Modelling Congestion with Travel Derived from Activities
Peter Davidson, Phillip Clarke and Ittai Sverdlov, Peter Davidson Consultancy
Paper given to the European Transport Conference, Applied Methods, Strasbourg, 2006

Abstract
Activity based modelling requires detailed time-of-day dependent attributes to determine the activity sequence, which in turn governs travel. This detail is not provided by conventional assignment models. This paper describes a time-dependent method for congested transport assignment which has sufficient detail to be sensitive to the time of departure or arrival. Activity based models need this sensitivity so as to effectively schedule activities. The paper describes the application of time-of-day dependency to an activity based model of parking congestion in Truro, Cornwall.

Introduction
Activity modelling schedules the household’s activities so that the person can undertake the activity and so that the household schedule of activities is the most preferred. This schedule depends upon a number of inter-related factors. It depends upon the travel time for different departure times. This can depend upon parking, both the availability of finding a parking space and the cost of parking. The cost of parking can depend upon the parking duration which depends upon the activity duration. The activity departure time and duration can be dependent upon and can help determine, the activity schedule.

The availability of finding a parking space depends upon whether other people have taken all the parking spaces – ie the parking history. This is similar to a road junction where the time taken for someone to get through the junction depends upon the length of the queue when they arrived at the junction – which depends upon the overcapacity history of the junction. These are aggregate problems which do not fit well with discrete choice models which deal with individuals, because the activity schedule of one household thereby depends upon the activity schedule of other households.

Models which schedule activities need the travel time from home to the location where the activity is to take place, for each alternative departure time of the day, so that the departure time choice model can be constructed. Travel times therefore need to reflect the differences of travelling at different times of the day ie they have to be time-of-day dependent. Conventionally this would require assignment models, which typically represent average travel for a one to three hour periods, for different times of the day. Conventional assignment models are not sensitive to the different travel times within the assignment period which looses some of the key variability needed for activity scheduling.

This paper outlines an approach which provides a continuum of progressively more detail so as to gain greater precision in the activity based models. This methodology also has the ability to capture the mechanisms poorly modelled such as parking and park and ride. The paper describes the application of the method to a model of parking in Truro.
Modelling Congestion

Congestion depends on the accumulated queue on the junction approach road which in turn depends upon the times at which the flow of traffic approaching the junction exceeds the capacity at which the junction can pass traffic through it. The excess traffic, queues on the approach road and subsequent traffic arriving at the junction has to wait in the queue until it reaches the junction stop-line whereupon it can be discharged through the junction. The time spent in the queue is therefore related to the amount of time the junction has been overcapacity prior to the vehicle in question arriving at the junction.

Junction design software uses geometric, signals timing and other data to determine junction capacity which when taken with the traffic arrival pattern, will forecast the queuing and delay using time dependent queuing theory. This typically takes the queue at the start of a 15 minute time period, adds the traffic which did not get through the junction during the 15 minute time period onto the queue and passes the resulting queue onto the start of the next 15 minute time period. This calculation is undertaken throughout the day (or part of the day) and the resulting delay to all traffic accumulated to provide a measure of how effective the junction is at accommodating the demand placed upon it.

Normal traffic assignment methodologies approximate this by assuming that traffic arriving at the junction over the assignment period is delayed by the same average amount. This would not actually occur. During the am peak traffic build-up, traffic arriving during the early part of the assignment period may incur little delay while that arriving at the end may incur much more. Furthermore they assume that all traffic arrives at all the junctions along its path simultaneously when in fact traffic arrives at the junctions along its path in sequence. These approximations tend to mask the detail needed to detect and model peak spreading, departure time choice and activity scheduling.

To make the normal traffic assignment more sensitive, the traffic demand needs to take account of the time-of-day or clock time of departure and of arrival at each junction along its path. We have called this clock-time assignment and it has a number of other useful additional properties. It also keeps track of the time of arrival at the destination so can be used to provide more accuracy with which to model parking: by keeping track of which cars are parked in which parking spaces, cars arriving to park can be allocated a vacant space and can park only if there is a vacant space. If it is part of an activity based model, the duration of the activity provides information about the duration parked and hence the cost of parking. The activity based model can keep track of where the car is parked so that the return trip can be routed via the parked car – this is especially important for park and ride.
Clock-time Assignment

The clock-time assignment method proposed here and embodied in Peter Davidson’s Visual Transport Modelling Software (Visual-tm) (1) is a more versatile way of assignment modelling for the day, which enables the whole day to be modelled as a continuum. The day can be divided into consecutive time periods and assigned in sequence with the output from one time period, as the starting condition for the next.

