

## TRAFFIC CONTROL AND DEMAND PROFILE CHANGES: THE CASE OF ATHENS

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**Abstract:** The present paper provides an empirical investigation of the potential impacts of advanced traffic control measures, such as route guidance information, on traffic flow patterns. The simulation-based quasi-dynamic traffic assignment model (DNA) used appears to be an efficient tool for capturing the demand profile changes of drivers under the presence of information-based control measures. The results obtained from the implementation of DNA in the Greater Athens Area network manifested the significant impact of routing on traffic flow patterns, particularly in terms of path spreading, whilst the largest benefits for drivers were derived for updating period of 15-30 minutes.  
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### 1. INTRODUCTION

The determination of the interaction between traffic control actions and driver choices is a key feature in evaluating the efficiency of advanced traffic management systems (ATMS) and advanced traveller information systems (ATIS). Allsop and Charlesworth (1974) were among the first who drew attention to the significance of considering the relationship between a (signal-based) control system and the traffic flow patterns. Many attempts have insofar been made (e.g., see Papageorgiou, 1990; Nihan, *et al.*, 1995; Meneguzzo, 1997) to optimise the operation of traffic control schemes for a network, particularly in terms of signal timing plans and route guidance information, by assuming that informed drivers will follow a user-equilibrium flow pattern.

This optimisation procedure usually consists of a dynamic traffic assignment (DTA), which may allow the estimation of drivers' response to various types of prescriptive/informative control measures. The DTA may be broadly classified into four approaches upon which it can be based: (a) *mathematical programming* (Merchant and Nemhauser, 1978),

*variational inequalities* (Ran and Boyce, 1996), *optimal control theory* (Friesz, *et al.*, 1989), and *computer simulation* (Smith, 1993). In the dynamic simulated-based assignment, the vehicles are divided into a number of packets (e.g. ten vehicles in each packet) and then loaded on the various paths of a network incrementally during a specific time interval. This approach allows the analytical and detailed investigation of behavioural aspects, such as those concerning the users' reaction to information conveyed to them in real time by route guidance systems (e.g. collectively by VMS panels).

In the present paper, a simulation-based DTA model is used in order to investigate its potential to capture possible interactions between routing information systems and users' demand profiles in a real-life urban traffic network. In the following section, the specific quasi-DTA model and its algorithm are presented. Section 3 describes the results obtained by the implementation of the model in the network of Greater Athens Area. In addition, an interpretation of the results obtained from the case study is carried out, particularly in terms of the inferred relationships between control interventions and users' route choice

behaviour. Section 4 includes a summary and the conclusions of the present study.

## 2. THE DYNAMIC NETWORK ASSIGNMENT

### 2.1 Description of the model

The DTA model used in the present study, known as DNA (Dynamic Network Assignment), was developed by Stathopoulos and Parmaksizoglou (1989) and is essentially a quasi-dynamic deterministic model based on the concept of *dynamic user-optimal (DUO) assignment*. According to this concept, any individual leaving his origin at any instant chooses a route that minimizes his travel cost along the route to his destination. The DNA model approximates the route time-based DUO conditions as an extension (generalisation) of the equilibrium conditions achieved by a conventional static traffic assignment problem, by incorporating to it two additional sets of constraints.

The first one refers to the *time-dependent capacity-related constraints*. By using these constraints, trips that would otherwise (using a standard assignment procedure) cause link or intersection capacities to be exceeded at any point during a time period  $t$  are stored in a matrix, the *transient origin-destination (O-D) demand matrix*. This matrix may be regarded as indicating the time-specific suppressed (transient) demand for movement over the network O-D paths. A matrix of trips (*queue matrix*) delayed beyond  $t$  is then included in the next time slice  $t+1$ , so as to retain the net balance of trips remaining in the network. The second set includes the *time-dependent flow conservation constraints*, which include those dynamic information that are used to build up the queue at each link's exit, if the link is oversaturated, or to dissolve the queue if the link is being de-saturated.

The DNA model ensures the DUO conditions by calculating a set of successive capacity-constrained minimum path trees, based on the updating of transient O-D matrices, until the flow conservation constraints concerning a predetermined (*background*) O-D matrix are satisfied. This consists a departure from the established dynamic traffic assignment (DTA) procedure and, therefore, it has been termed a quasi-DTA. The calculation of transient O-D matrices at regular time slices  $t$  (e.g., every 15 minutes), as it is analytically described in the following paragraph, provides an updated (quasi-dynamic) snapshot of the changing travel demand and traffic conditions over the network. Thus, it may offer a suitable tool for implementing dynamic route guidance information.

The basic reason for developing the DNA model was related to the need to assess the impact of real-time traffic control strategies on drivers' behaviour, given the use of available equipment for the provision of either collective or individual guidance information. The proposed model has already been implemented at a pilot level in order to assess the effectiveness of a system of VMS panel displays of parking supply information in Athens (PARCMAN, 1992). Despite

the fact that the provision of real-time information was found to be appealing to users, the depth and extent of the application have not been fully assessed. Nonetheless, the ongoing and widespread use of communication technologies enabling the transmission of traffic information in real-time using Internet, enabled cellular phones and other wireless devices offer a promising field for the application of the proposed or other similar methods.

### 2.2 The DNA algorithm

In order to calculate the minimum path trees in each time slice (updating period)  $t \in \{t_0, t_1, \dots, t_k, \dots\}$ , in which the overall time period  $T$  is divided, a time-dependent shortest path algorithm is employed. This algorithm basically follows the procedure of minimum cost tree building, as it is determined by the D'Esopo's algorithm (see Van Vliet, 1978). The steps of implementing the DNA procedure can be described as follows:

- Step 1:* Initialise the link flows, travel times, and the background O-D matrix, in order to execute the first network loading at  $t_0$ , which is the *background loading*.
- Step 2:* Combine the demand matrix  $X_{ij}$  for the current time slice  $t$  with the queue matrix from previous time slice  $t-1$ .
- Step 3:* Select randomly an initial origin (source)  $i^*$  or a transient origin  $i$ .
- Step 4:* Determine the minimum path tree from origin  $i$  (or source  $i^*$ ) to all destinations  $j$  based on the assigned link traffic loads of the time slice  $t-1$ .
- Step 5:* Select randomly a  $(i, j)$  or  $(i^*, j)$  pair to build the corresponding path tree.
- Step 6:* Assign the trips onto the calculated minimum paths. Check for each link whether the capacity constraints are violated or not. In case that the vehicles' flow assigned up to time slice  $t$  plus the currently assigned traffic load is less than the link capacity, then the current traffic load is added to the existing (already assigned) traffic load. Otherwise, the trips corresponding to the oversaturated traffic load are stored in the queue matrix of time slice  $t$ , and only the remaining amount of trips is further assigned to the given route.
- Step 7:* Check if the end of time slice  $t$  has been reached. If not, the next link is examined. Otherwise, the trips are stored to the queue matrix of time slice  $t$  and specifically to

the entries corresponding to the (transient) origins they have reached.

*Step 8:* Repeat Steps 6 and 7 for all paths  $P$  traversing the tree that has been built at Step 5.

*Step 9:* Repeat Steps 3 – 7 for all sources  $i^*$  and transient origins  $i$ .

*Step 10:* Repeat Steps 2 – 7 for all time slices  $t$  until the end of time period  $T$  is reached.

### 3. THE CASE STUDY RESULTS AND INTERPRETATION

The DNA model was tested by simulating the morning peak hour period of the Greater Athens Area. The network of the given area was modelled using 582 nodes and 1760 links. The different runs of DNA model were particularly focused on investigating the potential changes in traffic flow patterns under the presence of updating routing strategies, and the optimal time period within which such changes could be monitored.

#### 3.1 The route choice effects

The possible impacts of the implementation of a descriptive or predictive information-based control measure on the drivers' demand for usage of specific links and, hence, paths over the network, can be derived by comparing Fig. 1 with Fig. 2. The formulated assumptions concerning the regular updating of path selection every 15 minutes, as it can be induced by the presence of relevant route guidance information provision at points marked by flags (see Fig. 1), has significantly influenced the assigned traffic load pattern, with respect to the 'best route' or the complete route choice tree to be followed (see Fig. 2) across the whole peak hour period.



Fig. 1. The minimum paths generated from transient nodes for an updating period of 15 minutes.



Fig. 2. The 'best' route followed (route choice tree) for the total assignment period of 1 hour.

The sequential minimum path selections made by the users moving from the initial origin (source), at the north-east (NE) end of the network, to the final destination (sink), at the south-west (SW) end of the network, produce a well defined corridor along the main axis. This corridor, enclosed by the updated minimum paths as denoted by the circled numbers 1, 2 and 3 (see Fig. 1), essentially outline the travel pattern resulting from the trip rescheduling of travellers within the temporal horizon of the total assignment period. The resulted changes in demand and, subsequently, the traffic flow patterns may be interpreted by the difference between the experienced and perceived travel cost, which resulted from the effects of the capacity-constraints, queuing delay cost and suppressed traffic emerged between the successive network loading stages.

The described changes in route choice (or route switching) behaviour, as it is captured by the application of DNA model, implicitly assumes that *all* drivers reconsider and revise their initial 'best' route choice, predetermined by the background loading, having fully acquisition and acceptance of the en-route guidance information. This is because the DNA procedure is deterministic and, hence, does not endogenously consider the stochastic treatment of information acquisition and user response behaviour to real-time guidance systems. Though this assumption in practice may seem rather unrealistic, the fact of the limited range of link flow variations in such oversaturated traffic environments as that of the network of the present case study (see Stathopoulos and Karlaftis, 2001) reduces the impact of non-stochastic treatment on the accuracy of results.

