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Computer-based planning techniques and the appraisal of an underground railway extension

N.G. Harris
London Underground Limited, 55 Broadway, London, SW1H 0BD, UK

Abstract

The planning of railway extensions is a complicated affair, especially when they are added to a large existing rail system. Although standard network modelling procedures have been available for a number of years, these are not always sufficient to provide a solid appraisal which will satisfy the funding and political pressures inherent in a modern democracy. This paper describes the computerised processes used during the planning of the proposed extension of London Underground's Piccadilly line to Heathrow airport. Both network modelling and train service simulation have been used as integral parts of the planning process. The aim has been to produce the optimum extension, despite limited funding and a number of complicating issues including both inter-modal and on-rail competition, the latter from an express service not yet operational.

Background

London Underground Ltd. (LUL) operates a 270-mile network of heavy rail services in the Greater London area of South East England. The system comprises ten lines, and has gradually been developed since 1863, when the first parts of the Circle line were built. At present, a 10-mile extension of the Jubilee line to serve Docklands is under construction. In 1992-3, 728M passengers travelled a distance of approx. 3.6Bn miles on the Company's 33M train miles each year (LT[1]); the resulting high average load of 107 means that LUL makes a profit on operations. However, this profit is insufficient to provide full funding of capital expenditure requirements, and it is therefore supplemented by a grant from Government.

Estimating Passenger Demand

With a network as large as LUL's, a considerable amount of planning work is required in order to ensure that the network and services offered are as effective as possible. In order to remain successful, LUL's train services must respond to changes in land-use and trip patterns, and this leads to a requirement for sophisicated planning tools.

LUL have for a number of years had a computer-based Network Model. The model covers the entire rail network of South East England, including mainline and Docklands Light Railway services as well as those operated by LUL. Although the technical details of the model have been written up elsewhere (Harris[2,3]; Bach & Harris[4]), in summary the model is a classic traffic assignment model mounted on a 486-series personal computer and based on TRIPS software. It includes features such as congestion modelling (both on trains and in stations), multi-routeing through the complex network, graphics, and a variable trip matrix enabling the overall level of rail demand to respond to changes in the network or services offered.

However, since the model is a station-to-station model (using passenger counts as its base demand data), rather than a zonal model using census data, estimating the demand from proposed extensions involves external calculations as well as the Level-Of-Service (LOS) element of the model itself. The LOS sub-model estimates changes in the demand for travel between every station and every other, based on the change in generalised cost of that journey when services are altered, the initial demand, and a matrix of elasticities. Where there are no trips, however, as is the case for extensions, this marginal approach is inapplicable, and extra trips have to be added in based on external data (such as forecasts of the demand at facilities to be served, be they office blocks or airports, as here). When engineering cost estimates are also available, it is then possible to provide an initial forecast of the viability of the proposed extension.

Ensuring System Operability

The financial viability of a proposed railway extension is, however, entirely independent of its operability, and a railway needs to have a means of testing how a possible service will work in practice. LUL has its Train Service Model for this purpose. This is an in-house event-based simulation available for each of LUL's lines or groups of lines individually (Weston and McKenna[5]). It is able to model such problems as conflicts at junctions, trains bunching as they progress along a line, and timetable effectiveness from its input data relating to line, train and demand characteristics. Recent improvements to this model, also pc-based and using SALFORD FORTRAN, have included the development of a graphical interface, which enables service perturbations to be visualised easily (see Figure 1).

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Serving Heathrow Airport

LUL has served Heathrow Airport since 1977, when the Piccadilly line in South West London was extended as a double-track railway largely in tube tunnel from Hounslow West to Terminals 1,2 and 3 (also called the Central Terminal Area (CTA)). In 1984, a single-track underground loop was constructed to serve Terminal 4. Since opening, Heathrow has become a valuable source of LUL traffic, and currently contributes 12Mppa, or about 9% of Piccadilly line boardings. The journey time to Central London is between 45 and 60 minutes, depending upon the Central area station used, whilst a standard five-minute frequency is operated offpeak (15 tph in the peaks).

However, not only is Heathrow one of the world's busiest international airports, but air traffic has grown inexorably in the last 20 years. BAA, the operators of Heathrow, have been making plans for expanding the airport, since it now handles 46Mppa and is virtually at capacity. Although more passengers might be brought in through the use of larger aircraft, the terminals have insufficient capacity to deal with them. A new terminal has therefore been under consideration for some time.

