# A city-wide, capacity-constrained parking choice model

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## 1. INTRODUCTION

The supply of parking is considered to be a major factor in determining travel patterns within urban areas, as shown by the high number of policy interventions that focus on parking. These include parking meters, workplace parking levies, red routes, and many others. However, the behavioural mechanisms involved in determining individual parking choice are complex and difficult to translate into standard highway assignment programs.

This paper concerns an enhancement of the London Transportation Studies (LTS) model, which is the major multi-modal strategic modelling tool owned by Transport for London (TfL). TfL was created in 2000 and is the integrated body responsible for the transport system in London, England. Its main role is to implement transport strategies as devised by the Mayor of London and to manage those London transport services for which the Mayor has responsibility.

LTS is one of the largest strategic models in the world and it is used in a wide range of applications, providing forecasts using a comprehensive database of travel patterns within the London area.

One of the key features of LTS is the very large scale of the surveys on which it is based, including household travel diaries, public transport surveys and a large set of cordon counts. The model has been carefully calibrated on these datasets and then validated against further data to establish its robustness.

In 2008, TfL commissioned a series of independent reviews of its current transport modelling capability with a view towards developing a new generation of models better able to address its longer term policy analysis requirements. This comprehensive update would be lengthy, so a Medium Term Enhancements (MTE) programme was therefore instituted to improve both the model's fit to baseline observed data and the robustness of future LTS model forecasts.

Part of this programme was the development of a new parking choice model to replace an existing, simple approach. This existing model was incorporated into the highway assignment process, using deterrence curves on network 'parking links' to increasingly discourage traffic from travelling to zones as parking supplies were occupied. However, this model was considered to have a number of weaknesses, ranging from its application to only a subset of all London zones, to a lack of an explicit representation of parking capacities and different parking types and tariffs.

The new, more sophisticated model that has been developed is now a stand-alone component which interacts with mode and destination choice models to directly modify car demand to different zones. The main improvements over the previous model are in the treatment of parking choice and capacity constraints. A mechanism has been developed to take account of explicit supplies of parking spaces in all model zones in London, allowing the modelling of charge- and supply-based parking policies, as well as increasing the realism of the parking-related behaviour of travellers.

This paper is structured as follows: Section 2 provides the necessary background to the LTS model; Section 3 describes the previous parking model approach; Section 4 examines the new parking model processes and data, Section 5 outlines initial results, and in Section 6 we conclude.

Any and all opinions expressed in this paper are those of the authors and do not necessarily represent the views and policies of Transport for London.

## 2. THE LONDON TRANSPORTATION STUDIES (LTS) MODEL

### 2.1 LTS Model Background

LTS has an internal study area made up of zones which cover the Greater London Authority (GLA) and the remaining areas within the M25 orbital motorway. The GLA is the region covering the City of London and the 32 London boroughs, having an area of over 1500 $km^2$ and a resident population exceeding 7.7 million people. Trips made by residents of this internal area on a typical working weekday are fully modelled, whether within or into/out of the area. Also modelled are trips to and through the study area made by non-residents and visitors.

The LTS demand model is calibrated using data from 2001 household survey and travel diary data, though the current base year is 2007.

The presentation of results and the representation of some input data are often made on the basis of five regions:

- Central London;
- Inner London;
- Outer London Boroughs;
- Annulus Area (remaining area within the M25 orbital motorway); and,
- External Area (all other modelled areas).

The first four of these combine to form the LTS internal area, with the GLA comprising the first three. The regions are shown in Figure 1.