Trips in transit at the end of one time period are carried over into the next, with each part put into its correct assignment. So the assignment model only assigns trips to links if the trips are on the links within the time period being modelled. Those links which the trip goes along after the end of the time period, are assigned in the next time period. This is achieved by the assignment producing a too-late trip matrix which consists of all the trips which did not make it to the final destination within the time period being modelled. The too-late trip matrix records for each origin-destination zone pair, the number of trips, the time of departure from the origin and the node reached. This can be input to the assignment of the next time period which finds the path they would take and loads them onto the network for that portion of their path falling within the time period being modelled.

The starting queue at the beginning of the time period being modelled can either be estimated from counts or by running the previous time period in the assignment model. The day’s consecutive time periods could for example be midnight, 6.00am, 8.00am, 9.00am, 12.00 noon, 2pm, 4.30pm, 5.30pm, 7.30pm, midnight. Each one could, if necessary, have an assignment model so as to trace the queue build-up and decline throughout the day. Conventional models of the morning peak, evening peak hour and inter peak are entirely separate but with this methodology they can be connected together.

To get this greater precision into the assignment model so as to better model effect of time-dependent queuing into our junction modelling, required this new clock-time approach to modelling time (in the sense of time of day). The clock-time path builder records the clock time the path gets to each node, or boards or alights each public transport service in the network. For highway assignment, this is called clock-time assignment and for public transport it is called timetable assignment.

Time periods are generally for one to two hours and represent the time period covered by the trips in the assignment trip matrix. Time periods are divided into ten-minute time intervals and the clocktime/ timetable assignment keeps track of the clock time at each network node. Junction and interchange turning movement flows are accumulated for each time interval and passed to the junction and interchange simulators which pass back turning delays in each time interval, for the next assignment iteration.

Time intervals are divided into time slices of typically one-minute duration. The trip matrix, which represents one time period’s worth of traffic, is divided
into one time slice’s worth of traffic within the assignment process. Time slices are accumulated into time intervals for the highway junction and public transport interchange simulation. Time slices are also accumulated and output to the too-late trip matrix for assignment in the next time period.

**Junction Capacity**

The junction capacity for a particular traffic stream is generally a function of the traffic streams on other arms of the junction which may conflict with it – traffic streams which may vary over the course of the time period being modelled. This needs to be taken into account when calculating the junction capacity. Clock-time assignment does this by taking the turning flows by ten-minute time interval supplied to it from the assignment model. The capacity for each stream of traffic is calculated from the empirical relationships used to design junctions, which is embodied in TRL’s junction design software Arcady (2), Picady (3) and Oscady (4).

Having calculated the capacity of the traffic stream, we can calculate the amount of traffic which will pass through the junction during one particular time interval. That traffic which does not get through the junction adds to the queue on the approach road.

**Junction Delay**

We then take the queue at the beginning of the time interval, add the effect of the traffic which does not get through the junction in the time interval and calculate the queue at the end of the interval using time dependent queuing theory. Queues from the end of one time interval are used as the starting queues at the beginning of the next time interval. Each time interval in the time period is examined in turn and the queues and delays calculated and output. The time dependent queuing and delay is also calculated from the empirical relationships used to design junctions in TRL’s Arcady, Picady and Oscady.

**The Assignment Continuum of Progressively Finer Detail**

If the time intervals are increased to be the same as the time period (eg 1 hour) and the junction delays approximated then the clock-time assignment methodology defaults to be the normal assignment methodology. If the time intervals are made shorter then the assignment methodology can be made more precise. There is therefore a continuum of assignment methodologies which at the coarse end default to current assignment methodologies and at the fine end default to assignment of 15 minute (or less) time intervals of traffic which is used in junction design. The methodology can be used with activity based models which is illustrated by the Truro activity based parking model described below.

**Aims and Objectives of the Parking Model**

Currently in Truro there is significant car park congestion where on busy days the demand for spaces exceeds the supply. In order to help alleviate this problem Cornwall County council are considering introducing new improved park and ride facilities to Truro to assist in reducing the demand for spaces. However car park revenue in Truro is an important source of local government
funding therefore a model was required to assist in providing answers to the following questions:

- What impact will these P+R sites have on parking revenue?
- Can prices and tariff structures be changed to support the P+R?
- What parking policy measures will impact on parking and P+R usage?
- How will potential changes in activity patterns affect car park usage?
- What impact will increased work congestion have on parking in the city?