The proposed Terminal 5 will be larger than any of the existing terminals, and is designed to cope with 30Mppa in the long-term. Good surface access is clearly a key criterion for the efficient functioning of such a large airport terminal, and rail access is likely to be appropriate given the size of demand. BAA has recently started building a dedicated fast link between the airport and London's Paddington mainline station (the "Heathrow Express" (HEx) service), a link which may be extended to T5, but an underground extension serving other parts of London is also desirable. This is particularly the case since a number of hotels have grown up adjacent to Piccadilly line stations in Central London, whilst a significant number of airport workers already use the Piccadilly line from the Hounslow area. A further complication arises through the possibility of London's proposed East-West Crossrail railway also serving the airport; the effects of this have been examined through sensitivity testing.

Network Options for the Airport: Estimating Demand and Operability

Unfortunately, the site for T5 does not lie above the existing underground loop, but is almost one km from it. This is sufficiently far to rule out a satisfactory connection by travelator; a dedicated station is required. How this might be

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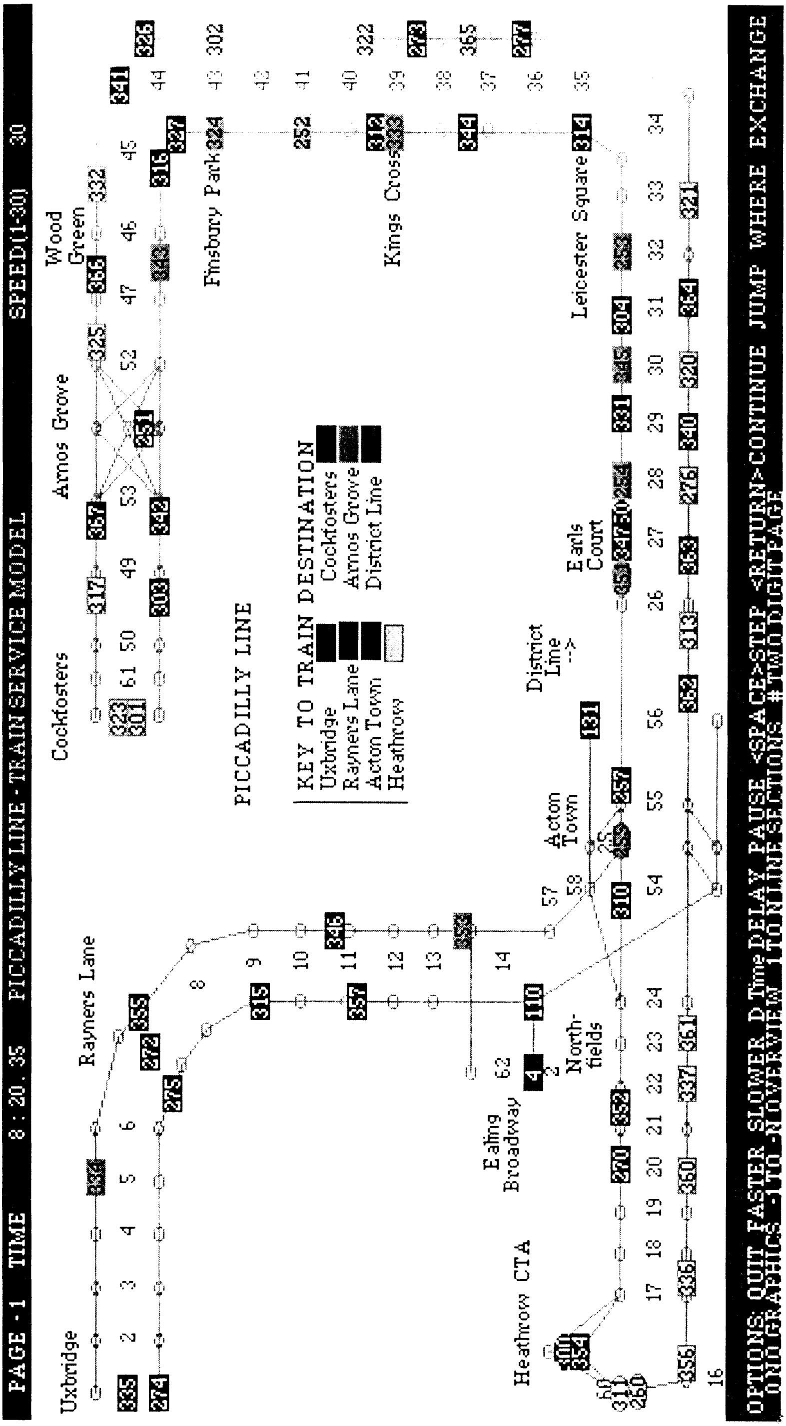
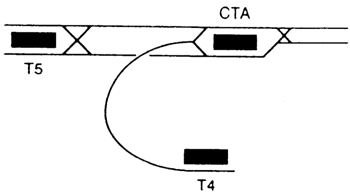
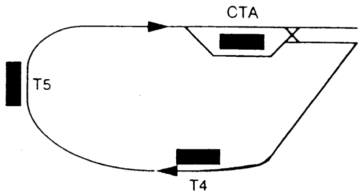