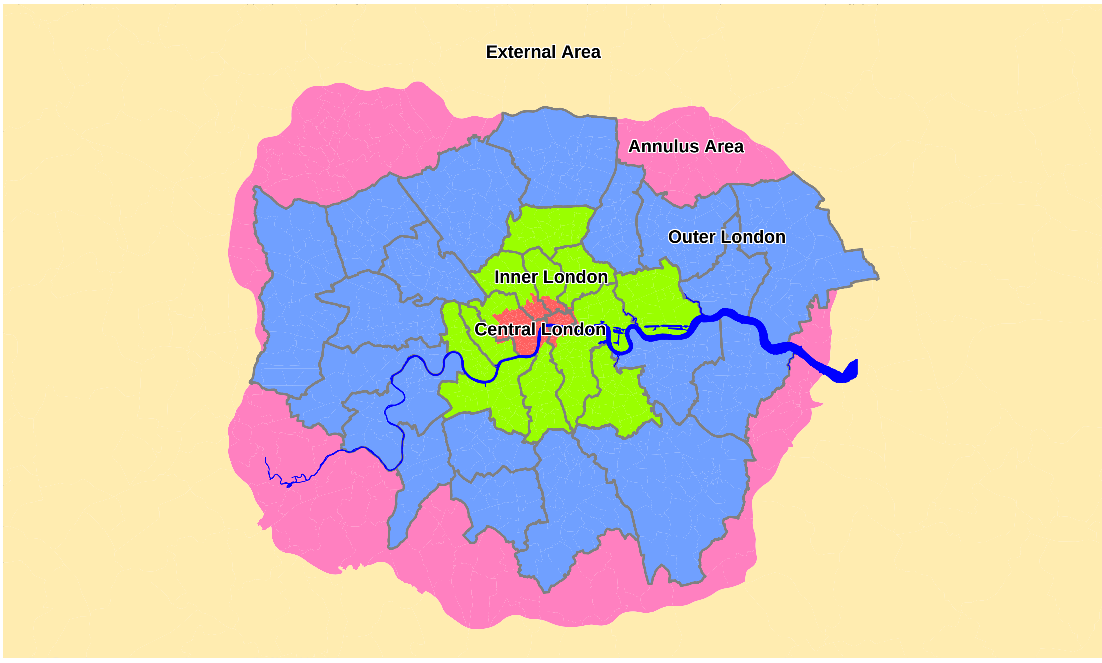

**Figure 1: Standard reporting areas of the LTS model**

LTS considers three weekday time periods:

- Morning peak (mp) 0700-1000;
- Inter-peak (ip) 1000-1600; and,
- Evening peak (ep) 1600-1900,

three main modes:

- Private car;
- Public Transport (PT) – bus, national rail, London Underground and Docklands Light Railway; and,
- Non-motorised modes – walk and cycle,

and seven journey purposes:

- Home-based “white collar” work (hww);
- Home-based “blue collar” work (hwb);
- Home-based Employer’s Business (heb);
- Home-based Education (hed);
- Home-based Other (hbo);
- Non-home-based Employer’s Business (nhe); and,
- Non-home-based Other (nho).

The LTS parking model considers only the hww, hwb, heb and hbo purposes.

## 2.2 Description of LTS Sub-models

A number of sub-models interact with each other to form the full LTS model. These modules are:

- PCOTE – Car Ownership and Trip Ends;
- DMS – Distribution and Mode Split – generates all-day trips in production/attraction (PA) format;
- PVC – Person to Vehicle Conversion – generates time period trip matrices in origin/destination (OD) format;
- Parking Model;
- Highway Assignment Model; and,
- Public Transport Assignment Model.

Each journey purpose is treated independently for distribution and mode choice, but they are combined into a smaller number of user classes within each assignment model.

Figure 2 shows the full structure of the LTS model components, together with interactions and iterative loops. The main outer supply-demand equilibrium loops iterate around seven cycles between the DMS and the assignment models via the PVC module. The Parking Model can be seen at the centre right operating to balance parking supply and demand between the DMS and PVC modules and applied in three additional internal loops within each main cycle.

Further information on the LTS demand model mechanisms can be found in Raha (2008).

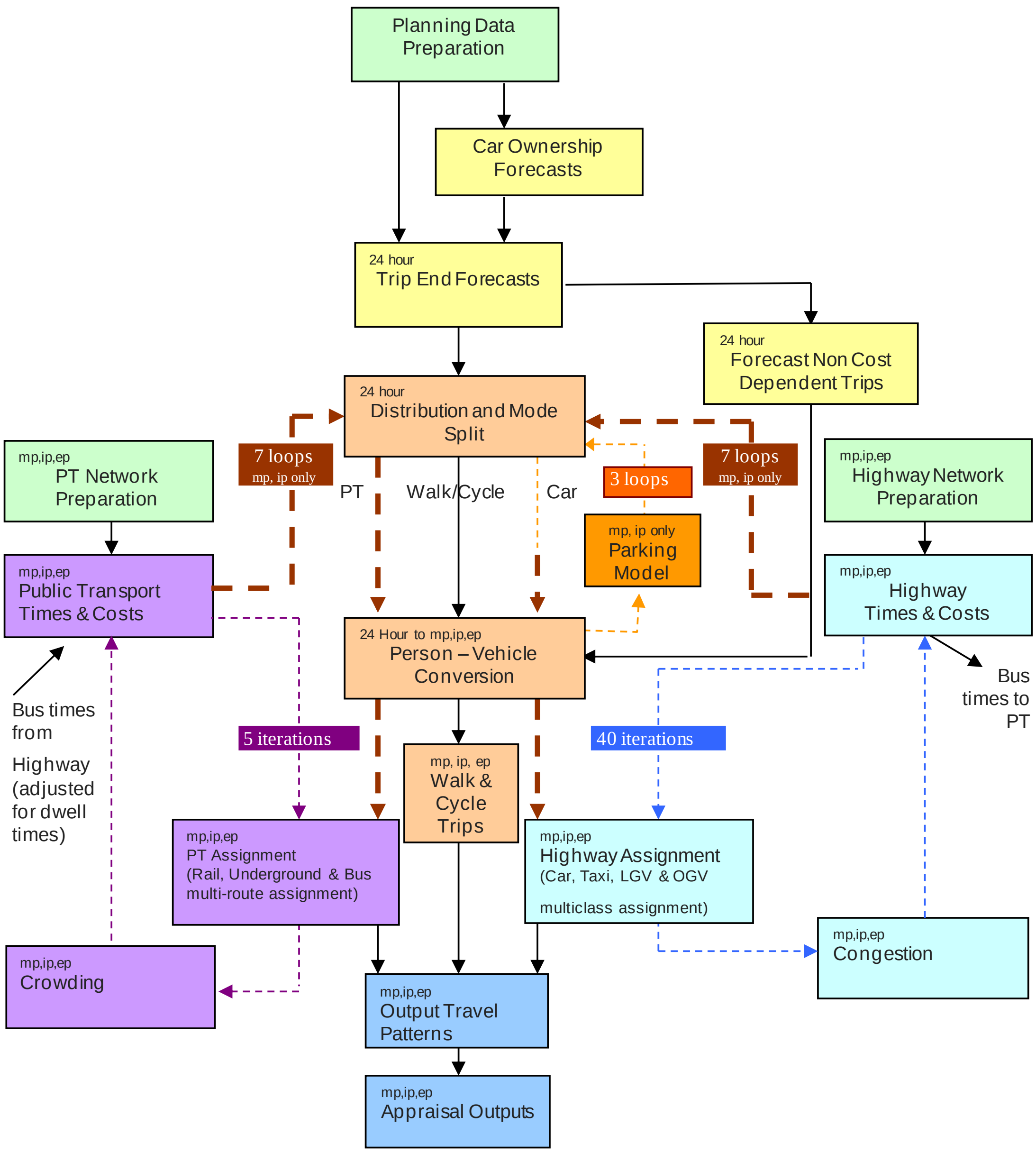


**Figure 2: LTS model structure**

## 2.3 Synthetic and Observed Trips in LTS Calibration

It is important for understanding of the parking model's algorithms and data requirements to appreciate the distinction between synthetic and observed trips as used in the calibration of LTS.

The synthetic OD data produced by the PVC for 2007 are obtained by using costs derived from the assignment of validated 2007 OD trip matrices. The observed and synthetic OD matrices are derived from different data sources after processing by different algorithms (logit choice models and matrix estimation). They are therefore expected to differ, though it is hoped that the differences are not very large.

To ensure internal consistency between the PVC outputs and the assignment matrices in 2007, LTS uses additive quantities called *deltas* which are defined by time period, mode and assignment user class so that with the deltas added to the synthetic matrices the required observed matrices are reproduced. The same deltas that are derived for 2007 are used in all runs of LTS in future years.

## 3. OVERVIEW OF LTS PARKING MODELS

### 3.1 Background

Prior to the MTE Programme, LTS used a network-based representation of parking as part of the highway assignment model to reflect the ability to park in Central London and in parts of the London Docklands. In particular, it dealt with parking-associated costs through the insertion of *parking links* between the highway network and zone centroid connectors.

Each link had a speed/flow curve which provided a crude approximation to the time taken to locate a space and park. As the flow to a zone increased, so did the time taken to traverse the parking link, reflecting the reduced availability of parking spaces. There was no upper limit imposed on the curve: it was simply extrapolated to continue increasing as capacity was exceeded. Therefore there was no limit to the demand that could, in principle, be accommodated with this arrangement.

This earlier parking model contained no information pertaining to the true availability of parking in each zone. Instead, the number of trips in the reference (base year) matrices which terminated in each parking zone was used to calibrate an initial position on each zone’s speed/flow curve.

### 3.2 Weaknesses of the Previous Parking Model

For car demand to a given zone to be modelled realistically and modified if necessary, a parking model needs to represent the costs associated with parking in a particular location, together with some form of capacity constraint,

The cost of parking involves not only the charge levied on a parking space but also the times associated with searching for a parking space and with travelling from the car park to reach the desired destination. Search times are expected to increase as parking supplies diminish, and travellers may well have to park away from their desired destination in order to find a space. Egress times are therefore expected to increase as parking spaces become harder to find.

Furthermore, different areas will have varying amounts of parking of different types – such as residential spaces, workplace car parks, on-street parking, and so on – which in turn will be subject to distinct charging regimes.

With this in mind, the simple link-based parking model used previously was deficient in a number of respects:

- Limited coverage – only zones in Central London and around the Docklands were affected;
- No distinction between different parking supply types;
- No differential responses by journey purposes;
- No explicit parking tariffs for different zones;
- No real capacity constraint applied to any parking zone; and
- Segmentation only into assignment journey purposes.

Consequently, the previous parking model severely limited the parking policies that could be modelled within LTS.

### 3.3 The New LTS Parking Model

The new LTS parking model is designed to rectify the deficiencies of the previous model and to provide the facility to model parking policies.

It primarily achieves this by modelling the explicit capacities of different types of parking, and the charges for using them, in almost all of the LTS internal zones. The model is now a separate component of the full LTS model run cycle. It passes information to the DMS sub-model for inclusion in the choices of destination and main mode, and adjusts car demand to the modelled zones to take account of the numbers of vehicles that can be accommodated by the available parking supply.

All zones in the GLA are modelled for parking supply and demand – constituting 879 of the 1285 zones in the whole model.

Of all trip purposes modelled by LTS, four are processed by the parking model: hww, hwb, heb and hbo.

Three different types of parking space are modelled:

- POS – Public Off-street car parks: spaces in publicly accessible car parks;
- PNR – Private Non-Residential car parks: spaces associated with business activities (e.g. shops, offices, leisure activities);
- OS – On-Street parking: spaces on single yellow lines, on-street pay and display, metered spaces, etc.

Different journey purposes have access to different types of parking. For simplicity, PNR spaces are made available to commuting (hww, hwb) purposes only.

Parking spaces of each type in each zone are assigned a cost equivalent to the average charge for an hour's stay.

The parking model is run for the mp and ip periods, with demand in each period being processed independently. The full parking supply in a zone is

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made available at the start of the mp period, with the supply available in the interpeak period dependent on the morning peak utilisation.

The choice of parking location is determined by an absolute multinomial logit model, and cars are permitted to park in zones other than their desired destination.

A demand suppression mechanism iteratively modifies the number of cars travelling to a destination zone if there is insufficient supply available to accommodate all of the demand. The mechanism changes the utilities used in the DMS to discourage car travel to zones which are over-capacity. These utility changes are referred to as *shadow costs*, since they act like increased costs used to make car travel less attractive to certain locations.

# 4. MODEL PROCESSES AND DATA

## 4.1 Total Demand for Parking as Used by the Model

The parking model's purpose is to inform trip distribution and mode choice by passing realistic parking costs to the DMS, which consequently alter the demand produced by the PVC for time periods and journey purposes.

The parking model does not itself directly modify the destinations of any trips in the PVC's output matrices. Hence, the assignment sub-models use the desired destination as the end point of a car journey, even if the parking model had internally allocated a trip to a parking site in a different location.

Not all LTS purposes are processed by the parking model. Education trips are not processed by the parking model as they are assumed not to park. Additionally, the use of shadow costs to reduce trip attractions to overloaded zones will have consequences for the productions of non-home-based trips. Hence, nho and nhe trips are not considered.

The total demand for parking spaces in each zone is derived from *synthetic* car vehicle matrices produced by the PVC. Synthetic demand is used because the "deltas" which convert it into observed demand for assignment are not available at the level of individual journey purposes. An additional complication is that only from-home trips are used. It is not therefore possible to obtain analogues of the observed demand for the purposes that the parking model processes. Furthermore, the synthetic data are, by definition, those trips that are responsive to changes in cost, and so naturally the ones to be affected by the outcomes of the parking model.

The existence of deltas means that the synthetic demand to a given zone may be lower or higher than the 'true' value for any journey purpose. Because of this, any real-world parking supplies that are obtained for each model zone and used as inputs will be mismatched with the distribution of synthetic demand, resulting in indications that in some areas there is insufficient supply when there is plenty, and in others that spaces are overloaded when in fact there is surplus capacity.

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This means that there is no need to use *actual* parking supplies as totals by area, but we can instead use *effective supplies*. These are chosen so as to ensure that in the base year the following situations obtain:

- No excess demand – i.e. all vehicles travelling to the GLA can be accommodated within available supplies; and,
- Reasonable parking space occupancies are achieved for different types of spaces.

Data obtained from another model used by TfL indicated that parking spaces in Central, Inner and Outer London Boroughs were approximately 90%, 30-40% and 20-30% full, respectively, across all parking types. The parking supplies and parameters used by the parking choice model were adjusted to satisfy these requirements at this aggregate geographical level.

However, the detailed zonal distribution of parking spaces within these control areas is calculated initially for each borough from London Parking Supply Study (LPSS: Dale and Hughes, 2000 and Dale, 2005) data. This was augmented with detailed distributional information from the London Area Travel Survey (LATS, 2001) household interview travel diaries, as the LPSS estimates a 'supply rate' for different types parking at London borough level which is not sufficient to distinguish the geographical distribution of parking at the detail of LTS zones.

### 4.2 Parking Areas, Zones and Desired Destinations

Demand to a specific destination zone is not required to park there as, in reality, it can make use of supplies in other zones that are defined as being 'nearby'. In combination, these nearby zones make up a *parking area* and such areas are defined separately for each zone. These parking areas can be quite general, with those for different zones expected to overlap. Using parking areas increases the effective supply that is available to the demand to each zone, but can also lead to competition between demand if their parking areas do overlap.

Because a trip to one zone may be allocated to a parking space in a different zone, a distinction is made between the *desired destination* and the *parking zone*, although the two terms can describe the same location.

Figure 3 shows a schematic representation of demand being distributed among parking zones in overlapping parking areas.

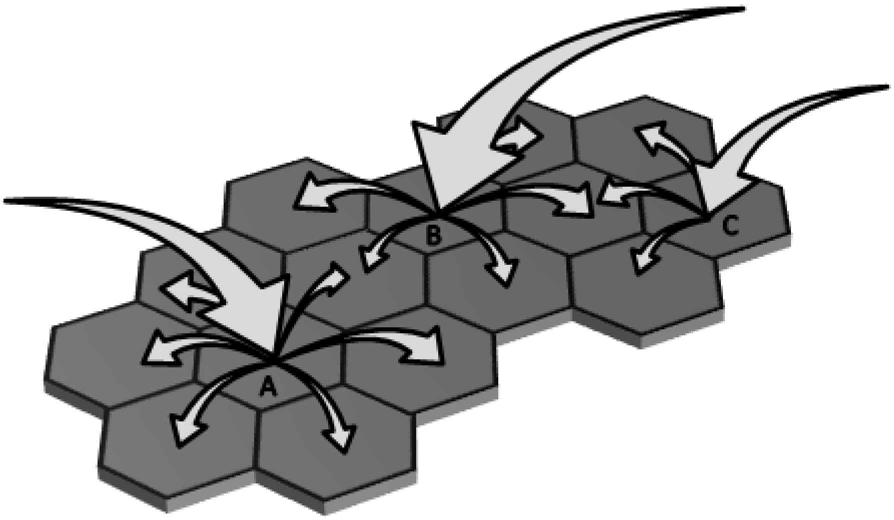


**Figure 3: Demand being distributed among parking zones**

Zones A, B and C are some desired destinations to which demand is allocated by LTS sub-models. Each desired destination has a parking area comprising itself and its nearest neighbours. Zones on the boundary of the modelled region have their parking areas truncated, as shown. It can be seen that the parking areas of these zones overlap, which is generally the case in LTS.

## 4.3 Parking Model Algorithm

The parking model carries out the following steps, considered in the next section:

1) Calculate total number of parking spaces required by zone, purpose and time period;
2) For each desired destination, calculate utility for parking in different parking types and parking zones in relevant parking area;
3) Calculate choices;
4) Allocate demand to available supply;
5) Assess excess demand for parking locations;
6) Check stopping criteria. If a stopping criterion is met, go to step 10;
7) Link excess demand in each parking site to desired destinations;
8) Redistribute excess demand from desired destinations to sites with available supply;
9) Go to step 4 to continue redistribution of excess demand;
10) If parking model has been run for the mp period, calculate parking supplies for the ip period;
11) Calculate average parking costs paid by those who could park, and calculate shadow costs for overloaded desired destinations;

## 4.4 Parking Model Algorithm in Detail

The following notation is used in this section:

- *i* denotes a desired destination – these are the *rows* of a matrix;

- *j* denotes an eventual parking zone – these are the *columns* of a matrix;
- *t* denotes a parking type;
- *p* denotes a trip purpose;

The total demand for parking is obtained by summing from-home OD matrices for each parking model purpose over origins for movements with destinations inside the GLA. From these a required number of parking spaces is determined.

The number of parking spaces required to accommodate a time period's demand can differ from the number of vehicles arriving in that period because of the amount of time for which spaces are occupied.

A vehicle arriving at the start of a time period and remaining for the whole of that period takes up one parking space. If the same vehicle occupies the space for part of the period, another vehicle may arrive later and use the same location. Consequently, more vehicles can in practice be accommodated than there are parking spaces.

The zonal demand for a particular combination of time period and purpose is allocated to available parking spaces in that zone's parking area by means of a multinomial absolute logit model. The probability that a particular parking type in a particular parking zone is used is:

$$P_c = \frac{W_c \exp(\lambda_c U_c + \Phi_c)}{\sum_{c' \in C} W_{c'} \exp(\lambda_{c'} U_{c'} + \Phi_{c'})},$$

where *c* denotes the combined choice of parking zone and type; *C* is the set of parking zones and types forming a zone's parking area; $\lambda$ is a cost sensitivity parameter, and $\Phi$ is an alternative-specific constant used for calibration. The utility, *U*, is the sum of the parking tariff, the egress time for travelling by non-car mode from the parking zone to the desired destination, and a search time. *W* is the number of spaces by zone and type, which is applied as a size term to increase the likelihood that a trip-maker will park in a zone if it has a greater supply of parking spaces.

Parking location choices are calculated independently by journey purpose for demand to each desired destination, but the allocation of demand to parking supplies is performed simultaneously across *all* desired destinations and trip purposes. For illustration, consider an example in which there are two zones, Z1 and Z2, and two purposes P1 and P2. For simplicity, one type of parking is assumed and each zone's parking area encompasses both Z1 and Z2.

Each purpose is processed separately at first, and the results of calculating the choice proportions for the demand to each zone might be:

| P1 | Z1 | Z2 | P2 | Z1 | Z2 |
|---|---|---|---|---|---|
| Z1 | 0.9 | 0.1 | Z1 | 0.75 | 0.25 |
| Z2 | 0.5 | 0.5 | Z2 | 0.5 | 0.5 |

This shows, for example, that demand to zone 1 may use parking spaces in zone 2, and 10% of the purpose 1 trips have done so.

The final number of parking spaces used in each zone is found by multiplying the demand to each desired destination by these probabilities and summing over parking zones and purposes. Introducing some example attractions, the total number of vehicles wishing to park in a zone can be calculated:

| All Attractions | | Probabilities (choiceprops) | | Takeup | | Vehicles Wishing to Park | | Total Demand | |
|---|---|---|---|---|---|---|---|---|---|
| P1 | | Z1 | Z2 | Z1 | Z2 | Z1 | Z2 | | |
| Z1 | 100 | 0.9 | 0.1 | 90 | 10 | 165 | 85 | | |
| Z2 | 150 | 0.5 | 0.5 | 75 | 75 | | | Z1 | Z2 |
| | | | | | | | | 250 | 140 |
| P2 | | Z1 | Z2 | Z1 | Z2 | Z1 | Z2 | | |
| Z1 | 60 | 0.75 | 0.25 | 45 | 15 | 85 | 55 | | |
| Z2 | 80 | 0.5 | 0.5 | 40 | 40 | | | | |

The number of parking spaces ‘taken up‘ is given by:

$$takeup_{ijtp} = choiceprops_{ijtp} \times allattractions_{ip}$$

and the total demand to a parking zone in each time period is therefore:

$$totaldemand_{jt} = \sum_{ip} takeup_{ijtp} \ .$$

After this initial distribution of demand among parking zones and types it is likely that some combinations will be filled above capacity. Where there is more demand to a desired destination than can be accommodated it is necessary to redistribute the excess demand to parking locations that still have spaces available. If no parking location is over-capacity in this period then all demand has been accommodated by the available supply and the parking model can terminate.

Excess demand in a parking zone is made up of contributions from demand distributed from multiple sources and it is the difference between the total demand and the available supply, when demand exceeds supply. The total excess is an aggregate across all parking zones, parking types and purposes. It is therefore necessary to calculate a new matrix, analogous to $takeup_{ijtp}$, in which the contents are only those trips contributing to the excess, rather than total movements between zones.

This matrix of the sources of excess demand is denoted by *allexcessmovements* and derived from the total excess through the following definition:

$$excess_{jt} = \sum_{ip} allexcessmovements_{ijtp}$$

leading to an obvious representation as:

$$allexcessmovements_{ijtp} = excess_{jt} \times P_{ijtp}$$

where $P_{ijtp}$ is the proportion of all cars parking in zone $j$ in parking type $t$ that have desired destination $i$ and journey purpose $p$.

It can then be shown that:

$$P_{ijtp} = \frac{takeup_{ijtp}}{\sum_{ip} takeup_{ijtp}} = \frac{takeup_{ijtp}}{totaldemand_{jt}}$$

and *allexcessmovements* is that part of the total *takeup* that could not be accommodated by the parking sites to which it was allocated. The result is that excess trips are linked to the desired destination to which they were originally heading. These movements are subtracted from the *takeup* matrix and then summed over parking zone and type so that they can be redistributed among those spaces that are not yet fully occupied.

Initial choice proportions were calculated for the situation in which all spaces were empty. There will now be spaces that are entirely filled and which cannot be used to accommodate excess. The excess is redistributed by first removing those options that are no longer available and then renormalising the remaining probabilities.

For example, if a set of four initial choices has been restricted to two as a result of changes to space availability, we might have:

$$Initial\ choice\ set\ \ probabilities = (0.1, 0.2, 0.3, 0.4)$$

$$Restricted\ choice\ set = (0.1, -, 0.3, -)$$

and hence we calculate new values for use in redistribution:

$$New\ choice\ probabilities = (0.25, 0.0, 0.75, 0.0).$$

After redistribution there will be a new *takeup* matrix, which may also result in overloaded parking locations. The redistribution of excess is likely to be carried out multiple times for a single time period – the parking model continues to iterate internally, redistributing excess demand, until a stopping criterion is met:

- No excess remains;
- Excess remains but there are no spaces to which it can be allocated; or,
- A maximum number of internal iterations has been performed.

When a stopping criterion is met, the model terminates and calculates two outputs for use by the DMS:

- Average parking costs incurred by cars that were able to park;
- *Shadow costs* for desired destinations which caused any unallocated excess demand.

Shadow costs are negative values that are included in the distribution model's utility. They discourage car travel to overloaded zones when the DMS module is next run by reducing the utility of travelling to them by car. Revised outputs of the DMS cause the PVC module to calculate new car demand for the next parking model run. The reduced demand to previously overloaded zones should lead to the parking model's being able to allocate demand to available supplies without any excess.

Shadow costs are calculated by assuming a multinomial logit model in which destination choice is given by:

$$p_j = \frac{\exp(U_j)}{\sum_{j'} \exp(U_{j'})}.$$

Here, $U_j$ is the utility associated with choosing destination *j*. This utility includes assignment costs as well as average parking costs.

Shadow costs exist *only* for zones that have excess demand, and these are defined by:

$$p'_{j \in S} = \frac{\exp(U_j + \Delta U_j)}{\sum_{j' \in S} \exp(U_{j'} + \Delta U_{j'}) + \sum_{j' \notin S} \exp(U_{j'})},$$

where *S* is the set of zones with excess demand, $\Delta U_j$ is the shadow cost, and $p'_j$ is the modified probability that a trip will choose to travel to zone j.

A shadow cost for one zone affects the distribution of demand to all other zones, including those with excess. Shadow costs and excess demand apply only to zones in the GLA, but it is necessary to include all internal zones in the calculation of the values of those shadow costs, so that demand can relocate to zones outside the GLA.

The shadow cost equations may be solved simultaneously for all zones, with the general solution:

$$\Delta U_j = \ln\left(\frac{p_z}{p'_z}\frac{p'_j}{p_j}\right)$$

where:

- *j* is the destination for which the shadow cost is being calculated;
- $p_j$ is the original distribution probability of choosing destination *j* when travelling by car;
- $p'_j$ is the new distribution probability that we want to achieve with the shadow cost;
- $p_z$ is the sum of all of the original distribution probabilities for the zones that had no excess: $p_z = 1 - \sum_{j \in S} p_j$ ; and,
- $p'_z$ is the counterpart of $p_z$, based on $p'_j$.

The simplifying assumption of a multinomial model in the derivation of the shadow cost equation means that the calculated shadow costs may not entirely remove all excess demand from modelled zones. The parking model is therefore run multiple times within a single LTS cycle to reduce excess demand before the highway assignment stages are carried out. We have found that 3 parking model runs in each cycle is a good compromise between the minimisation of excess and the restriction of run times.

Shadow costs are *changes* in utility, so the shadow costs calculated in one run of the parking model are *added* to those used in previous runs before being used in the DMS.

After a morning peak parking model run, initial parking availability in the interpeak is calculated. All parking spaces are assumed to be unoccupied at the start of the morning peak period and each trip allocated to a parking zone takes up a certain fraction of a parking space, as discussed earlier.

At the start of the interpeak period some spaces will be unavailable because they are still occupied by morning peak demand. The number of parking spaces available during the interpeak therefore depends upon the occupancy if spaces during the morning peak, and the portion of the interpeak period for which they remain occupied by that demand.

LATS travel diary data were examined to obtain estimates of the time spent in a parking space for trips of different purposes. Parking durations actually vary by location, parking type and trip purpose, but the simplifying step was taken of including the purpose-dependence only.

The following assumptions have been made:

- hww and hwb trips occupy parking spaces for the whole of the mp and ip periods;
- heb trips occupy parking spaces for the whole of the mp period and for half of the ip period;
- hbo trips occupy parking spaces for the whole of the mp period but vacate their spaces at the start of the ip period. These mp trips are assumed not to remain in any spaces during the ip period.

From the parking space usage in the morning peak the parking supplies for the interpeak period are therefore calculated.

## 5. RESULTS

The new parking model has been effective in redistributing demand for parking across parking spaces by type in the new version of the LTS model. Figure 4 shows the reduction in parking excess from a test run using three additional internal loops around the parking model in each of the seven outer supply-demand equilibrium.

