# A Computer-Aided Approach to Energy Contingency Route Planning for Transit Using TNOP

Thomas W. Friedman and N. Janarthanan

The energy crisis in 1973-1974 and the uncertain nature of oil availability have prompted many transit operators to plan for those emergencies that may produce sudden increases in ridership. An emergency can be handled by proper advance planning. Plans must be prepared to meet the requirements of vehicles, personnel, oil, and so forth to satisfy the increase in ridership demand. Beyond these requirements, an agency must understand the demand pattern so that efficient route-service plans can be developed in advance. In this study the use of a computerized transit planning package is tested for analyzing the demand pattern and for deriving high-performance plans for serving different fixed-demand levels.

The interactive graphic Transit Network Optimization System (TNOP) is a set of computer programs for use in designing and evaluating the performance of alternative bus and rail transit systems. TNOP is designed to analyze fixed-route, fixed-schedule transit systems. The TNOP system combines easily understood graphic displays with a user-friendly interface. Through interactive computing TNOP helps transit planners examine a wide range of design alternatives and compare performances to find better ways of providing transit services that match a particular demand pattern.

One of several recent applications of TNOP for energy contingency planning at Seattle Metro is described in this paper. Further documentation of the full study is available in Contingency Planning for Transit Services During a Gasoline Shortage Emergency Using TNOP (1).

## STUDY OBJECTIVE AND ASSUMPTIONS

The objective of this part of the study was to develop a collection and distribution system of transit routes that could be used to provide peak-hour (work and college) transit service in the event of another severe energy shortage. The study area, Bellevue, Washington, is located across Lake Washington from Seattle and is the fourth largest city in the state. Three levels of increased transit demand were considered: 100 percent, 75 percent, and 50 percent of all work and college trips.

The study assumes that local school district buses would be available in case of a gasoline shortage. The school buses must be used within the school district that owns them; therefore school buses are used on local collection routes and regular Metro buses are used on routes leaving the Bellevue area. A minimum headway of 5 minutes on external routes and 2 minutes on internal routes is used initially.

## DATA PREPARATION AND VERIFICATION

The data base for TNOP consists of a base street network, trip demand matrix, vehicle data, and geographic data. The Bellevue base network was constructed from land use, economic and existing street and headway details, and consisted of 225 nodes and 336 two-way bus links. The base network is shown in Figure 1. The demand for transit is specified in TNOP as an origin-destination (O/D) matrix. Each entry in the matrix represents the number of transit trips desired between each O/D pair.

The vehicle data contain information about the different types of vehicles that may be used, their capacity, and operating costs (per km and per hr costs). In this study two types of Metro buses (articulated and 40-ft buses) and three types of school buses were used.

## DESIGN GENERATION AND EVALUATION

The main steps involved in the design process using TNOP after the preparation of the data base are: (a) setting model parameters, (b) calibration of link travel times on the networks, (c) initial design and evaluation, and (d) modifications to increase performance until best design is found.

### Setting Model Parameters

The various model parameters in TNOP and the values used in this study are as follows:

| Model Parameters | Value |
|---|---|
| Minimum layover time at line terminals | 3 min |
| Minimum ratio of layover and trip time | 15 percent |
| Waiting time factor | 50 percent |
| Trip assignment parameter | 10 percent |
| Waiting time weight | 200 percent |
| Transfer time weight | 250 percent |
| Walk time weight | 150 percent |
| Maximum waiting time | 10 min |

### Calibration of Link Travel Time

For this study actual link transit travel times were not available, so the link file was initially constructed with posted roadway speeds. An existing Metro route was designed on the network and the travel time was calculated using TNOP. This travel time was compared with the actual Metro schedule. The same procedure was repeated for many routes. An average factor derived from this procedure was used to convert actual into TNOP travel times.

### Initial Design and Evaluation

Emergency level I, which means that 100 percent of work trips and college trips depend on Metro service, requires that 38,602 people be moved on buses from home to work or college in a 1-hour period.

The first step in creating the initial design was to analyze the O/D data. This process was aided by desire line and production and attraction graphics. The desire line map for the Seattle central business district (CBD) is shown in Figure 2. The production map for the study area is shown in Figure 3. Using these graphics as aids, routes were laid out on the Bellevue base network. Initially 16 routes were planned and designed. Nodes with trip origins that were not served by one of the bus routes were connected to a bus stop by a pedestrian link or links,

