. The long gaps between flights in the middle of the day would make "waiting time" the dominant element in the mean travel time. The centre-to-centre time by air, using buses to and from the airports, was 160 minutes from both Liverpool and Manchester to London. An arbitrary "mean travel time" of 190 minutes has been taken for these journeys.

The numbers of passengers per 1,000 population from the seven areas are given in Table 4. The town from which the journey times were calculated is given in brackets where it is not obvious.

The gravity model was

\[ f_i = \frac{kP_i}{t_i^n} \]

where
- \( f_i \) = total traffic flow from area \( i \) to London
- \( P_i \) = population of area \( i \)
- \( t_i \) = mean travel time from area \( i \) to London
- \( n \) = constant
- \( k \) = constant

and so

\[ \log (f_i/P_i) = \log k - n \log t_i \]

\( f_i/P_i \) and \( t_i \) are given in Table 4, so \( k \) and \( n \) can be estimated by linear regression. The value of \( k \) is assumed to be the same in the October survey as in the March survey \(^7\); \( k \) and \( n \) can therefore be estimated from the 14 pairs of values in Table 4.

---

\(^7\) The value of \( k \) might be expected to be different on different days and at different times of year, according to general daily and seasonal fluctuations in the amount of travel. But the total traffic from the West Midlands (unaffected by electrification) was very similar in the two surveys. The difference between the two totals was only 0.5 in 4350, or 1.1 per cent, and is not statistically significant. The slight decline in rail travel was offset by more car travel.
and no notice is taken from which survey each point comes. In the estimates of $k$ and $n$, each point is weighted by the number of passengers from it.

The regression line obtained leads to the gravity model

$$f_i = \frac{439 \cdot P_i}{t_i^{1.11}}$$

where $P_i$ is in thousands, and $t_i$ in minutes.

This curve is shown in Figure 6, together with the points from Table 4. The figure against each point is its relative weight. The exponent, 1.11, has a standard error of 0.13, which means that it is significantly different from zero.

If the travel time from any area is reduced by 25 per cent, the increase in travel expected from this model is 38 per cent, which agrees with the estimated amount of rail travel generated from the Northwest.

**Economic Considerations**

A full economic assessment of the London Midland electrification is outside the scope of this study: it would require the kind of information which has been obtained here, but much more of it. Further information would be required on passenger travel at weekends and to other destinations than London. Freight traffic has not
been considered at all in this study. Railway costs, about which there is little published information, would have to be considered. But a few remarks can be made as a result of the surveys described above.

There were two principal effects of this electrification scheme: a reduction in passenger train journey times, and a reduction in the operating costs of both freight and passenger trains. Freight train journey times were not reduced much, because freight train speeds are limited generally not by track or motive power, but by the stability and braking characteristics of the freight wagons. They should, however, be reduced progressively as more trains, such as freightliners, are formed of special stock.

Neither of these two effects is peculiar to electrification, nor would the simple replacement of steam by electric traction have been enough to bring about these effects. The introduction of diesel traction also results in increased passenger train speeds and reductions in operating cost. The London Midland electrification scheme included much work complementary to the introduction of electric traction itself: for example, the relaying and realignment of the track for high speeds, the re-building of stations and junctions, the installation of a new signalling system, and the construction of new rolling stock. All this work contributed both to the improvement in passenger services and to the reduction in costs; it could equally well have been associated with diesel traction. In a paper to the Institute of Transport[8] by H. C. Johnson, who was chairman of the London Midland Region during electrification, these associated works were reported to have accounted for nearly three-quarters of the cost of the London Midland scheme: of a total cost of about £160 million, the electric traction itself cost only £42 million.8

The installation of the overhead wire or third rail and its associated equipment makes the capital cost of electric traction higher than that of diesel traction. Two separate questions can therefore be distinguished when investment in a main line railway is contemplated: whether to develop the line for heavy loads and high speeds, for example by renewal of track, signalling, terminals and rolling stock; and, if this is to be done, whether to invest further and electrify. The second question, on which this paper sheds no light, is largely a matter of balancing the additional capital cost of electric traction against its convenience and lower operating costs; this question has recently been discussed by A. H. Emerson[9]. This paper is relevant to the first question, whether to develop a line for high speeds and heavy loads. It has been concerned with the effect on passenger travel of introducing a high-speed service, and has implicitly assumed that this effect does not depend on the method of traction, but only on the journey speeds and frequencies of the trains. We now consider briefly the effect of the faster London Midland passenger services from an economic viewpoint.

Effects of Speeding-up Passenger Services

In general there are three effects of reducing passenger train journey times, whatever the method of traction:

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8In 1960 the British Transport Commission reported to the Select Committee on Nationalised Industries[5] that, of a total estimated cost of £161 million for the London Midland electrification scheme, £113 million was attributable to electrification rather than to work which would be needed to maintain the line in its current state. This figure included ancillary work as well as the installation of electric traction itself.
INTERCITY TRAVEL AND THE LM ELECTRIFICATION

Andrew W. Evans

(i) A reduction in journey time for passengers already travelling by rail;
(ii) Generation of additional rail traffic;
(iii) A change by some travellers from other modes of transport to rail.

Reduction in Journey Time for “Existing” Rail Passengers

All rail passengers between the Northwest and London save about one hour compared with pre-electrification days. The second stage of the electrification reduced the journey time of travellers between the West Midlands and London by about half an hour. In the March survey, the two routes had about 3,300 and 2,500 passengers respectively in one direction. If we multiply these figures by two for the two directions, and by 365 (say) for the year, we can estimate the number of passenger-hours saved on these two routes as between three and four million. This is probably the bulk of the passenger time saved, as the only other major long-distance flow affected would be that from the West Midlands to the Northwest. The total time saved might be about 5 million passenger-hours per year, and this might be worth £2 million per year.

Generation of Additional Rail Travel

It was suggested by the general gravity model that a decrease in mean travel time of 1 per cent would create an increase in travel of 1.1 per cent. A decrease of 25 per cent in travel time caused an increase in travel of about 38 per cent.

The money spent on generated travel can be very roughly estimated from the results of this survey. The 38 per cent increase in travel to and from the Northwest is about 1,125 journeys each way per day, each journey being of about 200 miles. In the second stage electrification, the mean travel time from the West Midlands to London dropped by about 17 per cent, which according to the general gravity model would generate an additional 23 per cent travel. This is about 500 journeys, each of about 100 miles. The daily additional revenue is estimated by multiplying the additional passenger-miles by the mean national revenue per mile for ordinary (i.e., not season) tickets of 2.56d. (British Railways Board Annual Report 1966[1].) When the daily revenue is multiplied by 365, we obtain an estimate of £2.1 million for the annual additional revenue to British Railways from generated long-distance travel starting or finishing in London. In addition, travel will also have been generated between the Northwest and the West Midlands and between and other intermediate points, bringing the total up to, say, £2½ million. For comparison, in his paper to the Institute of Transport[8] H. C. Johnson said that the estimated additional revenue to British Railways was about £1.8 million in the first year on the flows between London and Manchester, Liverpool, Stoke, and the West Midlands. This figure does not include traffic from other places to London or intermediate flows; on the other hand, it does include traffic which transferred from other methods of transport to rail.

It is worth attempting to estimate the benefit resulting from this generated travel. The money spent on tickets for generated journeys gives a lower bound for the value of these journeys to those who make them: if a passenger valued a journey at less than the price of the ticket, he would not make it. The fact that generated journeys were not made before the new train services were introduced provides an indication of the maximum value of the journeys to those who make them. If there had been only
journey time reductions, but no changes in the price of tickets, it could have been argued that the maximum value of each generated journey is the price of the ticket plus the value of the time saved by electrification. If any journey were worth more than this, it would have been worth making before electrification, and so would not have been generated. So the value of a journey would be bounded below by the price of the ticket, and above by the price of the ticket plus the value of the journey time reduction. The normal procedure is now to assume that the values of all the generated journeys are distributed uniformly between these two bounds, and so the total value of the generated journeys would be the price paid for all the tickets plus, for each generated journey, half the value of the time saved on each existing journey. If the journeys had been generated by a price change only, the estimate of the value of each journey to the person making it would be on average, by a similar argument, the new price plus half the price reduction. The net benefit of the generated journeys to those who make them is the difference between the value to them and the price of the tickets.

In the case of the London Midland electrification, journey times were reduced on all journeys, and prices were reduced for some journeys. Both these changes will have helped to generate extra traffic, and the net benefit of the extra journeys to those who make them will consist partly of the value of time savings and partly of ticket cost savings. The net benefit will, however, be calculated as if the traffic was all generated by the journey time reductions, in the hope that the amount by which this overestimates the value of the time savings is of the same order as the amount by which it underestimates cost savings. The net benefit is then the number of generated journeys multiplied by half the value of the time saved on each existing journey, or about £4 million per year (to the nearest £½ million).

The revenue to British Railways from the generated passengers – about £2½ million per year – is all clear benefit except for the marginal cost of carrying them. This is likely to be very low. The present railway policy is to run trains at regular intervals (hourly or two-hourly), so that the number of trains run is not very sensitive to the number of passengers. The generated passengers might require trains to be generally longer than they would otherwise be, and also require a few extra peak-hour trains; no attempt has been made to cost these.9

A full economic assessment of the London Midland investment would require a detailed comparison of the operating costs when the line was steam-operated with those after electrification. The total costs after electrification would include the cost of carrying the generated passengers. The simplest method of assessing the benefits from generated travel might be to count the revenue from it as all gain to British Railways; the cost of carrying the generated passengers is then taken into account.

9A. H. Emerson has recently given some relevant figures[5]. Some of the costs per mile of running a 100 miles/hour peak-hour electric train throughout the year are: electric current, about 30 pence; maintenance of the locomotive, 14 pence; maintenance of fixed equipment, 8 pence. If such a train carried 200 passengers, each at 3 pence per mile, which represents a load factor of only about 35 per cent, its revenue would be 600 pence per mile. Although the costs given above are by no means complete (they do not include the costs either of the rolling stock or of the crew), they do suggest that, even where additional peak-hour trains have to be run to meet the generated travel demand, the marginal costs incurred are a small fraction of the revenue.
INTERCITY TRAVEL AND THE LM ELECTRIFICATION

Andrew W. Evans

when savings in operating costs resulting from electrification are considered. These savings will be rather less than if no traffic had been generated.

Swing to Rail from other Methods of Transport

The decrease in rail travel times from the Northwest caused a considerable swing from air to rail travel. However, the actual number of passengers changing their mode was small compared with both the number of existing passengers and the number of generated passengers. There was probably little swing from car to rail from the Northwest.

From the West Midlands, air services were negligible, but there will probably have been a small swing from car to rail with the second stage of the London Midland electrification. The reasoning for this is as follows. The distance from the Northwest to London is so great that even before electrification the speed advantage of public transport over the car more than outweighed the extra time at the journey’s ends. Hence most people who went by car were likely to be “captive” to the car in some sense—for example, because they wanted their cars at the destination or because they had a load of luggage. These people would not easily be influenced by journey time alterations. This explains the small proportion of car traffic, and also the apparent absence of any change to rail. On the other hand, from the West Midlands to London some journeys are quicker by car, particularly those to north London. Thus there are some “non-captive” car journeys from the West Midlands to London, and this explains the larger proportion of car journeys. When the electrified train service from the West Midlands began, some journeys previously quicker by car must have become quicker by train. Thus some journeys previously made by car might now be made by train.

People who changed their mode of transport will have gained a small net benefit, similar to that of the generated travellers. If the only rail improvement had been journey time reductions it could be argued, in the same way as for generated travel, that the average net benefit per diverted traveller was about half the time saved per existing traveller. The railway price reductions complicate this picture, but in any case the number of passengers changing their mode was so small that their total net benefit is probably less than £1 1/4 million.