A multimode transport model (5) has been developed to gain an understanding of trip distribution and mode choice decisions. An additional parking model component (6) was also required to answer the questions specifically related to parking.

Model Architecture
In many transport models parking is represented in a very aggregate manner, for example, simply applying an average parking charge to all trips destined for the town centre. For this project, this approach was seen as being inappropriate as it would not enable the client to test different parking strategies and therefore fall short of answering the questions described above. Parking is inherently geared towards the activity both in terms of the arrival time and the activity duration. It was therefore decided to use an activity based approach to model the demand for parking which would be disaggregate and thus would be able to deal with each individual travellers choices.

The Truro Activity Based Parking Model therefore uses a simple methodology to derive trip populations with the trip departure time, activity duration, destination location and market segment. This model is connected to the multimode model using skims of journey times and paths.

The Activity Based Approach
Activity based models offer a range of advantages over traditional models and enable much more complex interactions between social or demographic changes and demand for transport services. They enable users to test many more policy interventions and can provide much more detailed outputs from which to base decisions. A full activity based modelling approach could include the following stages (though this list is not exhaustive):

- Generate a household
- Generate the activity set for a household
- Generate the durations of activities
- Generate the locations of activities
- Generate paths and travel times
- For this activity set, generate the trip chain from the trip chain set
- Split into person trip chains
- Mode Choice
- Assemble chains into trips
- Assemble trips into trip matrices
- Check matrices with aggregate model
In our study, several of these elements have been modelled in aggregate by the multi-mode model. The activity based parking model therefore focussed on the effects central to parking for which the essential components were as follows:

- Departure time of the trip from home
- Activity duration leading to parking duration
- Ultimate destination actual building (not the zone of destination)
- Clock-time of the trip (arrival time at car park)
- Select only car born activities in Truro

Parking Model Methodology

The demand for car parking in Truro is dependant upon the number of car trips terminating in the city centre on a daily basis. The multimode supply-demand equilibrium model was developed to take account of trip generation, trip distribution and mode choice to ascertain the total number of cars wishing to park in Truro both in the base year and in future forecast years. This demand was represented in the parking model as an all day matrix of vehicle trips. However, the choice of which car park to use will be different for each individual trip in the matrix and therefore trips between the same origin and destination needed to be represented separately in the model. The trip matrix was therefore converted into a list of individual activity records that could be processed by the parking model.

The demand for car park spaces is usually defined on a first come first served basis therefore it was necessary to define the arrival times for cars in the city centre. This was done using a distribution of journey departure times using traffic count information collected around the city. The highway assignment model was then used to derive journey times from origins to destinations which were then added to the departure time in order to define the arrival time at the zone of destination. The model also needs an estimate of the required duration of stay for each traveller. This was derived from a set of distributions of parking duration obtained from parking survey data. Durations of stay are affected by the arrival time at the activity. For example a person arriving in the town at 8.00 am for work could on average, be expected to stay in the car park for a longer time than someone arriving at 3.00 pm for shopping. The distribution of duration of stay was therefore by arrival time.

Many workplaces or buildings in Truro have their own car park. If an individuals’ ultimate destination was a building which had its own car park then that individual would probably park in the building’s car park if there was space at the time the car arrived. Determining the actual building of destination was achieved using a distribution of office space for buildings within each zone where each individual traveller was given a distribution of all the buildings within that zone. This information was derived from the rateable value list held by the Valuation Office Agency.

After application of these processes, the above method has resulted in a list of individual activity records comprising the outward from home production zone, attraction zone, journey purpose, the departure time from the origin, the
destination arrival time, the required duration of stay and the ultimate building of destination. This was known as the person activity record and as the model deals with individual parking choices on a first come first served basis, these records were sorted by arrival time.

Each of these activity records now had to be assigned to a car park. As described above if the ultimate attraction was a building that had its own car park and this car park had available spaces at the time of arrival, then this activities car was allocated to one of the vacant spaces for the required duration of stay. If the ultimate building of attraction did not have its own car park or the car park was full, then the traveller would have to choose from the other available car parks. This therefore required the definition of a choice set of all the car parks that were available for the traveller. This was done essentially by creating a choice set that included all other car parks and then removing from this choice set all unavailable car parks on an individual traveller basis.

