OPERATIONAL PLANNING OF PUBLIC TRANSPORT SYSTEMS

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ABSTRACT

This paper describes a coordinated three-stage process for operationl planning of public transport systems. The process is intended (a) to generate possible routes that satisfy both operator and planner objectives, (b) to set their frequencies that meet the current travel demand, and (c) to create route-headway-optimized timetable graphs. The final product of this paper consists of a set of computer programs which are based on the theoretical concepts of the process stages. These programs are tested for the city tram system in Alexandria, and the derived alternatives (routes, frequencies and timetables) are described and discussed.

INTRODUCTION

Worldwide, the public transport operator attempts to offer the most attractive service to the traveler, while simultaneously makes an effort to reduce operating expenses. Increasing attractiveness means improving the supply elements; i.e., providing a denser network and more frequent comfortable service.

Improving the supply deteriorates consequently the financial situation of the operator because increased operating costs are not balanced by the increased ridership, particularly in case of a feeble elasticity of travel demand. Therefore, a better matching supply and demand is the only way to improve service quality and at the same time to decrease operating costs.

This paper presents an interactive graphic software package called OPERATOR, which is a planning tool for operators to improve matching travel demand and public transport supply through a coordinated planning process.

The main purpose of the proposed process is to optimize the following three operating elements for a whole system : (a) the geographic routing (sequence of stops of each route), (b) the headways (time interval between vehicles passing a given stop), and (c) the timetables (time-distance diagrams of the movements on the individual routes).

One of the principal desires of OPERATOR is to make the proposed process as transparent as possible to the operator. This desire is motivated by the fact that highly sophisticated models are only unwillingly accepted [6]. In addition, it is also decided to build OPERATOR with personal-computers. These low-cost computers allow the operator to find out near- optimal solutions, in a short time by using simple analytic techniques.

THE PLANNING PROCESS

Operational public transport planning has a short time horizon and for the purpose of this paper can be described as shown in Figure (1). The input to this planning process is a number of items that must be fixed.

These items are the travel demand in terms of trip origin and destination (O-D) matrices, which are stratified by the time of the day, a base network (terminals and stops), and the characteristics of the available rolling stock (types and capacities).

The planning process should generally be guided by user objectives (eg., minimum total travel time), and it is constrained by the financial conditions of the operator.

The desired output from this iterative process is a set of routes, the headways with which these routes are served, and route-headway-optimized timetables. This optimization is to be done separately for each operating period during which headways are constant.

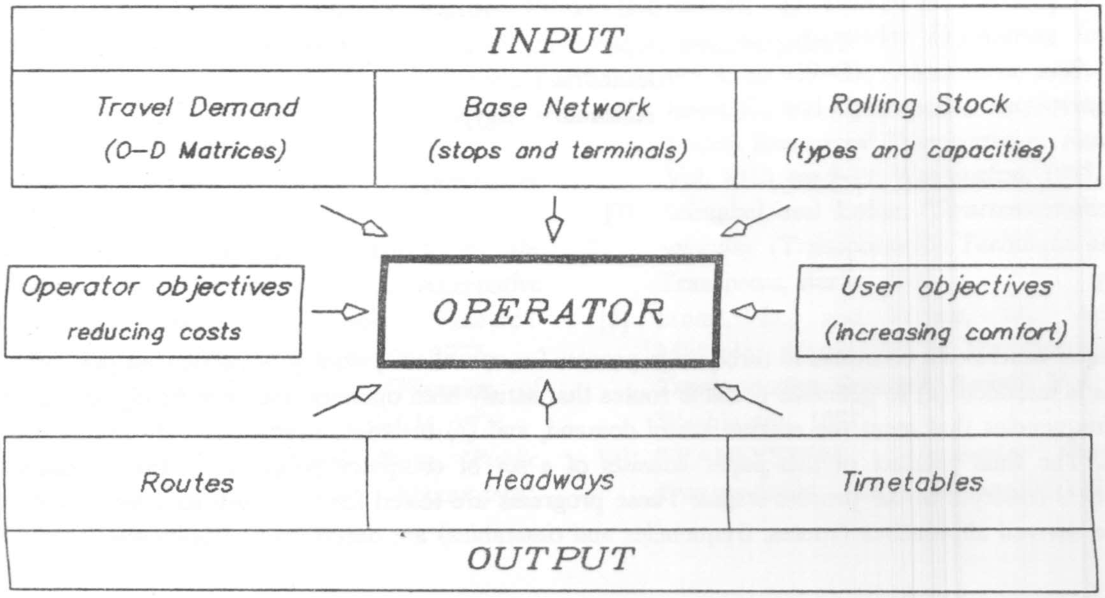

Figure 1. Operational planning defined by input and output.

A multipath stochastic model is used to assign the travel demand on the base network. An existing route structure is to be modified according to the private experience of the planner. The assignment allows the calculation of some performance parameters such as the load profiles, travel times and number of transfers. By iterating this design-evaluation cycle, the planner can quickly approach an optimum design that indicated by the choice of the planning objectives.

Alternative timetable graphs can, then, be created for all routes using a suggested comprehensive method based on load profile and running time information. This method provides various transport capacities to meet the passenger travel demand with different service levels (i.e., frequency of service and average vehicle occupancy). The decision for planner is a trade-off between passenger comfort and operating costs.

Finally, and most important, all functions of the operational planning is to be harmonized into a unified process, as shown in Figure (2). The problem is segmented into three stages. The data flow between these stages is explicitly linked (a) to highlight the dependence of one stage on the output of the preceding stages, and (b) to maintain the desired coordination of the process as a whole.

THE "OPERATOR" COMPUTER SYSTEM

The OPERATOR graphic system which recognizes this planning process is a comprehensive computer system of three core programmes (described later): ASSIGN, FREQUENC, and TIMETABL. All programmes are written in TURBO- PASCAL for the use on personal-computer (IBM or compatible). The graphic facilities of OPERATOR is closely linked with the AUTOCAD software package.

Modification of Routes

The purpose of modifying the existing routes of a public transport system is to adjust the route alignment to the current travel demand. Most cities keep the routes -once established- unchanged, and do not take into consideration the land use alterations and resulting travel demand variations. Even, by urban development, the routes may be extended without any technical consideration to optimize the whole route system [5]. Optimization means here the minimization of the average travel time, the number of transfers, and the operating costs.

In the first programme of OPERATOR (ASSIGN), the following data are considered to be constants:

1. The base network,
2. The travel demand, and

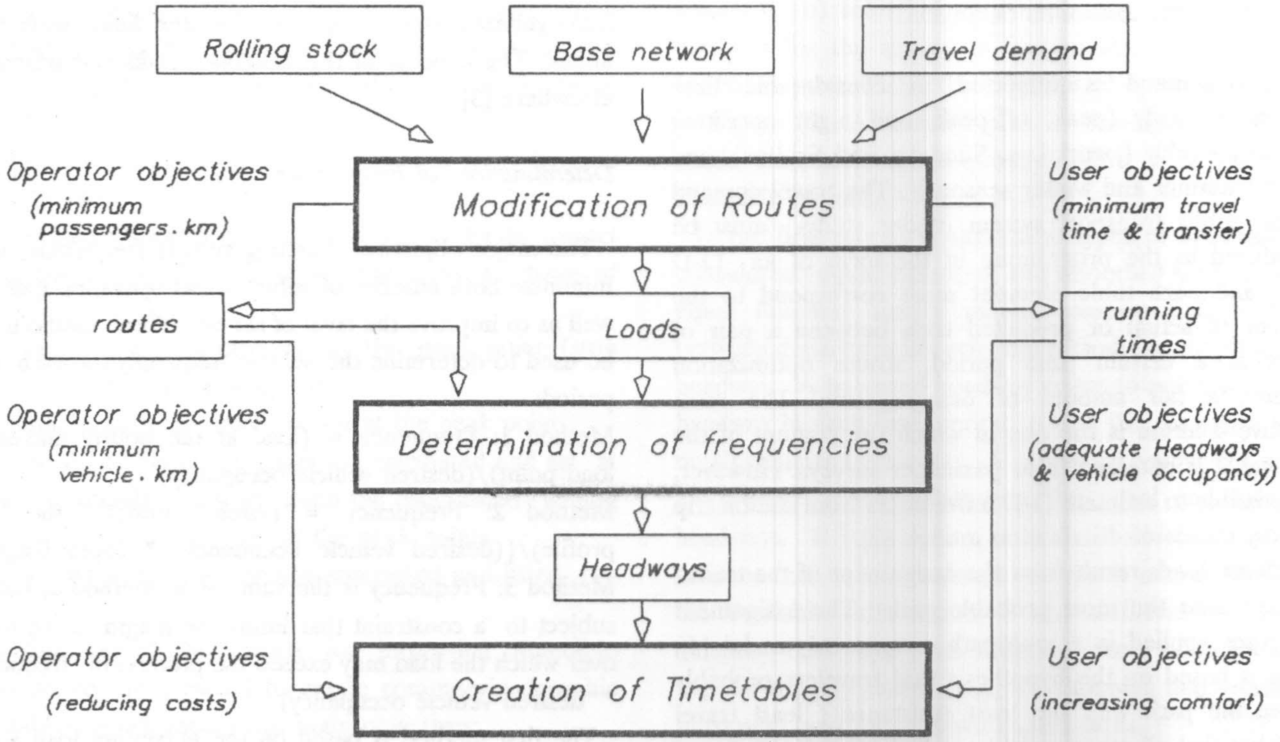

Figure 2. Coordinated three-stage operational planning process.

The base network is the set of all links that can be used by any public transport line. It contains, therefore, a part of the street network and the urban railway network. The stops, and terminals form the nodes of the base network. For display purposes, coordinates must be assigned to all nodes. Each link of the base network belongs to one or more of the following transport submodes:

1. Submode 1: bus on mixed traffic streets,
2. Submode 2: bus on exclusive separated lanes,
3. Submode 3: light rail vehicles on mixed traffic streets (Tram),
4. Submode 4: light rail vehicles on exclusive rights-of-way,
5. Submode 5: Metro-vehicles run in underground tunnels or elevated, and
6. Submode 6: Regional railway trains.

The length and the travel speeds of all available submodes must be assigned to each link.

The different types of vehicles are defined through the submodes and vehicle capacity.

The ASSIGN programme is an intuitive model, which is used to predict and to simulate the effects of network modifications. The intuitive model which is developed in the framework of this study, can be summarized as follows:

1. Assign the travel demand on the base network at each time period.
2. Based on the network loads, develop a set of alternative plans, each includes possible modifications to the existing route structure (manually).
3. Plot the load profile of the routes of each alternative plan.
4. Determine the quality of service expressed in mean travel time, and average number of transfers, as well as operating costs expressed in "passengers.km".
5. Eliminate alternatives that violate certain technical constrains (e.g., line and stop capacities).
6. Eliminate alternatives that can be dominated by others with respect to both quality of service and

operating costs.

7. Try to introduce new modifications that lead to a solution that cannot be dominated.

Travel demand is subjected to considerable time fluctuation: daily (peak, off-peak, and night operating periods), weekly (workdays, Sundays, and Fridays), and yearly (summer and winter seasons) . The travel demand of the public transport system -under study- must be introduced to the programme in the form of an O-D table, and each table element must correspond to the number of actual or predicted trips between a pair of zones at a certain time period. Route optimization requires a fair amount of desegregation. The most effective solution is the one in which the content of the O-D table is obtained from passenger surveys. However, it is possible to estimate O-D movements from station trip ends by means of distribution models [7].

Network loads result from the assignment of the transit demand onto the most probable paths. The assignment algorithm applied is a multipath assignment model [4], which is based on the hypothesis that travelers probably choose the path with the least resistance (least travel time) but that all other paths have a certain plausibility of being used. According to this splitting algorithm (equivalent in fact to a logit model), the travel flow (F_{aij}) on the link a between the origin i and the destination j can be expressed as follows:

$$F_{aij} = F_{ij} * w_{ij} / \Sigma w_{ij}$$

where

F_{ij} = the number of trips from i to j, and
$w_{ij} = \exp [b (d_{ij} - d'_{ij})]$

and where

b = A calibrated parameter,
d_{ij} = shortest path travel time from i to j, and
d'_{ij} = travel time from i to j

Note that the travel time from an origin to a destination is the sum of several components: pedestrian access time to a stop, waiting time, in- vehicle time, transfer time, and walking time from a stop to a final destination.

This multipath algorithm has originally been developed for highway trip assignment and therefore requires a homogeneous network (i.e. networks without transfer points). To transform a public transport network into a homogeneous one, imaginary transfer links should be added. The concept of the imaginary links was described elsewhere [3].

Determination of Frequencies

The major objective of setting vehicle frequencies is to minimize both number of vehicles and operating costs, as well as to improve the level of service. Three methods can be used to determine the vehicle frequency for each time period:

Method 1: Frequency = (load at the hourly maximum load point)/(desired vehicle occupancy)

Method 2: Frequency = (Area under the load profile)/{(desired vehicle occupancy) * route length)}

Method 3: Frequency is the sum as in method 2, but is subject to a constraint that limits the length of the route over which the load may exceed the product of (frequency * desired vehicle occupancy)

The first method is based on the maximum load along the route in each time period. It can successfully be used for relatively flat load profiles. The second method is based on load profile information. The load profile is plotted with respect to the distance traveled from the departure point. Thus, the area under the profile serves as a productivity measure in "passenger-kilometers". This area divided by the route length is the average load. This method can result in unpleasant travel for an extended distance over which the average load is above the desired occupancy. To control this undesirable occupancy, it is possible to establish a level of service criterion by restricting the total road distance that had loads greater than the desired occupancy. This is in essence Method 3.

To maintain an adequate service quality of a public transport system, the calculated frequencies should not be less than a certain value to assure a maximum allowed headway (policy headway) [1]. For regional railways and rail-bounded rapid transit systems, also a minimum permissible headway should be considered to guarantee safety operation (block section occupancy time).

The second programme of OPERATOR (FREQUENC) has been written for determining the frequencies at each time period, using each of the above mentioned methods.

Creation of Timetables

In current practice, schedule of a public transport system is usually made using a mix of manual and computer-generated reports, according to the following steps [2].

1. Running times are established for each route by time of the day.
2. Calculated speeds are examined in order to correct special cases of speeding up and slowing down of vehicles.
3. Headways are determined at the peak point (stop with maximum passenger flow).
4. Initial departures times are set at the peak point.
5. Arrival and departure times are calculated and set at all terminals and stops using the established running times and the headways at the peak points.
6. The final route timetable is completed and listed.

In this paper, the efforts for improving timetable construction are directed to create computerizedgraphic timetables, which satisfy two main objectives:

- better matching transport supply with travel demand, and
- integrating the operational elements of the whole system.

The proposed approach for achieving these objectives is a two-stage procedure. In the first planning stage, each route is separately treated to produce initial travel-demand- oriented timetables; one for each route. These timetables are then to be interactively modified, in the second stage, in order to integrate the operating services offered by the public transport system.

Matching demand and supply

With developing computerized timetable, there is a need to supply the planner with alternative schedule procedures, accompanied with an interpretation and an explanation of each alternative. Undoubtedly, it is desirable that one of the alternatives belongs to the manual procedure. In this way, the planner will be in the position not only to expedite the manual tasks but also to compare the various procedures with others in terms of the trade-off between passenger comfort and operating costs [9].

Present experience provides the basis for establishing the spectrum of alternative timetables. Three categories of options can be identified: (a) selection of the type of headway, (b) selection of a method or combination of methods for the setting of frequencies, (c) selection of special request. These three groups of options are shown in Figure (3). A selected path in this figure provides a single timetable. Consequently, there is a variety of timetable options.

In the first category, alternative types of headways are considered: equal, balanced, and smoothed headways. An equal headway simply means constant time intervals between departures in each time period; i.e., evenly spaced headway. A balanced headway refers to unevenly spaced headway in each time period so that the passenger loads on all vehicles are similar. A smoothed headway is simply an average headway between the equal and balanced headways. It is an option in cases in which the planner believes that equal headways will result uneven loads but the available information is not sufficient for setting balanced headways. Such situations occur often for some trips to the city centre (e.g., for shopping and recreation purposes), and for trips with short turns.

In the second category, it is possible to use the three frequency determination methods, previously described. However, it must also be noted, that determining frequencies should not always be based on the calculated load profile for each time period but rather on the observations, as well as other sources of informations.

The third category allows special scheduling requests, clock and prespecified number of departures. One characteristic of timetables is the repetiticn of departure times; i.e., the timing of passenger arrivals at a stop. The easy-to-memorize departure times are based on "clock headways" of 1,2,3,....,10,15, ..., and 60 minutes. The second possible special request is to allow the planner to prespecify the total number of departures during a time period. This request is useful in cases where a limited fleet size is available. Certainly, this request affects the desired occupancy values. The planner then is to make his decision concerning the acceptance of these values.

Using the third programme (TIMETABL) the planner can develop various alternative timetables according to the options shown in Figure (3). For each computer run the planner simply keypunches requests as follows:

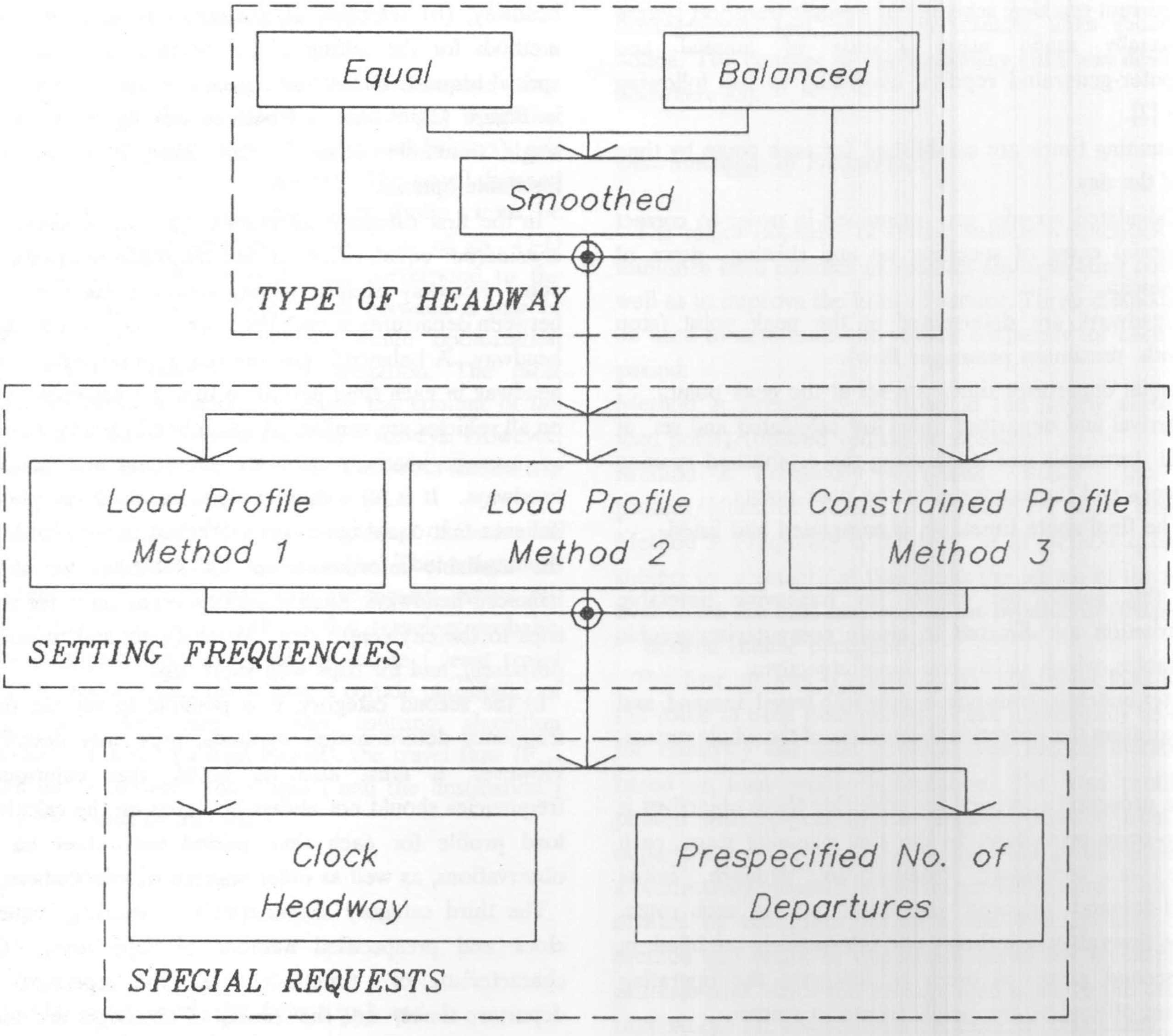

Figure 3. Creation of alternative timetable.

1. type of headway:
   1 for equal headway
   2 for balanced headway, and
   3 for smoothed headway.
2. "number" of the method to be used for determining frequency (1,2, or 3)
3. "number" represents the start of the time period and "number" represents the end of the time period
4. Clock headway:
   0 for not required, and
   1 for required.
5. prespecified number of departures:
   0 for no need, or "given number" of departures.

In this way, a variety of initial (travel-demand- oriented) timetables can be created. This may complicate the decision making process. However, it provides an opportunity to examine rapidly the consequences of the different timetable scenarios. It is anticipated that a skilled planner, while recognizing the full potential of the procedures, will select only a few alternatives to compare.

Integrating the operating elements

In order to integrate the operating conditions of a transport system, the planner may be inforced to modify the initial timetable graphs, generated from the first phase. The following measures can be considered the essential operating rules for such modifications (figure (4)):

- Integrating the movements of vehicles and trains between the lines, in case of deferential peak periods (Fill-in-trips).
- Integrating arrival and departure times at transfer points.
- Considering working times of large scale trip generators (e.g., companies, schools and universities).
- Arranging short trip turnrounds to reduce operating costs (i.e., avoiding low vehicle occupancies, and decreasing the number of vehicles required).
- Organizing of trip opposite without intermediate stop to direction of heavy loaded segments (Non-stop-trips).
- Organizing the movements of vehicles and trains from and to garages in order to decrease "dead run".

In addition to the rules controlled the creation of a route-headway- optimized timetable, other operating measures may be needed for more time adaptation of transport capacities to travel demand. These measures are often initiated by the operator in accordance with the current demand situation [8]. These are:

- At low-demand periods, deferential vehicle or train sizes can be operated; e.g., micro-bus instead of standard bus.
- Supplementary vehicles can be added to the fundamental service during peak periods to cover unexpected excessive demand.

The TIMETABL computer system is provided with the following editing facilities which allow the planner (using the computer-cursor) to carry out the essential modifications of the initiated timetable graphs interactively :

ERASE : Cancel the existence of a bus or a train from the timetable.

INSERT : Introduce the movement of a new bus or a train to the timetable graph, from a certain stop at a certain departure time.

CHANGE : change the travel performance of a bus or a train in the time-table graph; i.e., arrival or departure time, stop locations, and running speeds.

MOVE : Select a new position for the movement of a bus or a train in the timetable graph.

SYSTEM APPLICATION

The city tram in Alexandria has been selected to examine the computerized system. The city tram has no separated track, and runs on its network in the middle of the narrow roads of the old city. Thus, both the city tram trains and the individual transport cause disruption to each other. This intermixture consequently leads to a reduction of the running speeds (approximately 8 km/h at peak periods).

The network includes 9 lines, and 76 stops. The fleet size consists of 105 articulated vehicles with accommodation of 184 passengers (36 seated and 158 standing with 8 pass./m^2).

Possibilities for improving the city tram system are restricted, because the local conditions do not permit the separating of its track. Without rights-of-way facilities, it is not recommended to operate additional tram units.

Figure (5) shows the structure of the existing routes of the city tram system as well as the loaded network at the morning peak period. Network loading was based on actual data roughly collected (in April 1989), in the framework of this study, only to test the developed computer system.

For this reason, Figure (5) illustrates also the proposed routes to be tested, as an alternative. The

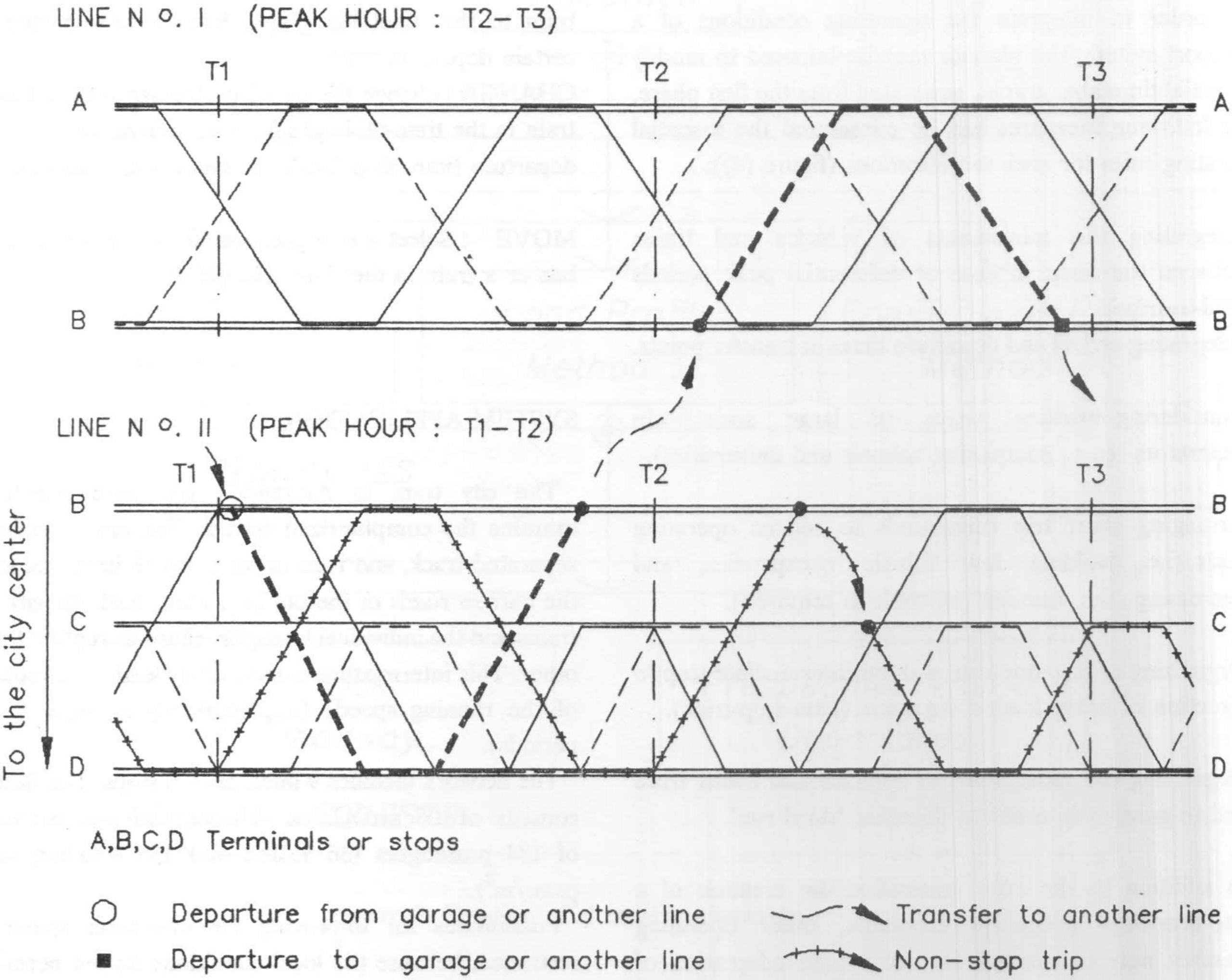

Figure 4. Integrating the operating elements in a timetable graph.

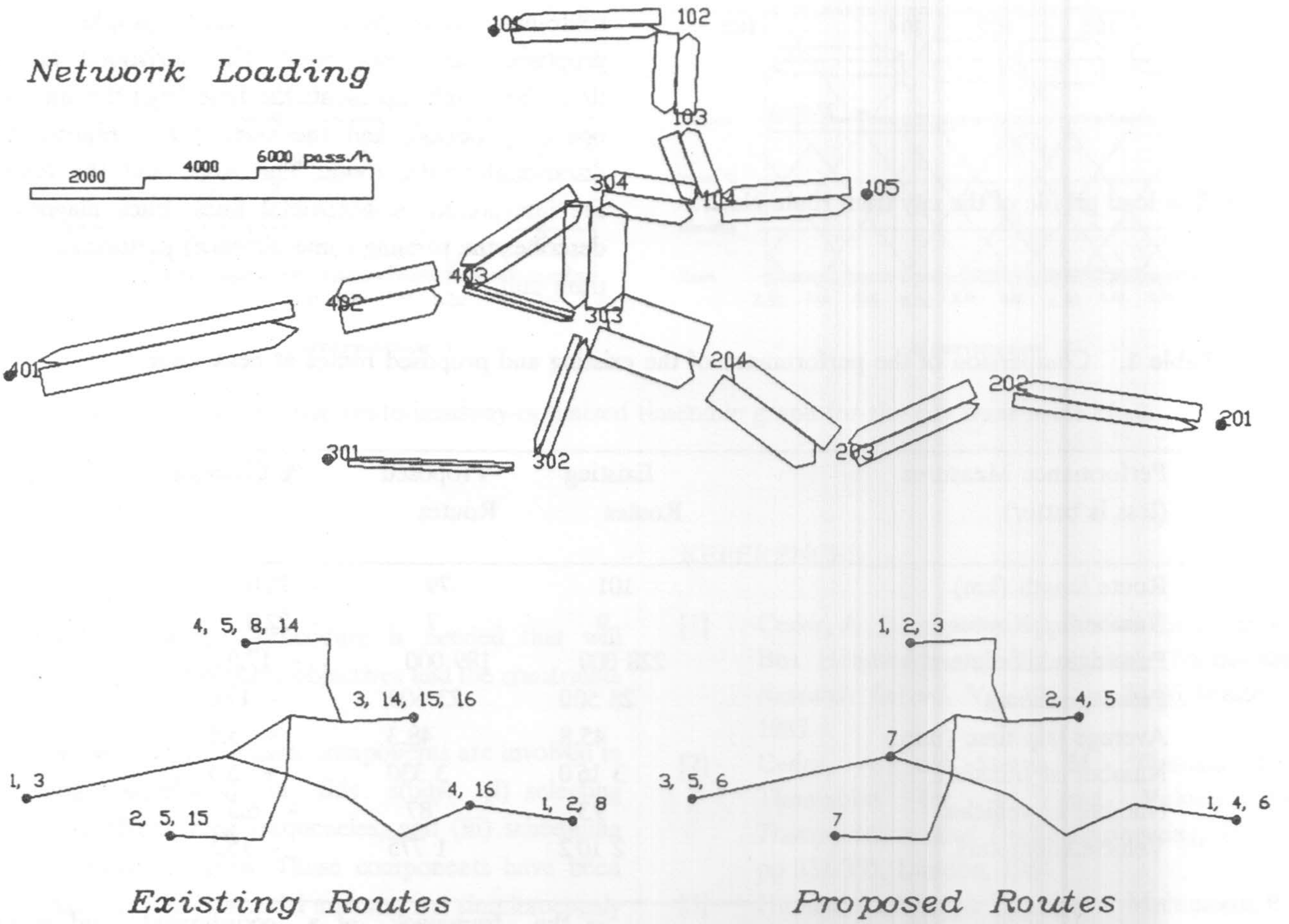

Figure 5. The city tram system in Alexandria -loaded network, existing and proposed routes-

route changes involved were simple. Four routes were left unchanged.

As shown in Table 1, encouraging results have been obtained by making these route modifications, and the service attributes to a better match with the current demands. The table gives a comparison of different performance measures for both the existing and the proposed routes. The data in the table indicates that, the proposed design is better in 6 of 8 categories of the performance measures, and worse in 2. Average total trip time and number of transfers are sharply up, and clearly this is undesirable results. But, this impairment hat to be traded off with the sharp drop in operating costs (expressed in number of vehicles and vehicles.km). Certainly, a large increase in operating costs alleviates the burden of more transfers and somewhat longer trip times associated with the proposed design.

For the proposed tram route No. 2 (5.40 Km length), a computer-generated load profile for the peak hour is provided as shown in Figure 6. On this route the hourly maximum load point lies between the node No. 102 and the node No. 103, while the loads on the segment between the nodes 101 and 102 are about 60 % of the maximum loads.

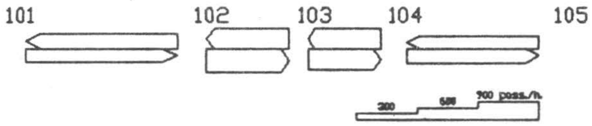

Figure 6. The load profile of the city tram route No.2.

Figure (7) shows two alternatives of route-headway-optimized timetable graphs for the proposed tram route No.2. The horizontal axis of a timetable graph represents the time from the start of the operating period, and the vertical axis represents the distance along the route. The stops and the terminals are interpreted by horizontal lines. Each diagonal line describes the running (time-distance) performance of one tram unit.

Table 1. Comparison of the performance of the existing and proposed routes at peak hour

Performance Measures (less is better)	Existing Routes	Proposed Routes	% Changes
Route length (km)	101	79	- 21.0
Number of Routes	9	7	- 22.0
Passenger.kilometers	228 000	189 000	- 17.0
Passenger.hours	28 500	23 600	- 17.0
Average trip time (min.)	45.8	48.3	+ 5.5
Number of transfers	3 160	3 330	+ 5.5
Number of vehicles	93	87	- 6.5
Vehicle.kilometers	2 102	1 775	- 15.5

The first graph (alternative 1) was based on the concept of equal headway (evenly spaced), and the other (alternative 2) was based on balanced headway (unevenly batches of routes). The later graph was established according to the assumption that 8.30 a.m. is the working start of a large number of activities at the city centre (Raml Station). Both timetable graphs were based on "clock headways", and the frequencies were calculated with Method 1 "hourly maximum load point".

The purpose of the interactive creation of both alternative timetable graphs was essentially twofold: a) determining minimum frequencies to accommodate the maximuum passenger load, and (b) planning short trip turnrond (at Anfushi) for resource saving and to increase the average vehicle occupancy on the low-demand segment (between Anfushi and Ras El- Tin).

Compared with the existing situation, the timetable graph "alternative 1" can provide the following advantages in the framewok of a coordinated and regulated operating system:

- Reducing the number of needed vehicles; one tram unit can be saved to be operated on another line, and
- improving the average vehicle occupancy at the section from Anfushi to Ras El tin with about 50 % (from 0.62 to 0.94).

Figure (7) (alternative 2) presents also the potential of OPERATOR for modifying a generated timetable graph. With the help of the editing facility MOVE the current movement of a tram unit in the graph can be changed to a new position (dotted line).

CONCLUSIONS

Planners have frequently criticized the lack of flexibility of operators in adjusting the transport service to the changes of demand patterns. On the other hand, operators have criticized the lack of understanding the complexities of the frequent route and service alterations. Thus, a

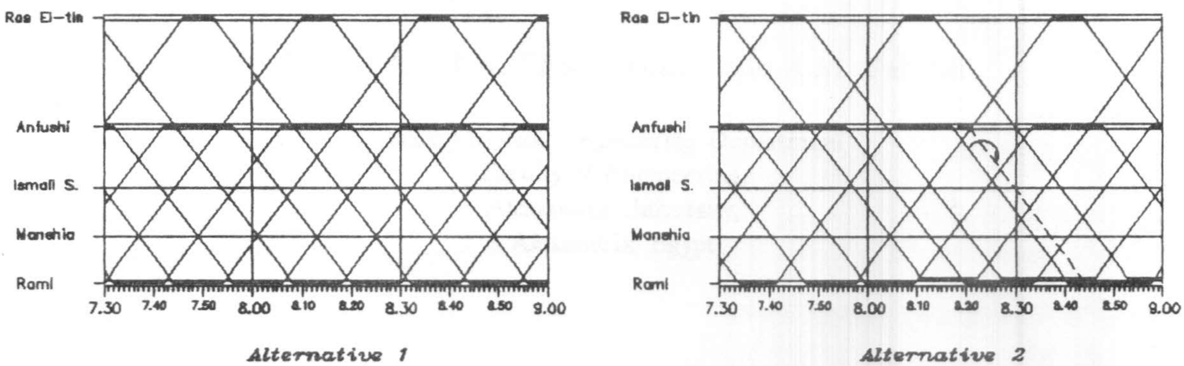

Figure 7. Alternative route-headway-optimized timetable graph for the city tram route No.2.

formalized coordinated procedure is needed that will account for both the planner objectives and the constraints of operators.

For this purpose, three basic components are involved in a procedure developed in this study: (i) selecting routes, (ii) determining frequencies, and (iii) scheduling transport modes to trips. These components have been traditionally treated in a serial manner, but simultaneously analysed. The procedure integrate then these components through the generation of route-headway -optimized timetables. These timetables can graphically be created by using the OPERATOR computer system.

The application of OPERATOR to the city tram system in Alexandria demonstrates its greatest benefit. It is an important tool to highlight the trade-offs that must be made between improving the level of service and the economic conditions. The graphic representation of timetables, and the editing facilities allow the operator to modify and to integrate the different operational elements, interactively.

Future work may include consideration of the following two aspects: (a) the structuring of routes and the assignment of frequencies is done for a given desired trip matrix. (b) the analysis of operating costs and passenger riding-time cost can be made more realistic by considering actual costs.

REFERENCES

[1] Ceder, A., "Computer Application for Determining Bus Headways and Timetables", *Transportation Research Record*, Vol. 1011, pp 76-86, Washington, 1985

[2] Ceder, A. and Stern, H., "Optimal Transit Timetables for a Fixed Vehicle Fleet", *Transportation and Traffic Engineering*, pp 331-355, London, 1984

[3] Hassan, A., "Sketch Planning of Multimodal Rapid Transit", *Alexandria Engineering Journal*, Alexandria, 1990

[4] Horowitz, A., "Extensions of Stochastic Multipath Trip Assignment to Transit Networks", *Transportation Research Record*, Vol. 1108, pp 66-71 Washington, 1987

[5] Matt, P., "Interaktive Liniennetzplanung fuer den OEPNV (Interactive Planning of Public Transport Routes)", *HEUREKA 87*, pp 417-426, Karlsruhe,1987

[6] Pierick, k. and Wiegand, K., "Prozessreglung im Verkehr (Process Management in Transportation)", *Der Nahverkehr*, Vol. 5, pp 30-36, Braunschweig, 1983

[7] Rapp, M., "Interactive Graphics System for Transit Route Optimization", *Transportation Research Record*, Vol. 559, pp 73-88, Washington, 1975

[8] VOEV and VDA, "*Bus Transit System*", Alba Buchverlag Gmbh, pp 109- 119, Duesseldorf, 1982

[9] Wren, A. , "Vehicle and Crew Scheduling", *HEUREKA 87*, pp 476-496, Karlsruhe, 1987