The revenue to British Railways from the passengers who changed to rail is almost all clear gain, as it was for generated passengers. The estimate of it is £1 1/4 million per year. The airlines will have lost revenue from these passengers, but they should have been able to reduce operating costs. If they were not able to reduce costs by as much as the lost revenue, then their net loss will have to be set against the gain to British Railways.

CONCLUSION

The investment in the London Midland electrification produced two major effects: an improvement in passenger services, and a general reduction in railway operating costs. The benefits resulting from the speed-up of long-distance passenger trains, calculated roughly in the preceding sections, add up to a figure of the order of £5 million per year. This figure does not include benefits to short-distance passengers.
in London, the West Midlands, Liverpool and Manchester. If the £5 million is taken as a net benefit resulting from electrification, it has to be assumed that the train service just before the new time table was not actually worse than it would have been without any modernization; i.e. that none of this benefit is merely recouping what had been lost as a result of train service delays due to construction work. The other major benefit, a reduction in railway operating costs, has not been considered in this paper, and no attempt has been made to compare electrification with the possible alternative of diesel traction. This paper has been concerned with the short-term effects of the railway improvement. There might also be long-term effects on the location of population and industry.

APPENDIX A

Matching Registration Numbers

A principal disadvantage of registration number surveys is that some errors in recording the numbers are inevitable, and errors cause the numbers not to match when they should. Matching was a formidable problem before the introduction of computers, even with mechanical aids. The computer makes it possible not only to speed up hand methods, but also to contemplate improved methods which would have been impossible by hand.

In this work, the registration numbers recorded in the road survey were punched on to paper tape and the matching carried out by a new method on the departmental Elliott 920A computer. It was found that, if a number appeared identically in the lists from two different sites, it could be accepted without question as indicating that the same vehicle appeared at both sites. Such a pair of numbers is called an "exact match". However, if the vehicle was to be accepted as having made a through journey in the desired sense, the time difference between the two appearances had to fall within specified limits. This was necessary to eliminate vehicles which made an exceptionally long stop on the journey, and also vehicles which, although appearing at both sites, did not make a journey between them. For example, a vehicle could appear at a London site in the morning, and at a Midlands site travelling towards London in the evening: it would appear to have made a journey from the Midlands to London with a large negative journey time. It can be shown that the smaller the possible journey time range is, the more precisely can recording errors be allowed for.

The journey time and occupancy results are based only on exact matches.

If two registration numbers which were almost identical, but not quite, appeared in the registration number lists from two sites, they were said to form a "non-exact match". The problem of estimating the total flow of traffic between two points is that of estimating how many of these non-exact matches contain two versions of the registration number of the same vehicle (at least one of which has been misrecorded), and how many genuinely contain two different numbers. The method adopted was to divide the non-exact matches into two groups: those in which the passing times of the two registration numbers were separated by a possible journey time, and those in which they were not. The latter group gives an indication of the rate at which non-exact matches between different vehicles occur by chance for a particular pair of
INTERCITY TRAVEL AND THE LM ELECTRIFICATION

Andrew W. Evans

sites, and from this it is possible to estimate the number in the former group which really do indicate a through journey.

This method was explored and much refined during the matching: it then gave very satisfactory results. The estimates of the traffic flows between major sites are probably accurate to within 2 per cent and those with smaller volumes to within 10 per cent.

APPENDIX B

Districts of Origin of Railway Passengers

The Ministry of Transport has devised a standard geographic zone system for Great Britain for use in transportation surveys. The zones are listed in detail, and the system is described in an unpublished file.10 The system is a three-stage breakdown of the country: the three stages are (1) economic planning regions, (2) combinations of counties or major urban areas, and (3) combinations of local authority administrative areas.

Unfortunately this system was not suitable for grouping the areas of origin of rail passengers, as the natural grouping is about railheads or railway lines rather than by administrative areas. However, in order to preserve compatibility with any other survey which may use the Ministry of Transport system, the origin stations of rail passengers were first grouped into areas based on the Ministry system. From this, the number of passengers from each of the Ministry's second-stage areas can be easily calculated. For the conclusions of this paper, however, the numbers of passengers were then regrouped into tracts of land labelled (for verbal convenience) districts. The districts are constituted in such a way that each district is served either by a single major railhead or by a single line of railway serving several medium-sized railheads. An example of the latter is the North Wales line. Each place is included in the district which contains its natural railhead for London, so all places in the same district are served by the same rail service to London. The districts chosen are large enough to ensure that the number of passengers from each district to London on each day was generally at least 100. Each district is named by its main railhead, or by a representative railhead if it is served by several. Thus North Wales is referred to as the Llandudno Junction district. The train service from a district is considered as that from its main or representative railhead. Although a large number of passengers from North Wales do not travel via Llandudno Junction, they all travel in the same trains as serve that station, so its train service is representative of that of the whole district. Most districts do possess a single major railhead, and the field sheets showed that these single stations accounted for the great majority of passengers.

APPENDIX C

Mean Travel Times by Rail

The principal effect of the electrification on train services was to reduce the journey times of trains. In addition more trains were run, so that, from some places,

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frequencies were increased. A measure of these improvements is required. The measure of travel time to London adopted is called “mean travel time”; this is obtained by averaging the time needed from any instant \( x \) at the provincial railhead for a passenger to be standing on the platform at the London terminus. The average is taken over all values of \( x \) from 7 a.m. to 4 p.m. This particular average was taken because it was desirable for practical reasons to treat all places in the same way, and from places a long way from London the last train of the day left at about 4 p.m. There is no reason to suppose that the mean travel times would have been materially different if averages had been taken over different periods. The formula for the mean travel time is

\[
\frac{\sum_{i=1}^{n} t_i (x_i + \frac{1}{2}t_i)}{\sum_{i=1}^{n} t_i}
\]

where \( t_i \) is the time interval from 7 a.m. till the first London departure after 7 a.m., \( t_i \) is the interval between the first and second departures, etc., and \( t_i \) is the interval from the last departure before 4 p.m. till 4 p.m. \( x_i \) is the journey time of the first train, etc., and \( x_i \) is the time from 4 p.m. till the arrival in London of the first train departing after 4 p.m. The expression in the bracket of the numerator is the journey time of the \( i \)th train plus half the interval since the previous train. This is averaged over all trains, weighted by the interval before the departure of each \( - i.e., \) by the relative contribution each train makes to the day’s service. If a town is served by a regular interval service and all trains have the same journey time, then the mean travel time is the journey time plus half the service interval.

It could be objected that this method of calculating travel time unduly stresses service interval, since only the actual journey time is inescapable; for many people the precise departure or arrival time is unimportant, and they are prepared to travel on a fast train whenever it runs. There is some truth in this, but the measure of travel time does have to be sensitive to the frequency. The properties required by the measure are that it should be reduced if either (a) an additional train is introduced into the timetable or (b) any train is speeded up. The “mean travel time” is a simple measure which possesses these properties. There is a compensating factor for its tendency to over-stress waiting times. This is that not only is the train journey time itself inescapable, but so also is a certain amount of waiting time.

In order to be reasonably certain of not missing the train, a passenger has to allow for variations in the journey time to the station. The time he allows for this journey must be greater than the average time actually taken, so that, usually, he will have to wait at the station for the train. How long he will usually have to wait will depend on the variability of the journey time to the station and on what risk he accepts of missing the train.

It is worth pointing out that different approaches to the relative importance of service interval and journey time are evident among the different railway regions themselves. To some extent service intervals can be reduced at the expense of lengthening journey times by inserting extra stops in schedules, or vice versa. The London Midland timetable from 18 April 1966 opted, in general, for a two-hourly service of fast trains from most places, whereas most towns on other lines have a one-
INTERCITY TRAVEL AND THE LM ELECTRIFICATION

Andrew W. Evans

hourly service of slower trains with more stops. The proportion of the travel time contributed by the "waiting time" is therefore greater from the places served by the London Midland electrified services than from most other places. The present London Midland approach generally produces less favourable results than that of other regions on the travel time criterion described above.

REFERENCES


University of Birmingham