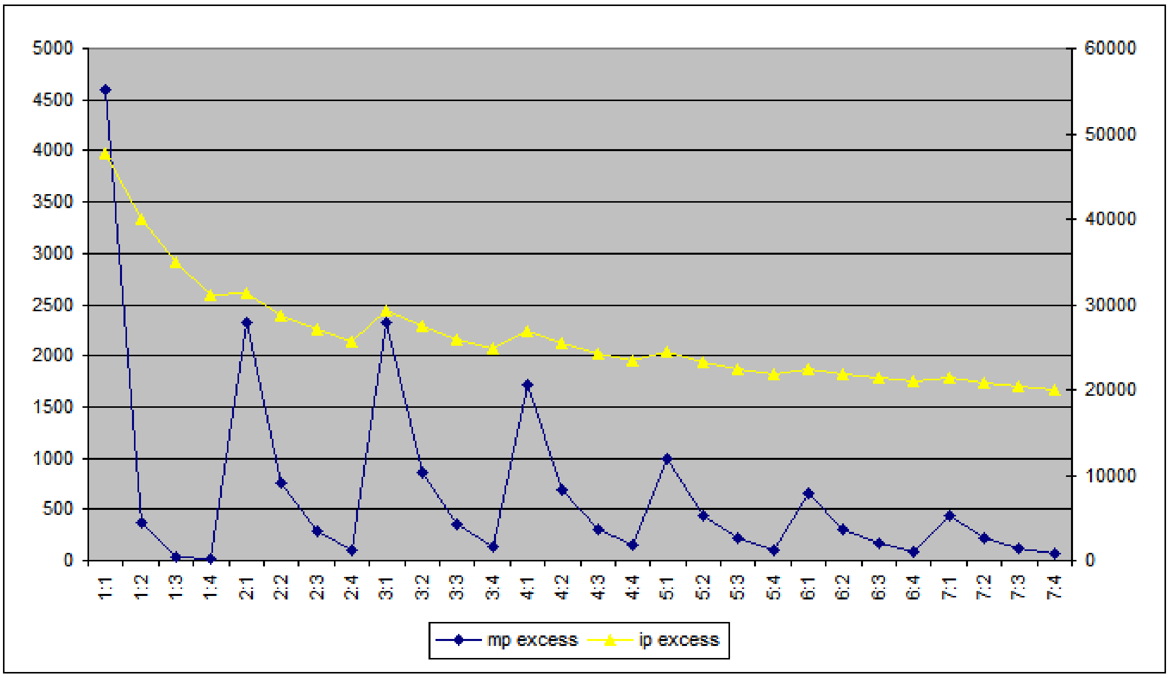


**Figure 4 Changes to mp (left axis) and ip (right) excess – 4 parking model runs per cycle**

The model is effective in reducing excess demand in the base year through redistribution of parking such that shadow costs are not required.

Plausible results were obtained under policy tests for sensitivities to changes in parking supply and parking charges. Under parking supply reduction tests, the use of shadow costs in this iterative process has been shown to be effective in reducing demand to zones in which there is insufficient supply to accommodate it.

## 6. CONCLUSIONS

The new LTS parking model covers all 800+ model zones within the Greater London Authority (GLA), and forms a separate module, sitting between the distribution/mode split (DMS) and assignment models. Each GLA zone is allocated a supply of three parking types: public on-street, public off-street, and private non-residential (workplace). Each parking space type has an associated parking charge, which may differ by zone, time period and journey purpose. The parking model runs in the morning peak and interpeak periods, processing synthetic from-home demand.

Different journey purposes may access different types of parking, with workplace parking available only to commuting trips. Parking spaces are assumed to be occupied for purpose-specific average durations, leading to an effective supply dependent on the purpose mix of demand to a zone. Parking spaces are assumed to be empty at the start of the morning peak, while supplies in the interpeak are a function of the utilisation in the morning peak.

The main improvements over the previous parking model are in the treatment of parking choice and capacity constraint. GLA zones are each associated with a set of nearby zones called a parking area. Trips to a given zone can utilise the parking supplies in its parking area, and parking areas for different zones overlap, leading to competition for spaces. The choice of parking location and parking type uses a multinomial logit that is a function of parking charge, search time and egress time components.

Iterative processes are used to simultaneously redistribute excess demand over available parking spaces within parking areas and to use shadow costs to suppress demand which cannot be accommodated. These have been shown to operate effectively just enough to remove the excess and satisfy the supply constraint.

The model can be used to assess “what if” scenarios covering a number of policy options varying geographically across London by parking type, such as parking supply control and changes to parking charges (including workplace parking levies).

The model would benefit from additional data collection. The greatest benefits would be obtained from:

- sample surveys to quantify parking space occupancy by type; and
- data on the location, spaces and occupancy of major public off-street parking facilities.

These would permit a more robust determination of likely relationships between parking zones and destination zones suitable for use in LTS or more detailed highway assignment models to modify the assigned pattern of movements.

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