All car parks that were within other buildings at the destination were excluded. Car parks where the allowed duration of stay was less than the required duration of stay were excluded. All car parks that were full at the arrival time were excluded. All car parks that were allocated for use by a different trip purpose were excluded. For example a shopping trip was not allowed to park in a car park allocated only for work trips. The remaining car parks were defined as the choice set for this individual traveller.

It was then necessary to calculate the choice attributes of parking in each of these potential car parks. The choice comprises a variety of attributes to the traveller including car journey time to the car park, walking time from the car park to the building of destination, car park cost etc. The car journey time was derived from the highway assignment model where each car park had been identified by its nearest node in the network and the assignment model was used to generate the journey time to this node. The car park may not have actually been at this node therefore the time from the node to the car park was also calculated using the crow-fly distance between the Ordnance Survey Grid Reference (OSGR) coordinates of the node and the car park to estimate the additional journey time. The OSGR of the car park and the building of destination where then used to derive the walking distance from the car park to the destination building. An average walking speed was applied to calculate the walking time. Car park tariffs applicable to car parks in Truro were input to the model and were used to derive the cost of parking in each of the individual car parks for the activity duration. Fig 1 below illustrates the process of calculating the travel time attributes.
The model has now generated for an individual traveller, the possible car parks available for them to park in, along with the choice attributes of each one. These attributes were then combined with choice coefficients that have been derived from stated preference research into a utility function which in turn was used in a multinomial logit model to calculate the probability of parking within each car park for this individual. These probabilities were then used to generate a distribution of car park probabilities and a Monte Carlo simulation was used to select a car park. The individual was then allocated a parking space within the car park for the duration of his stay and this space was removed from the set of spaces available for others to park in. The model records the individual and keeps track of the parking charge. The model then considers the next individual activity record and so on until all activities have been allocated to a car park. This process is described graphically in Figures 2 to 5 below.
Figure 2 – Generating the Population and Activity Patterns
Figure 3 – Illustrating the Process of Selecting a Car Park

Activity File

Does Building Have Its Own Car Park

If Yes

If No

Derive Car Park Choice Set:
Space at Arrival Time
For Activities Duration
Length of Stay Permitted
Not Somebody Else's Car Park

Derive Attributes

Choose a Car Park and Car Park Space

Is there space in Car Park at this Arrival Time

If Yes

Position Car in Car Park

Mark 1 Space in CP busy from Arrival Time for Duration of Stay

Go To Next Activity Record

© Association for European Transport and contributors 2006
Figure 4 – Deriving the Choice Attributes

1. Highway Skim Node to Node
2. Parking Inventory
3. Tariff Information
4. Building Inventory
5. CP Delay Functions
6. Parking Inventory
7. Car Park Space Availability

- Car In Vehicle Time from O Zone to Nearest Node to Car Park
- Car IVT from Nearest Node to Car Park to Car Park
- Cost of Parking in Car Park for this Duration of Stay
- Walk Time From Car Park to Building Destination
- Current Delay at This Car Park
Figure 5 – Choosing the Car Park and Car Park Space

Choice Set

Logit Model: Choice Probabilities for each car park

Choice Coefficients

Select Car Park and Car Park Space (Monte Carlo)

Position Car in CP

Mark 1 Space in CP busy from Arrival Time for Duration of Stay

Go To Next Activity

Record
Parking Model Results
The parking model was constructed and calibrated to observed base year data. Fig 6 below shows the comparison between observed and synthesised demand for pay and display car parks in Truro and shows that the models fits the observed data closely. Table 7 below shows the daily parking usage profile within Truro. Table 8 below shows the forecast revenue statistics produced from the model. Table 9 below shows car park usage statistics derived from the model. These show the good representation of the model to actual parking behaviour.