In addition, since the route switching behaviour is largely related to the desired arrival time at sink, the modelling of route decisions by DNA as a sequential process with respect to the remaining time available for reaching the final destination could be considered as behaviourally sound. The *path spreading* characterising the implemented trips in Fig. 1 under the assumption of real-time routing and path decision updating is mostly apparent when comparing the corresponding loading flows with those of Fig. 2 that pass through the central area of the network, that is

the city centre. In this area, the higher levels of congestion enlarge the difference between experienced and perceived travel cost and, hence, cause longer rerouting of the informed drivers with respect to the initially selected path tree. As mentioned earlier, the triangular flags placed along the route choice tree denote the location of transient nodes where the updated routing information is provided and, hence, a revised path selection is made.

### 3.2 The updating period length

A crucial issue concerning the investigation of the relationship between an information-based control measure and the demand and traffic flow patterns refers to the length of interval  $t$  within which the routing guidance is updated. As it can be observed from Table 1, the principal indicators of travel patterns, including travel speed, total delay, total distance travelled and total travel time, are significantly sensitive to different updating periods, ranging from 60 to 5 minutes.

**Table 1 Results of assignment runs with different updating period lengths in Athens test network.**

| Time slice duration                | 60 min. | 30 min. | 15 min. | 10 min. | 5 min. |
|------------------------------------|---------|---------|---------|---------|--------|
| Number of slices                   | 1       | 2       | 4       | 6       | 12     |
| Assumed O-D matrix split           | 1 x     | 2 x     | 4 x     | 6 x     | 12 x   |
|                                    | 1.0     | 0.5     | 0.25    | 0.167   | 0.083  |
| Average Speed (km/hr)              | 19.54   | 21.46   | 21.28   | 20.70   | 19.70  |
| Total Delay* (pcu - hr / hr)       | 13,83   | 12,03   | 12,85   | 14,04   | 16,77  |
| Total Distance* (pcu - km / hr)    | 453,1   | 458,5   | 483,1   | 504,2   | 554,2  |
| Total Travel Time* (pcu - hr / hr) | 23,19   | 21,37   | 22,70   | 24,36   | 28,12  |

\* in thousand

As the updating period length is being reduced and, hence, the simulated traffic conditions approximate the DUO conditions, the effects of network congestion on drivers' rerouting are becoming increasingly evident. In turn, this implies longer travel distances and greater travel times. Similar are the trends of the other travel cost measures. The gradual reduction of updating period length from 30 minutes to 5 minutes is followed by an increase in total delay and a decrease in average travel speed.

It is evident that, although updating periods between 30- to 15-minute long offer the most aggregate benefits to users, in comparison to those offered by a single updating period of 60 minutes, further reductions in the length of updating period arguably inhibit drivers from optimising their path selection. This is due to the exceedingly large segmentation of the remaining path, which is associated with such short updating periods, so that the users cannot realistically follow the route recommendations. Therefore, one can deduce that as the updating

period is shortened users are realising diminishing returns.



**Fig. 3. Comparison of the first three minimum paths successively generated from the trip origin for updating period 5 minutes with the respective minimum path generated for updating period 15 minutes.**

Fig. 3 provides a comparison between the first three minimum paths successively generated from trip origin, at the NE end of the network, for the updating period of 5 minutes, with the respective path generated for the updating period of 15 minutes (denoted by the encircled number 1 at the western part of the network). The drivers traversing the latter path (corresponding to the time slice of 15 minutes) have undertaken the longest route diversion. On the contrary, the paths corresponding to the time slice of 5 minutes are located in a narrow corridor and path spreading is limited. In practice, this limited route dispersion could be ascribed to the reduced response time available to travellers in order to adapt or re-optimize their origin/destination choices according to the prevailing traffic flow conditions.

As a result, the route produced by DNA for the time slice of 15 minutes effectively avoids the heavily congested segment at the north-eastern part of the network (marked by the arrows in Fig. 1). In contrast, the 'short-sighted' route generated by the updating period of 5 minutes was found to traverse this segment.

## 4. CONCLUSIONS AND FURTHER RESEARCH

In the present study, a quasi-dynamic network assignment procedure (DNA) simulated the evolution of demand and traffic flow patterns on the network of the Greater Area of Athens, assuming the presence of real-time route guidance information. The results clearly demonstrate the spreading impact of updated routing information on the path trees followed by drivers in such congested urban-scale networks. The updating frequency does also significantly influence the magnitude of travel cost measures. As it was derived from the simulation tests, an updating period of 15-30 minutes could provide the greatest benefits

to the users, in terms of total travel time, total distance travelled, total delay and average travel speed.

The impact of updating period length on the system performance in practice remains an issue of further research. The model validation procedure, which may include other control measures rather than only informative, would necessitate the comparison of the present experimental results with real-world calculations of measures such as travel times or estimates of expected arrival times. In addition, the validation procedures could provide insights as to how sensitive are the system performance measures in real-time traffic conditions with respect to the modelling assumptions adopted in the simulation study.

Such validation procedures are currently developed using probe vehicles and implementation of experimental subscriber-based information systems such as cell phone traffic alerts. These developments are the subject of further research conducted at various institutions. Their findings is expected to make invaluable contribution to further advancement of methods and algorithms.

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