Figure 1. Example of Graphical Output from the Train Service Model of LUL's Piccadilly Line

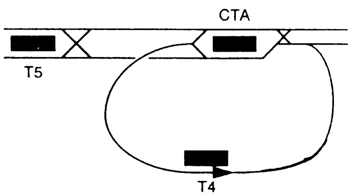
achieved, however, is a completely different matter. A large number of schematic options were devised (including those shown in Figure 2), and subsequently tested on the Network Model.



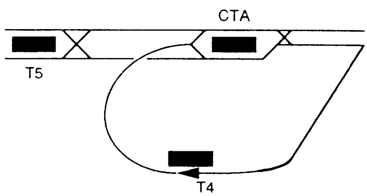
Option 1. Reversed Single-Track Branch to T4



Option 2. Extended Single-Track Loop



Option 3. Anti-clockwise "Merry-go-Round"



Option 4. Existing Loop Retained

Figure 2. Schematic Representation of Options for the Extension of the Piccadilly Line to Heathrow T5 (not to scale)

It was obvious quite quickly that some of the options were less attractive than others. For instance, serving T4 as a single-track branch from CTA (option 1) was shown to be difficult because the length of the branch (4km, taking four minutes in each direction), together with the required 15-minute minimum frequency, provided insufficient recovery/turning times for the reliability which was required for a service which was running to a destination 25 miles away right across London. In addition, the joint use of the Westbound track near CTA for Eastbound trains from T4 was shown to give insufficient time for all trains to pass over this junction without being impeded by other services.

There were also clearly disadvantages associated with extending the existing loop (option 2), since this would reach T5 on a North-South axis, which could only be accommodated at very low level under the terminal and, critically, below the proposed Heathrow Express extension. Options having a terminus at T5 were to be preferred on engineering cost grounds, since joint use could be made of the box likely to be constructed for the Heathrow Express station.

Using the Network Model was essential if differences in demand between the options were to be ascertained. Whilst other models existed to indicate the likely level of overall demand between the airport and Central London (for instance, BAA's logit-based Heathrow Surface Access Model (HSAM)), these were generally at too coarse a level to distinguish between the options.

Complications: Fares, Quality and the Correct Base

The analysis was especially complicated given the fact that the Heathrow Express services will not be part of London's Travelcard ticketing system but will carry a premium *fare*. They will also have significant *quality* differences from most other rail services in London (e.g. in terms of at-seat catering services, rolling stock specifically designed for the luggage requirements of air travellers, a train always waiting at the London terminus, and so on). In addition, the one-way operation of the existing Piccadilly line loop means that any new service may abstract more passengers travelling from London to the airport than vice versa, since the Piccadilly travelling time in the reverse direction is four minutes less. Even so, Heathrow Express, with its 16-minute journey time to Paddington, will be substantially quicker for many passengers, even if less frequent (four trains per hour are proposed).

After taking into account the various differences between the two rail services, estimates were made of the impact of Heathrow Express services on existing Piccadilly line demand. Alternative approaches included the HSAM model (itself using passenger behaviours determined from Stated Preference (SP) analysis), or manual methods of analysis based on generalised cost. As a result of these analyses, LUL adjusted the fare levied within the Network Model for passengers travelling on Heathrow Express services, as one of the few ways available of simulating service quality within a conventional network model.

However, estimates of demand for Heathrow Express services varied considerably, depending upon the method of analysis. Although the mode choice preferences were derived from SP analysis, they seemed unintuitively high to LUL. Technical discussions soon highlighted the main reason for the difference - the Value Of Time (VOT) applicable for the journeys. LUL's Network Model

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had been using a normal LUL VOT for underground journeys, which is approximately £5 per hour, whilst the SP work was based on the normal VOT for air passengers (around £30/hour). Clearly, passengers with higher VOTs are less likely to be deterred by the higher fares of Heathrow Express. Additional survey work confirmed these VOTs - but passengers arriving at the airport by LUL were also shown to have LUL VOTs. In other words, the existing LUL service appeals primarily to passengers with relatively low VOTs. However, many Heathrow Express passengers are likely to be taxi users at present, since this is the currently preferred mode for passengers with high VOTs. LUL and Heathrow Express may therefore only compete at the margin; the main effect of HEx may therefore be to increase the rail mode share of surface access to Heathrow from its current 22%. With this understanding, the estimates of demand converged.