Fig 6: Observed Vs Modelled Demand for Pay and Display Car Parks

<table>
<thead>
<tr>
<th>Parking Type</th>
<th>No Of Parkers</th>
<th>Revenue (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off Street Pay</td>
<td>5212</td>
<td>11,728.90</td>
</tr>
<tr>
<td>Off Street Free</td>
<td>3700</td>
<td></td>
</tr>
<tr>
<td>On Street Free</td>
<td>10508</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>19420</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Daily Parking Usage Profile

<table>
<thead>
<tr>
<th>Car Park Name</th>
<th>Total Daily Revenue</th>
<th>Revenue per parking space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old_Bridge_Street</td>
<td>£ 576.10</td>
<td>£ 4.65</td>
</tr>
<tr>
<td>Moresk</td>
<td>£ 579.00</td>
<td>£ 4.91</td>
</tr>
<tr>
<td>Edward_Street</td>
<td>£ 450.00</td>
<td>£ 4.69</td>
</tr>
<tr>
<td>Viaduct_Pyadar_Street</td>
<td>£ 1,585.70</td>
<td>£ 3.68</td>
</tr>
<tr>
<td>Garras_Wharf</td>
<td>£ 1,318.60</td>
<td>£ 3.90</td>
</tr>
<tr>
<td>Moorfield</td>
<td>£ 2,248.60</td>
<td>£ 3.11</td>
</tr>
<tr>
<td>Lemon_Quay</td>
<td>£ 1,876.30</td>
<td>£ 4.69</td>
</tr>
<tr>
<td>High_Cross</td>
<td>£ 2,220.20</td>
<td>£ 4.99</td>
</tr>
<tr>
<td>Tabernacle_Street</td>
<td>£ 874.40</td>
<td>£ 8.74</td>
</tr>
<tr>
<td><strong>£ 11,728.90</strong></td>
<td><strong>£ 4.23</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Forecast Revenue Statistics
Table 9: Car Park Usage Statistics (Pay and Display Car Parks)

Table:

<table>
<thead>
<tr>
<th>Car Park Name</th>
<th>Capacity</th>
<th>Max Used Spaces (Synthesised)</th>
<th>Total Time (Mins)</th>
<th>Number of Parkers</th>
<th>Average Duration of stay (minutes)</th>
<th>Parking space turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old_Bridge_Street</td>
<td>124</td>
<td>116</td>
<td>40320</td>
<td>399</td>
<td>101.05</td>
<td>3.22</td>
</tr>
<tr>
<td>Moresk</td>
<td>118</td>
<td>118</td>
<td>58950</td>
<td>193</td>
<td>305.44</td>
<td>1.64</td>
</tr>
<tr>
<td>Edward_Street</td>
<td>96</td>
<td>96</td>
<td>48270</td>
<td>150</td>
<td>321.80</td>
<td>1.56</td>
</tr>
<tr>
<td>Viaduct_Pydar_Street</td>
<td>431</td>
<td>412</td>
<td>152400</td>
<td>786</td>
<td>193.89</td>
<td>1.82</td>
</tr>
<tr>
<td>Garras_Wharf</td>
<td>338</td>
<td>331</td>
<td>156000</td>
<td>628</td>
<td>248.41</td>
<td>1.86</td>
</tr>
<tr>
<td>Moorfield</td>
<td>724</td>
<td>639</td>
<td>204630</td>
<td>1166</td>
<td>175.50</td>
<td>1.61</td>
</tr>
<tr>
<td>Lemon_Quay</td>
<td>400</td>
<td>373</td>
<td>121110</td>
<td>940</td>
<td>128.84</td>
<td>2.35</td>
</tr>
<tr>
<td>High_Cross</td>
<td>445</td>
<td>357</td>
<td>106680</td>
<td>654</td>
<td>163.12</td>
<td>1.47</td>
</tr>
<tr>
<td>Tabernacle_Street</td>
<td>100</td>
<td>98</td>
<td>41850</td>
<td>296</td>
<td>141.39</td>
<td>2.96</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2776</strong></td>
<td><strong>2539</strong></td>
<td><strong>930210</strong></td>
<td><strong>5212</strong></td>
<td><strong>178.47</strong></td>
<td><strong>1.88</strong></td>
</tr>
</tbody>
</table>

Conclusions

We have demonstrated a spectrum of assignment methodologies which use time dependant queuing and clock-time assignment. We have illustrated how this can be used in an activity based model context, by considering the tricky area of parking. The relevance components of an activity based parking model include generating a household and its alternative activity schedule, skimming networks to get the attribute values, selecting an activity schedule with its departure time and parking space by considering all the parking spaces available. The parking model developed for Truro was a good fit to the observed profile of parking which has shown that activity based modelling could be a much better way of modelling parking than conventional methods.

References:


