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INTERACTIVE PLANNING OF URBAN ROAD NETWORKS

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Abstract

The progress of low cost/high performance minicomputers provides an excellent opportunity to develop better techniques for the planning of urban road networks. In this paper an interactive graphic system called PLANET, developed by the author, is presented. It allows the planner to analyse, evaluate, and improve network modifications, designed to produce better accessibility to existing or proposed road networks. The paper describes the theory and the conceptual framework of the PLANET software package, as well as the possibilities offered by its various modules. The paper demonstrates also its application to a particular project in Alexandria. Conclusions are stated regarding the use of PLANET as a feasible planning tool.

1. Introduction

Numerous attempts have been made during the past few years to develop interactive transportation techniques for quick and efficient analysis and evaluation of scheme options designed to improve urban road networks. These efforts were aimed at overcoming the well known drawbacks of the so-called "traditional" planning models[1]. However, none of these models were found to be easily operative and applicable for planning of great networks, particularly in case of using personal computers.

PLANET (**pla**nning of **net**works) is a person-computer interactive graphic system, developed by the author, for planning of complex urban road networks. It is a menu-driven system, takes the planner step-by-step through the planning process. In an uncomplicated fashion, it enables him to analyse and to evaluate different alternative designs (network modifications), with an emphasis on interactive colour graphics displays. After the evaluation, the planner can modify the designs and thereby moves toward other candidate alternatives that come closest to the planning objectives.

PLANET serves the planner to find adaptations of a network structure to improve the level of service on a corridor or the accessibility on the whole network.

Because of the cycle of the planning process of a network takes only some few minutes, the search for an optimal design of a network from a large number of alternatives is more efficient with PLANET that it is with the traditional models.

The purpose of this paper is essentially twofold : (1) to present the fundamental structure as well as the theoretical concepts embodied in PLANET software package; and (2) to describe its application to a particular project in Alexandria, initiated by the Ministry of Housing, and New Communities, which is interested in the introduction of a new urban Highway in the road network of Alexandria [4].

2. The PLANET System

2.1 System Overview

Figure 1 shows an overview of the PLANET system. The base network (set of potential road links) should be coded, and the link characteristics as well as the traffic demand matrix (in vehicles per hour) should be entered. This input data is stored automatically on a computer disk, from which it can be displayed on the screen or printed.

By using an assignment algorithm, the computer then predicts the traffic volumes on the network links. These volumes as well as other output data such as travel time and average speed, which is numerically listed, can also be displayed graphically in colours.

PLANET emphasizes the analysis of network-related problems that need quick answers to "what if" questions, in order to obtain a fast evaluation helps bring to mind further possible better alternatives to be tested. Alternatives can be stored, recalled, and compared.

The following major factors are considered during the construction of the interactive PLANET system :

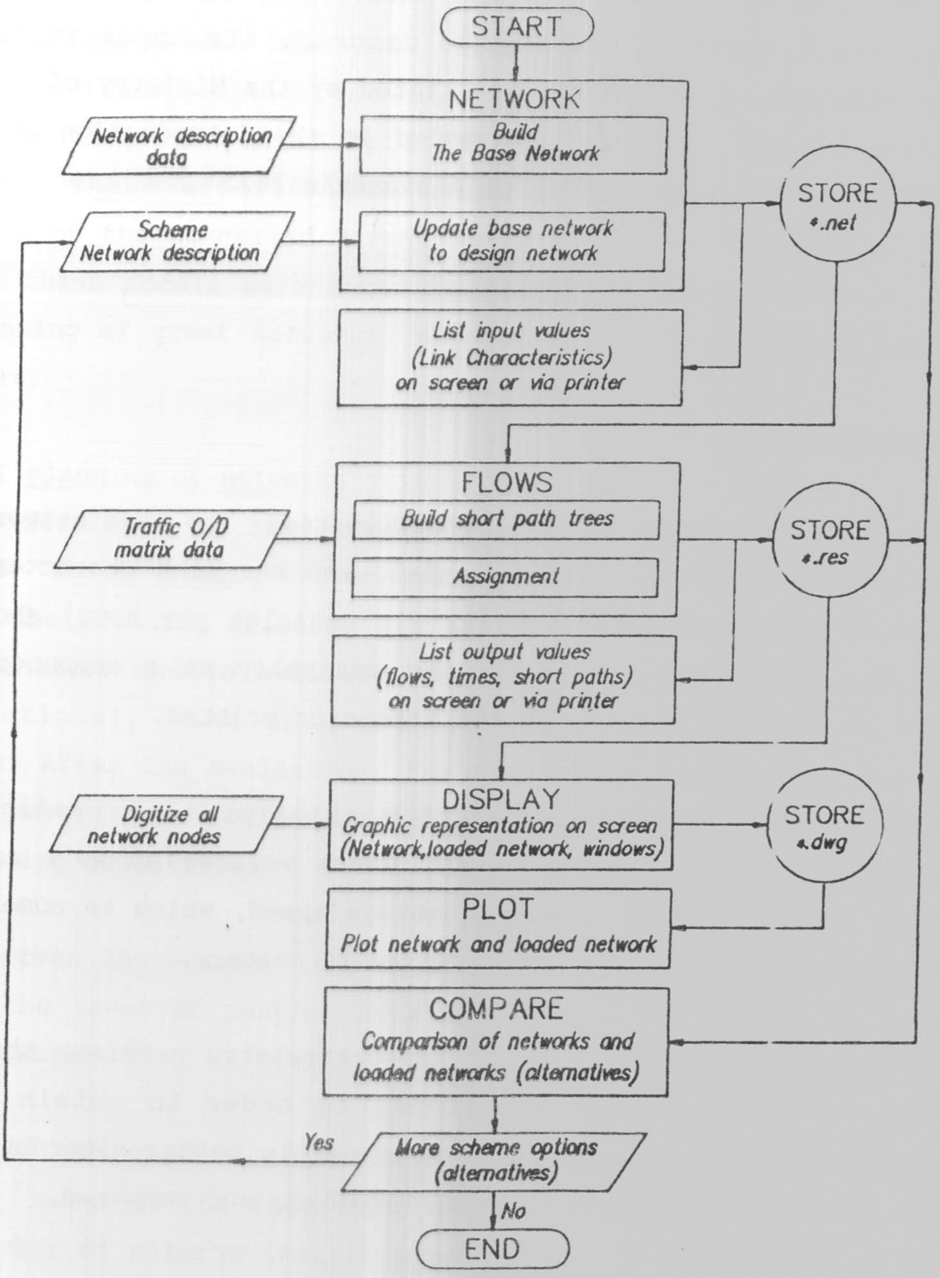

Figure 1 : The fundamental structure of PLANET

- easy of data input;
- immediately detecting and correcting errors in input data;
- reducing time needed for the computational steps;
- minimizing core-space required for on-line data storage; and
- colour graphical representation of results.

Therefore, the accuracy of the results could be increased through the availability of visual editing. The number of alternatives could also be greatly increased because of the interactive feedback loop capabilities in which the planner observes the results and revises input parameters to converge on an optimal solution. The evaluation process could be enhanced through the ability for direct interaction between the computer and the judgment of the planner.

The PLANET system is a comprehensive planning suite of five functional core programmes (described later) : NETWORK, FLOWS, DISPLAY, EVAL, and PLOT. All programmes are written in BASIC and primarily for the use on personal-computers (IBM and compatible). Graphic facilities, digitizers, and plotters could be used to enhance the visual effectiveness in the interactive planning process. Using an IBM PS 2 Model 50, PLANET handles network problems up to 99 traffic zones, 500 nodes and 2000 real links, with 10 different road classes.

2.2 The Programme NETWORK

This programme is used to define a base network. Every intersection of the existing network where roads merge, diverge, or cross is settled as a node and given an unique number. Other nodes may be added to these, where it is necessary to simulate access to the network. A link exists where it is a road between two adjacent nodes. The link is indicated by the numbers of a pair of nodes, and described by its characteristics (e.g. minimum travel time, capacity indices of speed/flow curves).

NETWORK can also be used to check-out or to update an existing network, after its nodes have been defined. Links can be added or deleted, and link characteristics modified globally as a function of a link class.

Input values can be stored on a computer disk (hard or floppy disk), or displayed on screen. Also, the planner can optionally obtain a print-out of the network description. The resulting file (*.net) is treated to form a suitable input for further processing programmes.

2.3 The Programme FLOWS

FLOWS may be thought of as a sophisticated traffic assignment process. It falls into three parts : the first defines travel demand, the second builds short paths through the network, and the third assigns travel demand onto the most probable paths.

The travel demand is introduced in the programme in the form of an O/D trip table, which must correspond to the number of actual or predicted vehicle trips between a pair of traffic zones. The trip table should correspond to the peak period, and it is therefore neither symmetrical nor triangular. The programme is provided with editing facility to modify and manipulate the O/D trip table. The travel demand can be displayed, printed, or stored on a disk as a file (*.dat).

The second part of the programme FLOWS determines the short path from one zone to each other zones on the base of time or cost. It accepted the network description produced by NETWORK, i.e. all files (*.net).

In the sixties and early seventies much attention was paid to the short path algorithms, especial to their efficiency and memory requirements. The growing computational speed and memory capacity of mainframe computers in the following years reduced the need for efficient algorithms. Nowadays, however, with the boom in relatively small and slow microcomputers, efficiency in short path algorithms is important again.

The short path algorithm provided in the programme FLOWS is based on Dijkastra tree building. The theoretical concept of this algorithm and its mathematical solution are presented in [3]. This algorithm, although developed in the early sixties, are still in use nowadays. It is a simple algorithm, straightforward to implement and do not required great memory space. Computer time increases linearly with the network size, and maximum link length does not influence its behaviour, neither does network form [9].

Finally, the programme assigns the O/D travel demand to the network. The assignment algorithm provided in the programme FLOWS is the "successive equilibrium assignment", which is based on the Principle of equal and minimum travel time on all used roads between two zones [7].

A large number of studies have demonstrated the importance of using the equilibrium techniques to assign the traffic flows on highly-congested urban road networks [7, 8]. Not only these techniques possess a superior fit of predicted with observed flows, but they are also relatively inexpensive in terms of computer running time; since these accelerate the rate of convergence and reduce the number of iterations needed to find a stable solution.

The "successive equilibrium assignment", as used in FLOWS, may be described as follows :

1. Set all link flows F_{ij} to equal zero (F_{ij} = the number of trips from an origin i to a destination j).
2. Build short path trees between centroids from each origin to each destination.
3. Choose a maximum number of iterations n_{max}
4. Set n=1; where n =1,2,3,.....n_{max}
5. Assign the O/D traffic flows, divided by the maximum number of iterations (F_{ij}/n_{max}) to the short paths to procuce a set of link flows.
6. Multiply the assigned flows by a factor (n_{max} / n), and alter the travel time in accord with the resulting flows, using a travel-time function.
7. Build new short paths, using the new generated travel times.
8. Set n = n + 1, when n = n_{max} then stop, otherwise return to 5.

The programme FLOWS uses the following travel-time function [2] :

$$T = t_o . \{ 1 + x . (M/C)^Y \}$$

where

T = travel time on a link
t_o = travel time on a link at free flow
M = the link flow
C = the maximum capacity of the link

x = parameter depends on the ratio between the travel time at maximum capacity and the travel time at free flow

Y = the curve form parameter.

The Bureau of Public Roads, USA, utilizes certain values for the curve form parameters, varying according to the road classes [2]. However, before a travel-time function can be used, it has to be made to fit the present-day situation and the specific conditions of the roads in the study area; i.e. the parameters must be calibrated.

The output results produced by FLOWS (i.e. traffic volumes, travel time, average speeds, and short paths) can optionally be listed, printed, or saved on a computer file (*.res) as an input to the programme DISPLAY.

2.4 The Programme DISPLAY

Graphics display in colours is undoubtedly one of the best methods for representing the output results; link flows on the screen (or on a map) are far more immediately intelligible to the planner than the same data presented as a table. Therefore, a separate programme DISPLAY has been developed to code the node coordinates of the processed network, and to permit the planner to map out loaded and unloaded networks as colour graphs on the screen. DISPLAY is closely linked with the AUTOCAD software package. The following graphic facilities are interactively available by the programme DISPLAY :

- easily detection of logical coding errors .
- readily modify and rescale of node coordinates.
- easily identify of overloaded links and bottlenecks.

- the possibility to display the shortest routes.

Since the influence of a certain alternative is not equally distributed over the whole network, DISPLAY is provided with interactive zooming facility "Window Focusing". It focuses on a fully detailed presentation of the important part of the network. Link data such as flows, travel times, or speeds can thus be displayed and analysed.

Any graph produced on the monitor screen is saved in a file (*.dwg) for subsequent plotting with the help of the programme PLOT.

2.5 The Programme EVAL

EVAL can be applied to compare a series of network modifications with a "do-nothing" alternative, defined as the maintenance of the existing road facilities. The purpose of this comparison is to guarantee that the consequences of the proposed network modifications are preferable to the consequences of the do-nothing alternative. If the effects of the proposed modifications are worse than the do-nothing, then, these modifications should not be taken.

EVAL is based on a comprehensive evaluation method. It forces the planner to judge that one solution is better, and offers greater net value to the planning objectives, than the others. This method connect the evaluation of alternatives to these objectives, which should in turn be expressed in some measurable way by specific quantitative criteria.

This evaluation method, which is defined in the field of operations research as multicriteria decision making [5], contains four steps :

1. Identification of evaluation criteria

Generally, the evaluation criteria can be divided under three basic issues :

- Economic feasibility (e.g. capital and maintenance costs, productivity in veh.km).
- User benefits (e.g. time value, saving in operating costs, decreasing the number of accidents, increasing level of service).
- Nonuser impacts (e.g. air pollutant emissions, land consumption, noise level, dangers).

The planner should choose the proper evaluation criteria that achieve the planning objectives of the project under study. Each evaluation criterion must be measured, and all measurements must apply to the same period.

2. Rating scale

Each criterion yields a range of measurements, one for each alternative solution. These are placed linear on such a scale that the worst value is set equal to 0 and the best to 10. Thus the scale is related only to the difference between best and worst.

After this stage in the evaluation process, each criterion has been arranged on a rating scale from 0 to 10, but clearly a score of 5, for example, on a scale is not necessarily to be equated with the same score on another scale.

3. Weight assessment

Weighting is a subjective process in which one or more groups or individuals attach numbers to each criteria (relative weights). Obviously such weighting will vary with the type of the project and the planning objectives as well as with the interest and the experience of the individuals and the groups doing the weighting. The weights may be attached by technical experts on a planning commission or a consultant's staff, politicians or by a citizens advisory group.

4. Alternatives analysis

For any one of m alternatives, the rating scale S_{ij} for a particular criterion j multiplied by the weighting value W_j for that criterion gives the overall score U_i of the i^{th} alternative :

$$U_i = \sum_{j=1}^{j=n} S_{ij} \cdot W_j \qquad \text{for } i = 1,2,3,\ldots\ldots m$$

where

n = number of criteria
m = number of alternatives

The overall score, which indicates the ranking of each alternative is then tabulated by the alternative number.

Figure 2 illustrates the basic structure of the programme EVAL, which contains five modules.

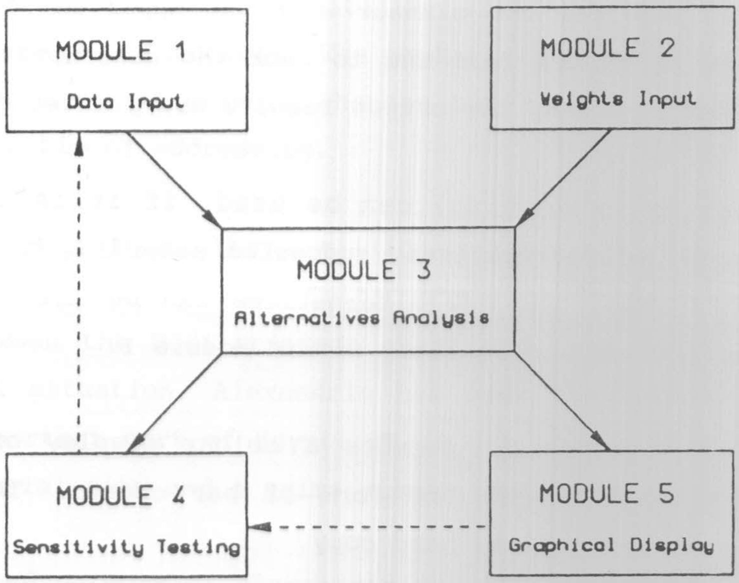

Figure 2 : The structure of the programme EVAL

Module 1 is an input routine, designed to enable the planner to create data sets for the various alternative solutions (the name and the measurements of the selected criteria). Like the rest of the package PLANET, it is menu-driven programme, takes the planner step-by-step through the evaluation process, if required, editing some of the stored data. This input routine arranges automatically the evaluation criteria on a 0-10 rating scale.

Module 2 (weight assessment) allows the planner to entry the weights attached in the evaluation process for each criterion.

Module 3 (analysis of alternatives) brings the weights and the data together and undertakes the calculation of the overall score for all alternatives. It provides the planner with the opportunity to view the adjusted weights in matrix form and to rank the alternatives according to the total points scored. The output results are printed on request.

Module 4 (sensitivity testing) can be used, if it is necessary to evaluate new modified alternatives, suggested according to the analysis results. In this case, the new alternatives can be introduced in the programme using the editing facility within Module 1.

The final Module, number 5, permits a colour display of the scores (weighted and unweighted) in the form of bar charts. The graphs so created can also be run off as hard copy.

2.6 The Programme PLOT

This programme uses as input a file saved by DISPLAY (*.dwg) to produce an essentially identical plot, except for the possible rescaling of the network and the character size, as well as the chance to change the colours. It has been designed to be used with (A3 flat bed) Roland DXY-880 plotter, although other plotters can also be used.

3. Application of PLANET

3.1 Project description

The first application of the PLANET system has been realized to modify the road network of Alexandria with two objectives, (1) illustrating the

PLANET system with some qualitative results, and (2) developing a preliminary usage methodology. The emphasis here will be not so much on the implementation of network changes but rather on the problems that PLANET is capable of addressing.

Alexandria, with about three million inhabitants, is located on the northwestern edge of the Nile Delta, where it is developed on a linear pattern between the Mediterranean coast and Lake Maryout. Favoured by this coastal situation, Alexandria has over the course of time become the most important port of Egypt. It is not only a main port but also a major industrial city and a prime summer resort for domestic tourism.

The urban road network of Alexandria is, like the city itself, oriented along the east-west axis. The grid of the road network is only constituted by two primary longitudinal corridors from the East to the city centre (Cornesh and Horia Roads) and one corridor from the West to the city centre (El-Max Street). In the central area, the traffic has to be carried by a few number of narrow streets. The transverse connecting system of the network is also very poor. All the links of the network have physical limitations which represent irremovable constraints to the future traffic growth.

Because of the shortage of longitudinal roads in Alexandria, the Ministry of Housing and New Communities has decided to construct an urban expressway at the location of the Mahmoudia Canal. One of the object of this road is to provide an external connection between the various zones of the urban area (as a semi-ring road) to improve the accessibility on the whole urban network.

The scheme options for the planning of an expressway at the Mahmoudia Canal were :

(a) the "do-nothing" case, in which no new roads will be constructed until the year 2005;
(b) the scheme proposed by the Ministry of Housing and new Communities, involving the construction of a four traffic lanes Highway over the Mahmoudia Canal after its infilling;
(c) modified scheme to the above described proposal, including the construction of six lanes Highway (instead of four); and
(d) the alternative derived by the City of Alexandria which includes the widening of the banks of the Mahmoudia Canal and re-classifying them as an urban Highways.

The filling of the Mahmoudia Canal as proposed from the Ministry is based on the fact that the stretch of the canal in Alexandria is since a long time not more reasonable; neither for navigation nor for irrigation. In some places, the canal is total empty. The cost of improving the canal conditions is generally so high that it practically excludes competition with other systems.

3.2 Data base

Two components were required to form the set of data for the current application of PLANET : (a) the base network of Alexandria on which modifications were designed, and (b) two traffic demand matrices, one for the base year 1983 and the other for the planning year 2005. A valuable part of the needed data was retrieved from the "Alexandria Traffic and Transportation Study", which was established on a comprehensive traffic survey and a household interview [6].

The base network was the coarse road network of Alexandria, i.e. an abstract version of the street system, aggregated to 67 nodes and 218 real links presented actual network roads.

The programme NETWORK was used to define the base network. Each link was indicated by the beginning and ending nodes, and described by length, minimum travel time and road class. The interactive system allowed the rapid modification of the base network as well as the introduction of the various scheme options. These data were then saved on computer files (*.net), together with the specific characteristics of each road class; namely maximum capacity and maximum capacity speed. The network roads of Alexandria were classified into eight different road classes[4].

For graphics representation, the coordinates of all nodes of the base network were digitized and stored on a file (*.dwg). The interactive graphic editor of the programme DISPLAY permitted the quick correction of network coding errors and the creation of the different network modifications in comfortable fashion.

In addition, the origin-destination matrices (9 x 9 zones) of workday vehicle trips for the morning peak period from 08 00h to 09 00h were also entered into the programme FLOWS, and saved on files (*.dat).

3.3 Parameters calibration

For each road class, the two parameters (x and Y) of the travel-time function involved in the assignment must be estimated. The estimation of these parameters can be carried out in a trial-and-error procedure that consists of selecting parameter values, performing a traffic assignment on the existing roads, and comparing predicted with observed flows (Figure 3).

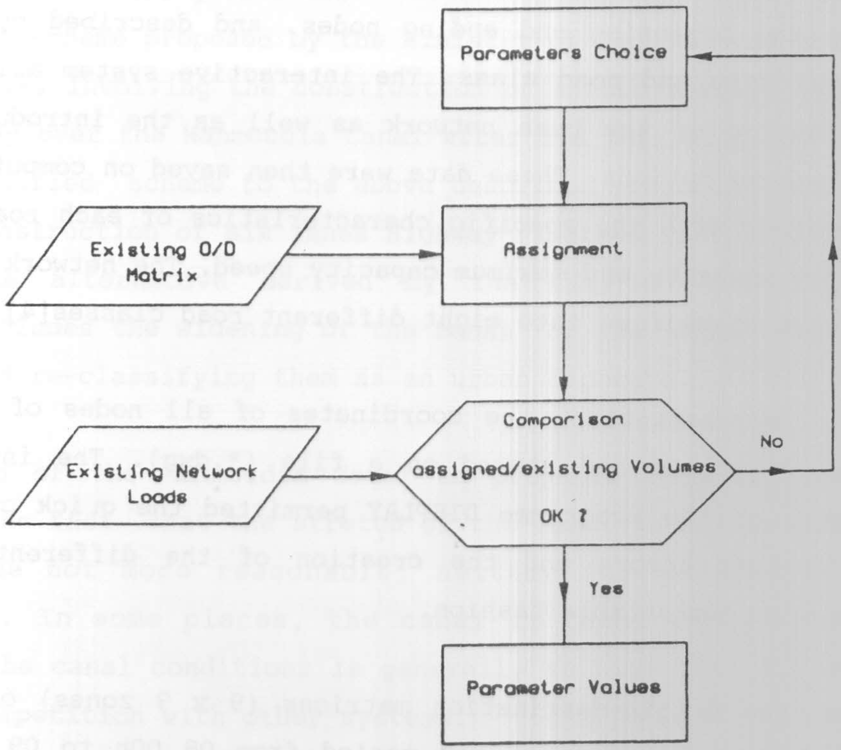

Figure 3 : The calibration process

If the comparisons are not in close agreement then adjustments should be made to the initial parameters by multiplying the used values by the ratio of the average observed to predicted flows. The calibration process is repeated until a satisfactory results are achieved (e.g. difference of maximum 15 percent between predicted and observed flows).

Table 1 lists selected streets in Alexandria and compares observed-predicted flows achieved by applying the proposed calibration procedure.

Table 1 : Comparison of observed with predicted flows on selected roads in Alexandria, a.m. peak hour, 1983 [4]

Street	observed flow veh./h	predicted flow veh./h
Cornesh Road	4849	4802
Horia Road	4558	4528
Raml Tram Str.	1542	1540
Port saied Str.	1568	1529
Mostafa Camel Str.	1262	1215
El Max Str.	1769	1735

Once the PLANET system was established, and successfully fitted to the traffic conditions of the network of Alexandria, it could be applied to examine the network under the proposed modifications.

3.4 Alternatives analysis

For the planning year 2005, the assignment procedure prognosticated the link flows on the base network of Alexandria under the different modifications. The results expressed in terms of link loads and travel times were displayed in colours on the monitor screen and then saved on files (*.res) as tables, and also on files (*.dwg) as colour graphs. Figure 4 shows the loaded network of the alternative (b), as a sample of the graphic output that is made possible by the PLANET system.

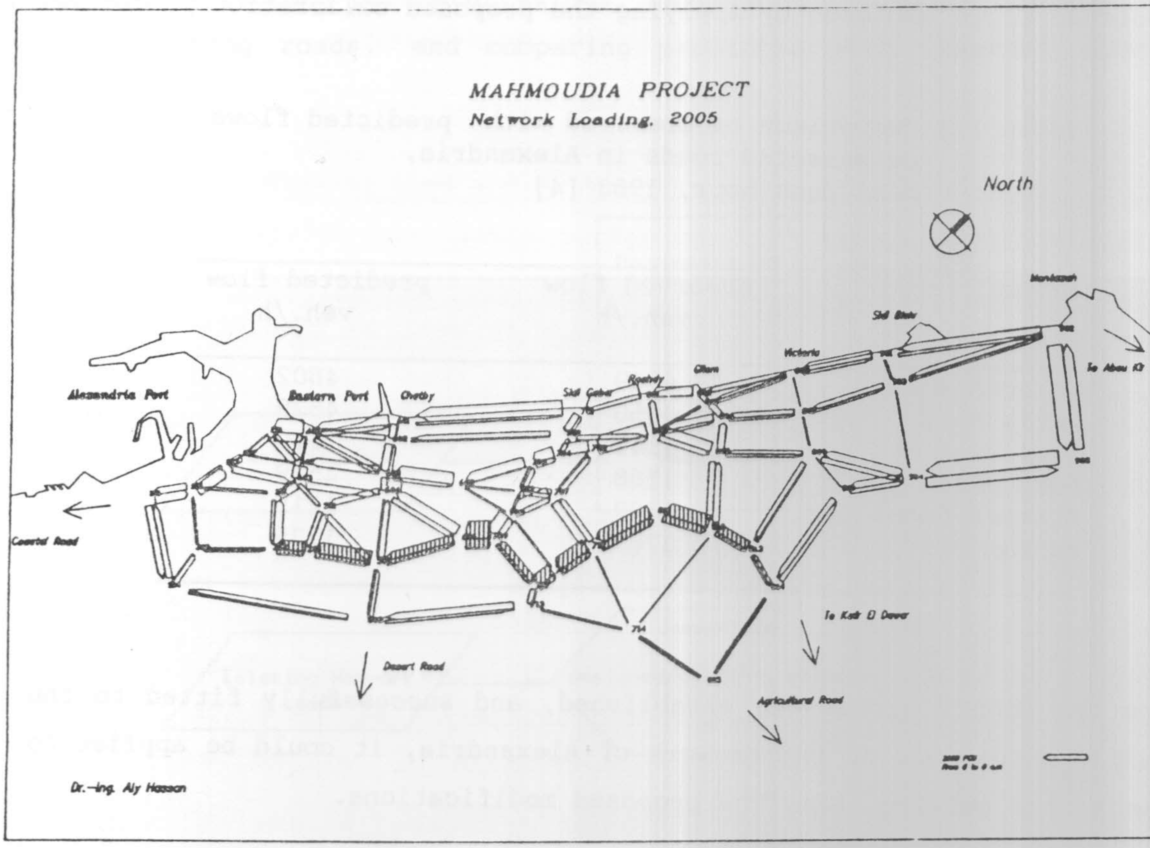

Figure 4: Plot of the loaded network of Alexandria of the scheme option (b); hatched flows on the Mahmoudia Canal Highway

In addition, it is frequently desirable to examine a subarea of the road network such as the small area illustrated in Figure 5, where the loaded links are shown at an enlarged scale.

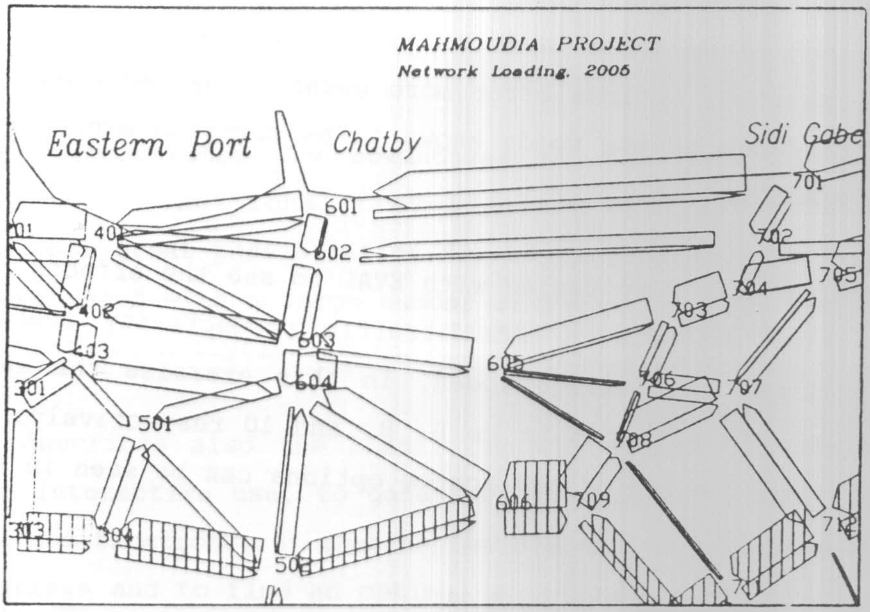

Figure 5 : Plot of loaded links on a window

Table 2 compares the predicted flows in the year 2005 on selected roads of the base network of Alexandria under the various scheme options with those achieved for the do-nothing alternative.

Table 2 : Comparison of predicted changes in link flows between the different schemes and the do-nothing; am peak hour, 2005

Road	Flow changes in the year 2005		
	scheme b	scheme c	scheme d
Cornesh Road	299	62	142
Horia Road	- 3997	- 3997	- 3991
Raml Tram Str.	- 1857	- 1857	- 1923
Port Said Str.	- 455	- 455	- 561
Mostafa K. Str.	- 2008	- 2008	- 1598
El Max Str.	- 977	- 977	- 755

The "do-nothing" alternative leads to considerable worsening of traffic conditions. The other options offer more benefits by reducing the peak-period traffic flows on the roads known to be carrying excessive levels of traffic in Alexandria.

The alternatives were then tested with EVAL to see the effects regarding three evaluation criteria : total traffic productivity (vehicle-Km); average trip time; and average speed. In this exercise the weights of these criteria were adjusted to be 6, 8, and 10 respectively. The display of the overall score of the scheme options can be seen in Figure 5.

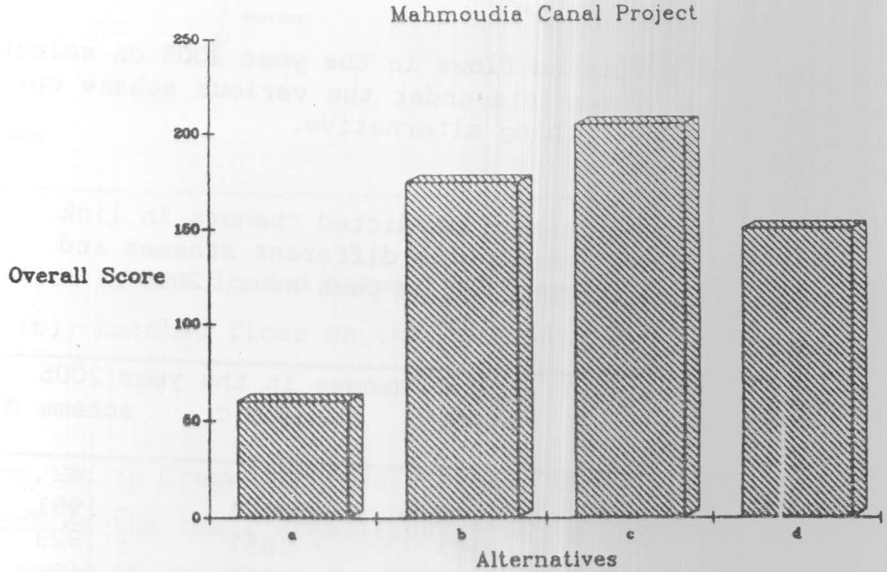

Figure 5 : Plot of the overall score of the alternatives

Conclusions

This paper demonstrates the advantages of the interactive planning techniques over traditional travel demand analysis methods. These techniques open great possibilities for solving network problems, where planners are faced with a large number of variables that can not easily be brought into an analytical form.

The paper describes also the PLANET graphic system, developed by the author for interactive use, to generate, evaluate and rank the impacts of network modifications. It enables the planner to explore a wide range of alternatives and to find an optimal solution for improving the level of service on a corridor or the accessibility on the whole network.

The recent application of PLANET to modify the road network of Alexandria, had confirmed the anticipated benefits to be derived from the use of interactive planning techniques. The visual representation increases the accuracy and greatly reduces the time required for editing network modifications and data bases, because visual displays are much more easily comprehended than printed tables. The person-computer interaction enhances the evaluation process of alternatives and allows the observation of the results and the revision of the input data to converge on a better solution.

Additional important features of the PLANET system are the both algorithms used for short path finding and equilibrium assignment of traffic flows. These led to the increased accuracy of the results and the reduced analysis time per alternative.

The application indicated also the usefulness of the PLANET system as a planning aid for urban road networks. The exercise provided a clear demonstration of the power and efficiency of the package. However, modelling is an on-going process, and the development of a planning system is always improved by its application.

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