Linking Scheduling Dimensions of Individual's Daily Activities with Macro-Level Dynamic Network Loading Models

Muhammad Adnan*

Introduction:

Several strategies and policies are viewed as an alternative to reduce congestion on the roads with the aim to induce change in people's travel behaviour. Modelling adjustment and changes in the activity scheduling dimensions of an individual due to network congestion is necessary to efficiently examine impacts of policies like flexible working hour schemes, dynamic tolling strategies and time dependent parking fees. This requires a model that utilises a mechanism based on trade-offs between benefits gained through participation in an activity in relation to the disutility of travel on the road network, and that extends it further to incorporate a series of out-of-home activities planned in a day by an individual. On this basis, a model is proposed in this research that attempts to integrate dimensions related to individual daily scheduling of activities with the dynamic network loading models. The model is formulated as a fixed point problem that brings the system in equilibrium through an iterative feedback mechanism. Travel times on the road network are determined from the dynamic network loading model and are fed into the utility function which involves generalised travel cost along with the utility of activity engagement that follows a timing activity utility concept for explicit consideration of timings, sequence and duration of activities in a daily activity-travel pattern of an individual. This paper contains a critical review of relevant literature, a description of the proposed model framework and finally presents some preliminary remarks after implementing the model for a very restricted case on a simple network.

Literature Review:

Modelling congestion in conjunction with trip scheduling has been an active area of research over the last four decades. The work presented by Vickrey (1969) has remained pioneering in this regard; further extensions and refinement of his work in many dimensions have resulted in a well-known scheduling theory for the morning commute. Attempts have also been made to integrate the morning commute with the evening commute (home to work tour) through the same framework, with an argument that scheduling of the morning work commute may well depend on the travel cost of the return to home trip, the duration of the work activity and variation of the utility of the work activity with its start and end times (Zhang et al 2005). Several empirical studies have also recognised the fact that due to growing concerns about congestion on the road network and policies that are aimed at reducing it (e.g. road pricing), people tend to bring changes in their activity patterns. For example, such changes may involve inclusion or exclusion of an activity from an already planned activity pattern, changes in start and end times of activities, their durations, changes in mode, destination and route choice (Ettema et al 2004, de Palma and Lindsey 2002). Therefore, a model capable of reflecting changes in individual activity schedules due to the conditions on the road network is required to accurately foresee the impact of policies aimed at reducing congestion.

Recently, Lam and Yin (2001) and Lam and Huang (2003) proposed a discrete choice framework in discrete times to model activity, destination and route choice together. They adopted a variational inequality-based formulation in order to assign traffic dynamically and brought out mutual consistency between activity choices and travel times. However, the modelling framework does not model activity duration, which is considered as a vital dimension for linking the same day activities (Zhang et al 2005). Abdelghany and Mahmassani (2003) formulated and analyzed a stochastic dynamic user equilibrium (SDUE) problem in which drivers simultaneously seek to determine their departure time, route choice and sequence of their intermediate activities at the origin to minimize their disutility for travel. Their modelling framework is limited to the morning commute only with three intermediate stops i.e. it does not deal with the complete activity pattern of an individual for a whole day and also in their model duration at intermediate stops of the morning commute is treated as a fixed and a given parameter. To overcome the deficiencies of earlier works, Zhang et al (2005) investigated variation in the departure time within-a-day for the home to work tour as a trade-off between travel cost and the utility of participation in the work activity. The home to work tour is linked with work duration and the model follows a hierarchical nested logit structure. In addition to this, they established an equilibrium condition between the schedule choice pattern and network congestion by solving a fixed-point problem.

* *PhD Student, Institute for Transport Studies, University of Leeds,*
Leeds, LS2 9JT, UK.
e-mail: m.adnan04@leeds.ac.uk

Furthermore, they considered a single user class and one origin-destination pair linked through a single traffic corridor and employed the timing activity utility concept in their modelling framework. The model presented in this paper can be viewed as an extension of what have been presented earlier (i.e. Zhang et al (2005), Abdelghany and Mahmassani (2003), Lam and Yin (2001), Lam and Huang (2003)) by integrating some more dimensions of activity scheduling (i.e. duration, sequence, activity start and end timings and route choice) in order to deal with more complex tours and activity patterns. This extension is crucial because it provides the basis for application of theoretical concepts in a broader context which is helpful in examining their practicality because earlier works presented only for the simplified examples.

The model proposed in this paper combines scheduling of activities in a day with network congestion effects in a single framework. The mechanism through which an individual may vary their activity scheduling dimensions within-a-day is based on a trade-off between benefits gained through activity participation in relation to the travel cost. The model can consider several user classes and analyses complex home-based tours as an individual daily activity travel pattern. In addition to this, a stochastic dynamic user equilibrium (SDUE) condition is formulated between scheduling of activities and flows on the network. Activity scheduling dimensions are modelled using random utility models and network congestion effects are incorporated through a suitable dynamic network loading model which fulfils the desirable properties of traffic flow propagation i.e. first-in-first-out (FIFO), flow conservation, causality etc (Heydecker and Addison 2006). The model paves the way to appropriately analyse the impacts of several time dependent policy measures on the overall individual activity pattern for macro level planning schemes. For example, these policies could include dynamic tolling strategies, time-dependent parking fees, flexible working hours and working at home options available to individuals. Additionally, it would also help analyse the temporal variation of demand levels at a particular activity location.

Components of the Proposed Model and their modelling considerations:

In this section a theoretical framework of the proposed model is presented along with the description of its components at length. In simple terms, the model contains three major components: (1) Demand side, (2) Supply side and (3) the component that deals with the integration of the demand and supply sides.

1. Demand side:

The demand side describes the modelling dimensions involved in the activity scheduling process and the procedure of modelling these dimensions together. Within the demand side the following issues are required to be considered:

- Choice dimensions involved in the Activity scheduling process
- Approach for modelling activity scheduling dimensions
- Specification of a utility function for scheduling of activities in a given day

Firstly, considering the activity scheduling process; this is generally viewed as an important component in the activity-based models along with the component that deals with the generation of activities for individuals within their household. Activity scheduling is defined as "*the joint choice of the time, duration, location, mode and route for a sequence of activities drawn from a given set of aware activity needs*" (Lee and McNally 2006). Apart from that, Bhat et al (2004) also added a joint participation element (i.e. involvement of two or more persons of the same household in an activity at the same time) in the activity scheduling models with several other dimensions of activity scheduling. To set up the model in this research as a meaningful extension of the work described in the above section of literature review; departure times (activity start and end times), duration, sequence and route choice are considered for modelling and the focus remains only on those activity patterns which consists of a single home-based tour with several combinations of secondary activities around the main activity of the tour. For the development of the model it is considered that only the list of activities that an individual needs to perform in a day is given. Therefore, the next concern here is how an individual takes a decision to schedule his/her activities by choosing timings, duration, sequence and route for the day's activities.

Secondly, about the issue of appropriate approach for modelling activity scheduling dimensions; a range of activity based modelling systems has been developed using different approaches to model some of the dimensions of activity scheduling discussed above. These modelling systems utilize econometric principles and heuristic rules (also known as computational process models (CPM)) to guide simulation of the individual decision process, which actually lead to the determination of their daily activity schedules. The econometric approach involves using the systems of equations to capture relationships among the macroscopic indicators of activity and travel, and to predict the probability of the decision outcome However, in CPM a set of heuristic rules are used in the form of a condition-action (If-Then) structure in order to solve a particular task at hand (Bhat et al 2004). The econometric approach allows investigation of the causal relationships among various characteristics of activities, land use and individuals and on the other hand CPM due to its explicit nature provides a more flexible approach to represent complex travel decision making (Lee and McNally 2006). In this research, the econometric approach is utilised to model dimensions related to activity scheduling, as this approach is fully compatible with the requirements of the supply component of the proposed model and also it provides a very useful setting to mathematically solve the problem of equilibrium between the demand and supply side by incorporating available optimization algorithms. Within the umbrella of econometric approaches models related to a discrete choice framework like MNL, NL and Probit etc. are more useful. These models are utilised in the literature for modelling scheduling of activities (for example Bowman and Ben-Akiva, 2000; Bhat et al, 2004; Shiftan et al, 2004; Zhang et al, 2005) and provides flexibility to assess the effects of correlation and dependence of various scheduling dimensions with each other and their alternatives. This compels to have a general modelling framework at the demand side, so that any discrete choice model can be used to determine the choice probabilities.

The third and final issue within the demand side specification is definition of a utility function for scheduling of activities of a given day. In the proposed model, the individual takes a decision about the modelled scheduling dimensions of his complete activity pattern in such a manner that maximises his/her overall utility of the activity pattern. It has been generally accepted that the utility of any activity at a particular time is a function of the satisfaction of performing activity itself and intensity with which the activity is performed. Both of them are dependent on time, therefore a concept is emerged which result in a time-of-day dependent utility of an activity (also termed as marginal utility, expressing the utility gained from one time unit of activity participation). Very recently, Ettema et al (2007) discussed and empirically supported the arguments that an activity utility function should contain three different components of activity engagement namely time of day preference, satiation effect (duration related) and scheduling constraints. Time of day preference for an activity is captured through a continuous marginal utility function varied over time of day, satiation effect of an activity is considered using a marginal utility function which decreases with duration and scheduling constraints of an activity is included in order to represent constraints that are not reflected completely from time of day preference component such as work or school arrangements and opening hours of stores and facilities, these are represented through schedule delay approach (Small, 1982). This utility function seems more comprehensive as it contains all the important ingredients from which an individual derive benefits through activity engagement. In addition to this, Ettema et al (2007) presented the way through which this specification of utility can be operationalised. Furthermore, this concept is more general in nature and almost all various sorts of activities can be accommodated within it. This is in contrast with the already developed econometric activity-based models (e.g Bowman and Ben-Akiva 2000 and Shiftan et al 2004) which are also using discrete choice models but their definition of the utility function is not based on a generalised notion that can carry different activities together. An activity utility function that approximates the above characteristics is utilised in this research along with the disutility indicators such as travel time and travel cost in order to model dimensions related to scheduling of activities.

2. Supply side:

The second major component of the proposed model is the supply facet. Within this component it is assumed that the road network is given with some known geometric features. The travel time (as a component of the generalised travel cost) of a particular path that connects an origin-destination pair is determined using a supply model in order to represent the congestion effect. For the supply facet the issues that need to be addressed are:

- Dynamic representation
- Macroscopic dynamic network loading models

Regarding dynamic representation; time is very crucial in the demand side of the model because utility of the scheduling of a day's activities is a function of time-of-day. Therefore, a static representation of congestion on the road network through the supply side would not be accurately compatible with the demand side of the proposed model. Furthermore, the dynamic version allows explicit representation of reality, as flow on the network varies spatially and temporally; the same is not true with the quasi-dynamic case in which queues are carrying over to the next departure period in trying to simulate the same process. In addition to this, Lam and Huang (2002) stated that advances in computer and methodology promise that the development of a dynamic representation is not a big challenge anymore. Following this course, in this research it was decided that a dynamic representation of congestion on the road network should be considered.

Concerning the second issue in the supply facet; the application of the proposed model lies in assessing the macro level planning policies, the focus therefore remains only on macroscopic or analytical traffic loading models.

Whole-link models which fulfil the desirable properties (for instance; first-in-first-out (FIFO), flow conservation, causality, positivity, etc.) required for dynamic traffic assignment suggested by Heydecker and Addison (2006) are utilised to reflect time varying congestion effects on the road network. Similar to the demand side, the supply facet of the proposed model is also generalised in a sense that various whole-link models can be used. This allows carrying out a comparative analysis of the results obtained from deployment of these models and sensitivity of the model can also be assessed within the supply part. Linear travel time model, Point-queue model and divided linear travel time model are found as possible candidates within the whole-link models; it is noted that they are relatively simple in their mathematical structure and require less computational efforts for their implementation (Friesz and Bernstien 2000). Additionally, they are also successfully incorporated in many dynamic traffic assignment studies and the results obtained from them are accepted as a fairly good approximation of the real time condition of the traffic on the road network.

3. Linking demand and supply side:

The third component integrates the demand and supply side of the proposed model. It is realised that the demand side of the proposed model is dependent on the supply parameters i.e. the utility function for activity scheduling contains variables like travel time and travel cost which are actually the products of the supply component of the proposed model. Similarly, the supply facet of the proposed model requires time varying demand in order to estimate the travel times required to travel from one point to another on the road network at a particular time of the day. Therefore, both these components are dependent on each other and a consistent solution to both constitute a fixed point problem, the solution of which provides an equilibrium condition i.e. both demand and supply parts are stabilised together. The integration of demand and supply components in a fixed point problem framework gives rise to stochastic dynamic user equilibrium (SDUE) condition. Figure 1 illustrates the proposed model components and how they are integrated with each other.

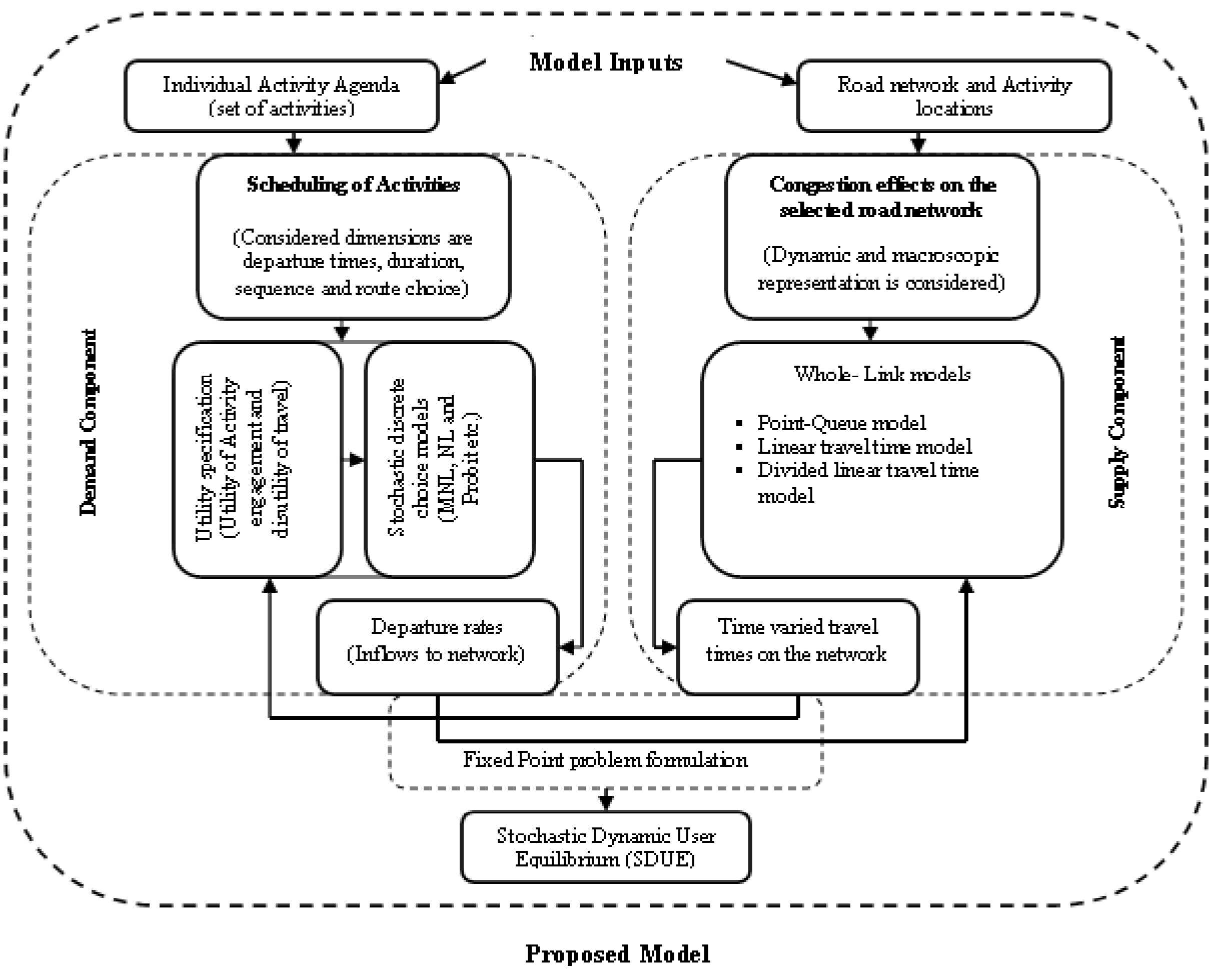

Figure 1: Proposed Model, its components and their interaction

Model Implementation Results and the Way Forward:

A simple activity pattern i.e. home to work tour was considered on a very simplified network that contains a single link between the home and work locations for the numerical example. The joint choice of departure time from home and work was modelled for the morning and evening commute, utilising the MNL model for a bell-shaped marginal utility profiles for home and work activity. The parameters responsible for the shape of these marginal utility profiles are consistent with the three important requirement of the utility of an activity engagement described earlier. The Point-Queue model was considered with smaller time intervals at the supply side and the system was brought in equilibrium by first converting the fixed point problem into an optimisation problem and then solving it through an optimization algorithm which follows sequential quadratic programming approach. Behaviour of the morning and evening peak dispersion was examined by implementing policies for example, time-dependent toll and flexible working hours. Sensitivity analysis was also carried out for various aspects; such as using different discrete time interval settings at the demand and supply sides of the model and changing the parameters of marginal activity utility for home and work activities. The model was also tested for a different supply model such as Linear travel time model and also employed NL and Probit probabilities at the demand side in order to investigate the differences in results and their impacts when different congestion reduction measures were taken. It has been found that the model reports significant variation in the results when different traffic performance models were used, however, less variation in the results was reported when different discrete choice models were utilised at the demand side. Therefore, care should be taken to adopt proper forms of the loading models when model is used to assess the impacts of any policy.

This paper reported progress on planning an integrated model for scheduling of activities an individual is supposed to do in a given day with the representation of congestion effects on the road network. In the future, research work would be carried out to present the mathematical and numerical illustration of the proposed model for a realistic medium size network with some complex activity pattern. Therefore, the proposed model when implemented in its full, forms the basis of a very useful tool for the practitioner community. The proposed model could be further extended in various ways: (1) representation of more scheduling dimension like mode and location choice, (2) incorporation of secondary and tertiary tours within the framework of the proposed model, (3) linking the proposed model with an activity-generation model to develop a full activity-based model with supply component, (4) theoretical examination of the convergence pattern and stability of the proposed model in order to accurately approach at stochastic dynamic user equilibrium condition and (5) development of a more integrated generalised package that would be more user friendly and practically applicable for any reasonable sized road network and activity centres within it.

References:

Abdelghany A F, and Mahmassani H S, (2003): Temporal-Spatial Micro-Assignment and Sequencing of Travel demand with Activity/Trip Chains, paper presented in 82nd Annual meeting of Transportation Research Board.

Bhat C. R, Guo J. Y, Srinivasan S, Sivakumar, A. (2004): A Comprehensive Econometric Micro-Simulator for Daily Activity Travel Patterns (CEMDAP); TRR, Journal of Transportation Research Board, Paper No: 04-4718

Bowman, J.J. and Ben-Akiva, M. E. (2000); Activity-based disaggregate travel demand model system with activity schedules; Transport Research Part-A 35; pp: 1-28.

de Palma A, and Lindsey, R (2002); Comparison of Morning and Evening commutes in the Vickrey Bottleneck Model. Transportation Research Record 1807, 26-33

Ettema D, Bastin F, Polak J, Ashiru O, (2007): Modelling joint choice of activity timing and duration, Transportation Research Part-A, vol 41, pp: 827-841

Ettema D, Ashiru O, Polak J W, (2004): Modelling Timing and Duration of Activities in Response to Road-Pricing Policies; TRR, Journal of Transportation Research Board, No. 1894 TRB, pp:1-10.

Ettema D, Timmermans H, (2003): Modelling Departure time choice in the context of activity scheduling behaviour, TRR, Journal of Transportation Research Board, No. 1831 TRB, paper No: 3-2425, pp: 39-46.

Friesz, T.L, Bernstein, T.E, (2000): Analytical dynamic network modelling, chapter 12, In handbook of transport modelling. Page 183-210

Heydecker, B G. and Addison, J D. (2006); Analysis of dynamic traffic assignment, In the proceedings of First International Symposium on Dynamic Traffic Assignment, Leeds, June 21st – 23rd 2006.

Lam, W. H. K. and Yin, Y (2001); An activity-based time dependent traffic assignment model, Transportation Research Part-B, vol 35, pp: 549-574

Lam, W. H. K. and Huang, H (2002); A combined activity/travel choice model for congested road networks with queues, Transportation 29: 5-29, Kluwer publications

Lam, W. H. K. and Huang, H (2003); Combined Activity/Travel choice models: Time dependent and dynamic versions, Networks and Spatial Economics 3, 323-347

Lee M, and McNally M G, (2006); An empirical investigation on the dynamic processes of activity scheduling and trip chaining, Transportation 33: 553-565

Shiftan, Y, Ben-Akiva M, Proussaloglou K, Jong de G, Popuri Y, Kasturirangan K, Bekhor S, (2004): The Tel Aviv Activity Based Model System. Paper presented at the EIRASS Conference on Progress in Activity-Based Analysis, May 28-31, 2004, Vaeshartelt Castle, Maastricht, The Netherlands.

Small K. A, (1982); The Scheduling of Consumer activities: work trips. The American Economic Review, 72, 467-479

Vickrey W. S. (1969), Congestion theory and transport investment, American Economic Review (Papers and Proceeding) Vol 59, pp: 251-261

Zhang, X., Yang, H., Huang, H. J. and Zhang, M. H. (2005); Integrated scheduling of daily work activities and morning-evening commutes with bottleneck congestion, Transportatin Research Part-A 39, pp: 41-60.