Abstract

The London Underground is presented as a case study for the exploration of configurational effect on a global public transport networks. Several over ground and underground configurational models are analysed against entry/exit movement level of each tube station using multivariate analysis to explore the relationships between configuration and other network variables. This paper examines two approaches towards understanding the factors influencing foot traffic to and from public transport stations; the first derived from standard public transport planning, the second derived from space syntax configurational approaches. Standard transport planning considers primary variables; employment density, population density, land use, and buffer distance from stations. The configurational approach to transport activity holds that the performance of each transport stop will be influenced by its position in the network structure as much, if not more, than from other factors such as land use and density.

Two hypotheses are tested. First, above ground spatial configuration influences the degree of boarding and alighting activity at Underground stations. Second, the topological configuration of the below ground Tube network itself is a significant measure of boarding and alighting activity. Preliminary results demonstrate that the below ground configuration model correlates with all day 120 station activity with an r-squared of 0.54 Above ground configuration also appears to influence station utilisation, but is more difficult to define without more precise, non-metric catchments area definition. The presence of multimodal interchanges such as regional rail or bus services also affects utilisation. These findings suggest that a better understanding of area definition is important to gain an understanding of the ‘sphere of influence’ surrounding public transport stops, and that additional research resolving the complexities of modelling above- and below-ground systems in tandem is necessary. The paper concludes with a discussion of the necessity to include public transport systems in conjunction with pedestrian and vehicular modes to create a fully configurational urban simulation model.

1. Introduction

London is one of the world’s largest capital cities, with a population of over 7 million and an area of nearly 618 square miles. Over a million people each day travel into central London for work; over 60% of them using the London Underground public transport system. There has been a 70% increase in the demand for travel on the Tube in the last decade and London relies upon its “Tube” as a major social and economic enabler for the city. The oldest metropolitan subway in the world is also now a major business, with over 12,000 employees providing over 3 million trips per day. Other underground systems across Europe have experienced similar increases in demand during recent years,
solidifying underground rail’s importance to modern European capitals.

An understanding of the factors which influence underground public transit systems like the Tube is important if such demand is to be met efficiently. Transport planners traditionally manage such demand through the use of complex travel demand models which can cost hundreds of thousands of Euros to construct and maintain. Such models often use primary variables; fare level, demographics, employment density, land use distribution, and a gravitational decay function moderated by distance from transit stations. Other factors such as the distance between stations, stop placement standards, and policy or economic considerations are also play a role in such models\textsuperscript{1}.

The benefits of the recent JLE extension were initially forecasted by the 2000 Railplan model runs. Railplan is a morning peak period model\textsuperscript{2}. Unfortunately, as deplored by the Transport Studies Group University of Westminster in their final report “the forecast and underlying methodology do not appear to have been well documented.” The same lack of methodology detail is to be found in the Buchanan report. However, it is said that the basic procedures used to forecast the demand for urban transport have not changed appreciably since the traffic forecasts were prepared. Primary reliance is based on the LTS Model. This is a standard zoned land use-employment density transportation gravity model which has evolved over time.

The report continues on evaluating the model. RailPlan suffers from the disadvantage that it only deals with public transport modes and does not model the important trade off between the quality of public transport and the use of the private car. Although the current version of RailPlan does model all bus routes in London, it does not model all short hop bus trips within a single zone. This may underestimate the levels of usage on the bus network at certain locations. Such a criticism is valid to our configurational approach and current study are undertaken to start to understand bus network and ridership with a configurational approach.

The output from RailPlan that has been used is limited to the three hour AM peak period. Travel patterns in London and other major cities are very different in the peak than at other times of day. Whilst it is clearly right to focus initially on the peak, we believe that the effective design and appraisal of a major transport investment also requires that a representative off-peak period is also modelled in detail.

A key point that has come out of our appraisal of the JLE is the crucial importance of anticipating the effect that any transport investment will have on land use. We appreciate that this is not easy to do, but it is of vital importance to improve the quality of land use forecasts which are needed both for the detailed design and for the overall appraisal of the investment. This might best be achieved by using a fully interactive land use-transport model for forecasting the impacts of major new transport investments. So doing should also encourage the early implementation of any beneficial land use change which can expect to be stimulated by the project. It seems that this point is a weakness of vehicles demand model too.

The problem definition proposed was first to evaluate in what way the underground performance considered as a global line network that is a network of lines without the frequencies and departure time of the line is affected by a network effect\textsuperscript{3}, second, to

\textsuperscript{1} TRL Report (2004).
\textsuperscript{2} Transport Studies Group University of Westminster (June 2004), p. 45. Colin Buchanan and Partners (May 2004), p.3-1. Note that the reappraisal is as well based on a morning peak model (7.00 to 10.00).
\textsuperscript{3} Hillier B. Iida S. 2005.
evaluate in which way the spatial accessibility of each tube station affect performance.

1.1. Challenges in standard appraisal of new transport investment impact

Space Syntax is a theory of the city that has originally intended to show the importance of topological configurational analysis and its interplay with metric integration for the understanding of relationship between pedestrian, cyclist, vehicular movements and land use distribution and density\(^5\). Public transport study has so far not been addressed by space syntax research community. We summarise below issues at stake in standard impact appraisal of new transport investment. These are complex issues linking spatial and socio-economic analysis.

The JLE was quantitatively appraised using the standard procedures for the assessment of transport costs and benefits at that time. Since then the procedures for the appraisal of transport investment schemes have been revised, with the development of the New Approach to Transport Appraisal\(^6\) (NATA) part of the Economic Impact Reports (EIRs) and the Guidance on the Methodology for Multi-Modal Studies\(^7\) (GOMMMS). This is particularly the case of the evaluation of regeneration, renewal and regional development (nicknamed the 3Rs) that have specific spatial focus.

The weakness of the approach is that there is no recognised way of comparing the relative importance of the different indicators. The appraiser can and should predict and estimate the consequences, sometimes in monetary terms, of what is expected to happen. There is, however, no one set of criteria which can be used to say whether those consequences are such as to justify the investment.

A particularly important issue for appraisal is the extent to which changes in land and property values should be included. Traditionally, little attention has been paid in the appraisal of transport investment to the impact of the investment on land and property values. This is because it has been argued that the increase in land values brought about by a new transport investment is due to the change in transport accessibility, the benefits of which are directly measured as part of the transport cost benefit analysis in terms of travel time savings. To include both these benefits and the increase in land values would therefore be double-counting the same underlying benefit. However, there are several counter arguments that parallel the multiplier effect of movement sensitive land use locations:

First, if changes in land and property values are used as a major means of financing new transport investment, as TfL and others are currently proposing, then it will be essential to estimates these values and include them in some form in the appraisal.

Second, only a part of the increase in property prices is likely to be directly attributable to the increase in accessibility. After a short period of operation of the JLE, any further uplift in value is likely to be due to multiplier effects associated with enhanced area attractiveness due to the initial accessibility-stimulated investment. These agglomeration

\(^4\) Transport Studies Group University of Westminster (June 2004), p. 159-168.


\(^6\) NATA arose from the Government White Paper ‘A New Deal for Transport: Better for Everyone’ (DETR 1998). NATA aims to deal consistently with competing proposals, be even handed across modes and take account of a wide range of effects.

\(^7\) http://www.webtag.org.uk/
Third, increases in property prices and land values have important distributional effects. For example, anecdotal evidence that some low paid employees have had to move to cheaper accommodation outside the area and commute in. Further, those who gain financially from price increases may be different from those who benefit from time savings.

Finally, whether or not changes in land or property values are used to help provide finance or feed directly into the appraisal, it will always be important to include an assessment of the potential effect of the proposed investment on land and property values. Changes in land and property values are crucial to understanding the regeneration process. They represent one of the main drivers behind proposals to develop or redevelop areas. They give a clear indication of market demand for property in an area; the prevailing prices largely determine the attractiveness of refurbishing or redeveloping a site, and influence the density at which it is worth constructing new development.

Until this point very little attention has been given to the effects of network configuration on underground rail travel in these models. Findings from past space syntax research has found that network effect and structure powerfully corresponds to pedestrian, vehicular, and cyclist movement. It is argued that similar effects may be found in underground transport networks in general, and that movement levels in the London Underground are influenced by the configuration of Tube station in the network in specific and by the location of the station in the pedestrian network.

Qualitative evidence suggests that this may be the case. The recent Jubilee Line Extension (JLE) was one of the United Kingdom’s biggest construction projects as well as and the largest addition to the London Underground network in more than 25 years. This project created a 16-km-long extension of the Jubilee Line, forging a direct link between London’s West End and the East End. The primary reason for constructing the extension was to assist the regeneration of areas of the East End, including the Docklands and
serve Canary Wharf. But a report on the JLE made by Colin Buchanan and Partners for Transport For London (TfL) found that, “the busiest JLE sections are currently not, as forecast; from London Bridge to Canary Wharf but further west”\(^8\). The sections that have therefore taken most advantage of the JLE were those already well connected to the Tube network. This discrepancy between the JLE’s planned utilisation and its actual use has been explained in terms of different employment levels from those forecasted in the original model\(^9\). This paper argues that although this may be the case, the importance of network configuration has not been adequately researched and that it may play a more important role than traditional models expect.

This paper explores this approach through two hypotheses. First, that above ground spatial configuration influences the degree of boarding and alighting activity at Underground stations. Second, that the topological configuration of the below ground Tube network itself is a significant measure of the performance of each station.

2. Methodology

2.1. Rail Transport Data

To test these hypotheses, data was gathered on 2002 weekday entry/exit statistics provided by Transport for London\(^10\). This information provided detailed records of the amount of use each station received through the day, covering all stations in the Underground network except those exclusively served by a sister rail network, the Docklands Light Rail (DLR) line.

This data, analysed for weekday periods, is divided into five time periods. These were:

- **Early A.M**, defined as 4 A.M to 7 A.M
- **A.M Peak**, defined as 7 A.M to 10 A.M
- **Inter Peak**, defined as 10 A.M to 4 P.M
- **P.M Peak**, defined as 4 P.M to 7 P.M
- **Evening**, defined as 7 P.M to 10 P.M

Preliminary analysis of the data found that:

- the different periods showed a low correlation (\(r=0.5\)) between the total entries and exits and the entries in early morning. This can be easily explained by the fact that all the stations don’t have the same hours of opening. It was therefore decided to exclude the Early AM time period from the study.

- stations performed differently, but fell into two general performance profiles. These were classified as Type A and Type B stations, which are outlined below:

  - **Type A** - Those stations which had more exits than entries during the A.M peak time and inversely less exits than entries during the P.M peak time. Entries and exits during Inter Peak were found to be nearly the same for these stations.

\(^8\) Colin Buchanan and Partners (2004b).

\(^9\) Transport Studies Group University of Westminster (June 2004).

\(^10\) http://tube.tfl.gov.uk/content/stats/
Figure 272: Differential plot between entries and exits AM and PM peaks, all day - Type B.

- Type B - Those stations which had an exact opposite profile: more entries than exits during A.M peak time and more exits than entries during P.M peak time. The differentials are not as extreme as for type A.

Not surprisingly, 80% of the stations of Type A are found in the inner zone of travel in the Underground network, known as Zone 1. Over 80% of Type B stations were found outside of this central zone. Several Type A stations were found outside of Zone 1, but were all easily explained by the fact that they were located in commonly identified local centres such as Camden Town, Hammersmith, etc.

Both types A and B, have a remarkable balanced entry / exit totals. The relative balanced total between entries and exits for both types encouraged the idea of looking at the global performance of each station without making any distinction of type or between entries and exits.

Entry/exit data for all stations were found to be highly non-normal and was therefore normalised using the fourth root of observed station activity. This variable was then regressed against spatial variables generated during the modelling process described below. The results of this analysis are described in Section 3.0.

2.2. Configurational Transport System Model

Because no published precedent for analysing underground systems was found in published space syntax literature, two approaches were tested\(^\text{11}\). The first was to model underground connections as a graph with stations as the nodes direct connections between them. But the position of the station in its “above ground” spatial context was thought to be equally

\(^{11}\) We acknowledge discussions with Alan Penn, Tim Stonor and Shinichi Iida in providing us with ideas derived from previous experimentations.
important, so a second, separate model was created which embedded Tube stations within their urban context.

The first model compared underground network integration with observed entry and exits at each station, while the second model compared above ground integration with this use data. It is important to note that stations lying outside of the Greater London axial map used in this study were excluded from the study. Underground rail stations which connected to the larger regional rail system (such as Waterloo or Victoria Station) were also excluded, as such stations clearly experienced increases in usage due to their larger global connections. A total of 120 stations were modelled according to this criteria.

2.2.1. The Underground Model

To construct this spatial model, each portion of underground line between two stations was drawn as a single axial line. This approach was taken because individuals riding on the Tube have no actual spatial referents to take navigational cues from. Instead the abstracted network diagram of the Tube map is their only navigational aid, resulting in a condition of abstracted node-to-node connection below ground. Indeed, qualitative evidence suggests that passengers gauge their travel time in terms of the “number of stations” between A and B as opposed to more traditional metric or geographic considerations.

Because of the time and effort involved in switching between two Tube lines, it was hypothesized that such a change would have greater topological cost than simply staying on a train going between two stations. The topological cost of such a change was evaluated in two ways. First was through the addition of an additional axial line, resulting in two steps of depth as opposed to just one, and second through the addition of a third line resulting in three step depth changes. The three step approach was found to correlate best to observed movement at the global level and was therefore used for the remainder
of this research. Such a cost could be tested by conducting a stated/revealed preference study between routes where a change is necessary against a route where no change is needed but are between 2 to 4 stations further away.

After construction, the underground graph model was processed using traditional space syntax techniques to compute measures such as integration, connectivity, etc. These measures were then compared to actual station movement rates for the first stage of analysis; described in more detail below. It was assumed that the train frequencies on the different lines were similar.

2.2.2. The Above Ground Model

To calculate the integration of Tube stations in their above ground context posed additional problems. The first and arguably most intuitive idea was to select all the axial lines which connected to the entrances of a station and then assign an integration value to the station based on the sum or mean of the integration value of these lines. This technique proved to be problematic because stations located one along several low integration lines often had higher summed integration values than those located in higher integration areas but lying only on a single axial line. Similar confounding effects were found when the mean was taken if the number of tube station entrances was varied.

To determine the best method, two separate above ground models were created. In the first, the three most integrated lines within three steps of the station were summed. In the second, the average integration value of all lines within a 500 meter buffer was taken. These values were then tested against the number of passengers entering or exiting a station at both local (R3) and global (RN) levels. Although the difference between these two models was slim, it was found that using the average R3 integration of all lines within a 500 meter catchment area performed the best and was thus used for the remainder of
Configurational Exploration of Public Transport Movement Networks: A Case Study, The London Underground

Figure 275: LEFT: Centrality boundaries and tube station locations. 35 out of the 40 busiest stations and 82% of all tube journeys start or end in central London (Zone 1). RIGHT: London Underground network, configuration Rn analysis before the JLE.

the above ground analysis.

Both of these models (underground and above ground) were then regressed against observed use at each station to determine the effect of network configuration on Tube travel.

3. Findings

Three major results were found in this study; one stemming from the underground correlation model, one from the above ground model, and a third from a combination of these variables into a multivariable regression analysis. These are presented currently.

First, it was found that the underground network model value for each station correlated with entry /exit $r = 0.73$, approximately 54% of variance in station entry and exits ($r^2 = 0.54, p < 0.0001$). Second, it was found that the above ground network model correlated to entry/exit $r = 0.59$ approximately 36% of variance in entry and exit data ($r^2 = 0.36, p < 0.0001$). Finally, a correlation $r = 0.79$ approximately 63% of the variance ($r^2 = 0.63, p < 0.001$) was found when these network models were combined.

The residual, the deference between actual and predicted of the above model (the underground variable and the aboveground variable) was also analysed. Among the stations that were over-predicted (or when the predicted amount of passenger flow was too high), several different findings were produced.

First, station that had a very low total number of daily passengers (less than 5,000) appeared to be poorly represented by the above ground model. Such stations, including Royal Oak, Surrey Quays, and Goldhawk Road for example, were all located in very low integration areas. This suggests that the above ground model may have either failed to capture the full impact of the spatial segregation of such stations or that such stations may have also been highly segregated in the underground model as well.
Second, stations which were very close to each other may have suffered from competition in use, resulting in lower than forecasted movement rates. The Tube stations of Bayswater and Queensway are a good example - two stations which are located less than 200m away from each other.

Among the stations that were under-predicted (or where the daily activity was found to be lower than in actuality), several issues were found. The suburban and terminal train stations were consistently under predicted. Adding dummy variable did not perform. We have chosen to exclude them from the data set. The stations located in very popular areas of London such as the West End (including Oxford Circus, Tottenham Court Road, Leicester Square and Piccadilly Circus) were found to experience more activity then their above ground integration would suggest. It is possible that the addition of other variables acting as multiplier effect such as employment density and land use may account for this discrepancy\textsuperscript{12}.

Among the stations over-predicted by the underground model, a majority were stations where the Tube line separates into two or several branches. As the models take the sum of the value of the integration Rn of the lines, the predicted Y-variable is much higher for a station where the Tube line branches out. This seems not to be a problem if the branches are long enough as they can be then compared to new Tube lines that generate an important users flow. However in case of small branches with few stations like the ones on East London Line, the model seems to give a value of the underground variable too high. As expected this is line with the very high correlation found between line length and overall performance. An additional variable regarding the depth of the Tube lines/branches that could add a weight on each line may solve this problem.

4. Discussion

This case study of a configurational modelling of the London Underground clearly shows that both the topological configuration of the underground and the spatial accessibility of the above ground station surrounding are related to the number of passengers boarding and alighting at each station. Underground configuration appears to have a particularly important influence ($r^2 = 0.54$) and underlines the power of the network effect on underground general movement.

4.1. Conclusion

This pilot study suggest that configurational analysis can lead to a better understanding of the influence on the level of all day movement of the configuration of a public transport network. The interaction of line connectivity on overall system performance which is not well taken into account or simply ignored by standard public transport demand model

Another important aspect that is underlined by this paper concerns the aboveground modelling of the station surroundings: it is suggested that further research is necessary to:

- identify configurational boundary definition encompassing each station and/or sub centralities catchment’s area in the light of previous configurational analysis of pedestrian network.

\textsuperscript{12} See ODPM (April 2004).
• determine how the configuration make up of each station and/or sub centralities influences the level of boarding and alighting.

This pilot study uses of local integration measures suggest that it could lead to a systematic identification of sub-centralities and a better understanding of their roles in the global performance of a station. This approach could be compared in term of similarities and differences to metric catchment’s area and town centres boundary definition.

These first results and comments show that several aspects of the configurational effect are still to be developed and improved. This is particularly important in the wake of transit oriented development, where increased residential density with mixed use developments is seen as more likely to create a lively well-used location, and not just an interchange point with residential ghetto. There is a need to create a pleasant and safe environment around the public transport node in order to encourage walking to the station, interchange or stop.

This study show promising results of the underground model and demonstrate the importance of understanding the configuration effect of the LU network. This may help to prioritise variables and disentangle demand forecasting difficulties. Current work on buses network will make possible the investigation of an all mode configurational effect analysis, while keeping each variable separate.

**Literature**


A. Chiaradia, E. Moreau, N. Raford


RICS Policy Unit, (October 2002) Land value and Public transport, Stage 1 - summary of findings, ODPM.


Internet websites http://tube.tfl.gov.uk/content/stats/www.trainweb.org/tubeprune/