When assessing a project, however, care must be taken when determining the *correct base case* for comparison of options. Base cases considered here included no Terminal 5 at all (unhelpful), T5 without any rail access (thought unlikely), and T5 with HEx and Crossrail (unlikely, since the extension of Crosrail to the airport is currently in doubt). The base case taken here was therefore no Piccadilly extension to Terminal 5, although some passengers would still be expected to access T5 using the Piccadilly line and a shuttle bus from the CTA. Even after this traffic is included in the base, a net increase in Piccadilly line demand from the extension of several Mppa is forecast.

The Better Options

Two network options remained as serious contenders; engineering estimates showed that the two had similar construction costs. The first (the 'merry-go-round' option, option 3 in Figure 2) comprised a double-track extension from CTA to T5, with a circular feeder service, running only in an anti-clockwise direction, constructed from the remains of the T4 loop. The second option (option 4) also constructs a double-track extension from CTA to T5, but retains the existing loop, with around one in four trains expected to use it.

The Train Service Model was run to examine the impacts of the proposed services on the rest of the Piccadilly line. This was crucial; although Heathrow is an important market for LUL, it only comprises 6% of traffic on the Piccadilly line, and retention of the remaining 94% of traffic is vital. In fact, neither of the two remaining options were shown by the TSM appeared to have a significant impact on the journey times of Piccadilly line passengers; simulation in a number of conditions showed that service reliability might even improve, because the existing loop prevents the timetabling of layovers which can be used to recover from disruptions.

Forecasts were required for two distinct dates: 2002, when T5 is expected to open, and 2016, when it is expected to be at its full capacity. Interpolation between these two dates was carried out using a traffic build-up curve.

The Optimising Process

The two remaining options were extremely similar in their performance, although there were differences. Option 4 was shown to have:

(a) slightly lower demand;

(b) slightly lower capital cost;

(c) increased operational flexibility (it is very easy to alter the balance of serivce between the termini if this is required); and

(d) the possibility of adjustment to the merry-go-round option if required at a later date (when demand will have built up), by subsequent construction of the South-West curve at Hatton Cross.

Item (c) was of particular concern to underground operators, not only in order that they can maintain the best possible service during periods of disruption, but also because rebuilding work is also expected at terminals 1-4. When this happens, aircraft are likely to be diverted to different termini for a year or two, and LUL will be able to respond effectively.

Although several million passengers p.a. are expected to use the extension, the costs of underground railway construction, and its subsequent operation, are sufficiently large to prevent overall profitability based on rail revenue only, as has previously been hinted at by the author (Harris[6]). Additional sources of funding are therefore required. One possibility is government grant; the British Government will, for selected projects, provide some funding if the time savings to passengers and other benefits exceed the net cost by at least 1.3:1 (a Benefit:Cost ratio approach), but they need to be satisfied that the scheme being presented to them has been optimised. One issue that typically arises in negotiations over such grants is whether or not farebox revenue has been maximised.

This lead to the consideration of premium fares on the LUL extension. Although in general, premium fares can theoretically be used to improve scheme viability (even at the expense of some social benefit), the opportunity

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for premium fares in this case is limited because of the existence of the HEx premium-fare service. Although LUL services will generally be of lower quality then HEx (in the sense that they are not specifically geared to air passengers), they are also expected to be much cheaper (typically £2.50 for a single trip to Central London, compared to £7.50 on HEx). With such obvious rail competition (irrespective of that accruing from taxi, bus or private transport), the potential for premium LUL fares is clearly limited. As the price differential is reduced, the Network Model showed that, as expected, traffic merely switches from the Piccadilly line to Heathrow Express.

Conclusions

This work has examined the extension of the London Underground network to a new air terminal at Heathrow airport. The analysis has been made especially difficult through the large number of options and variables, including the lack of knowledge of a fast rail link to the airport currently under construction. A number of network options have been examined (both with and without Crossrail), whilst network models have also had to incorporate service quality elements (such as at-seat catering) and fares differing by route. Options performing poorly in train service terms were highlighted by using the Train Service Model, but the decision between the two remaining options was made on a number of criteria including operating flexibility, once it had been shown that the financial cases for these two options were very similar.

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