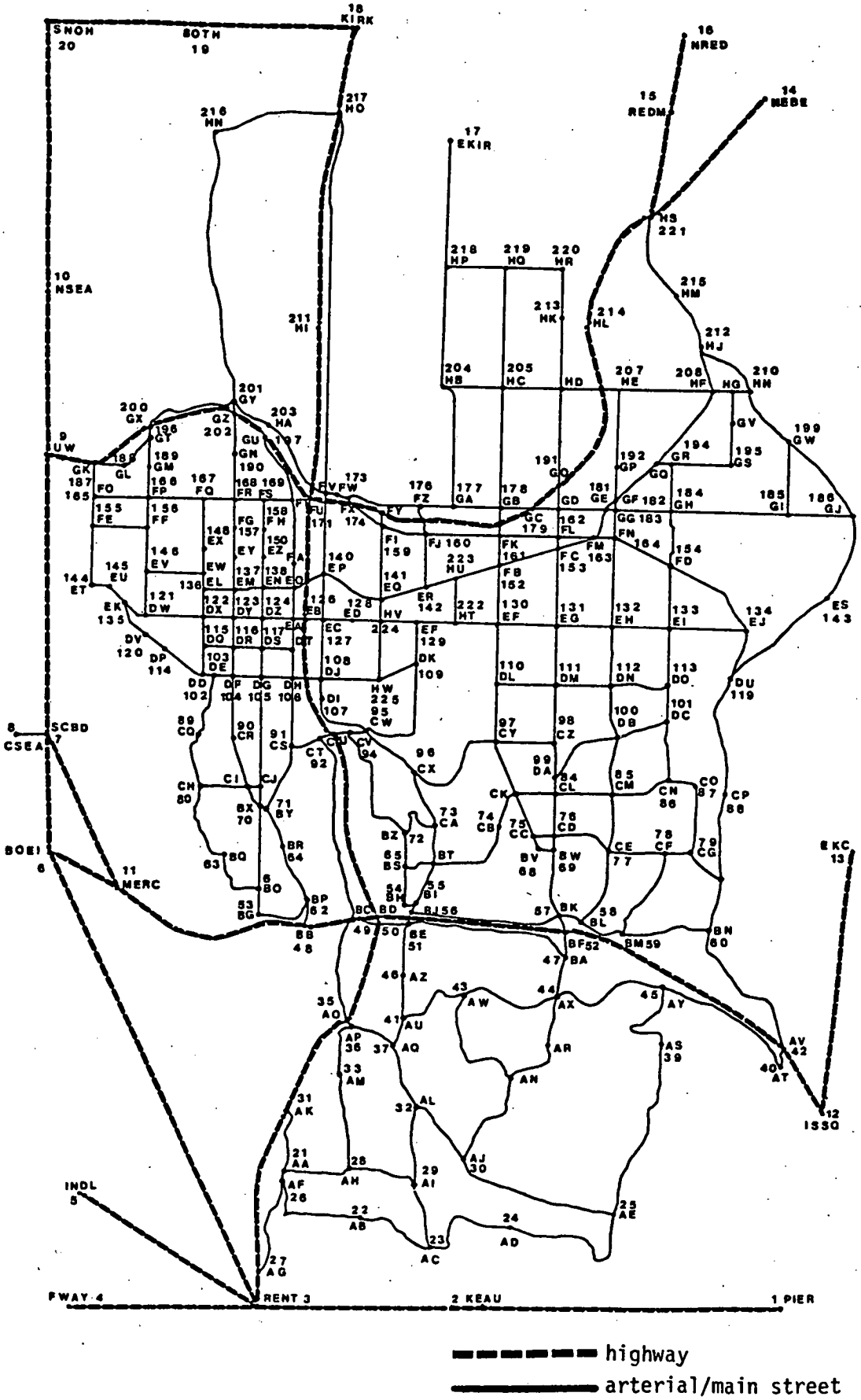


Figure 1. Bellevue base network.

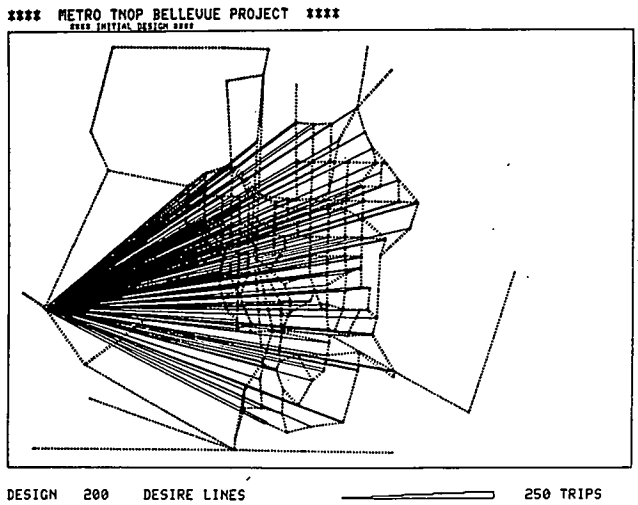


Figure 2. Desire lines to Seattle central business district.

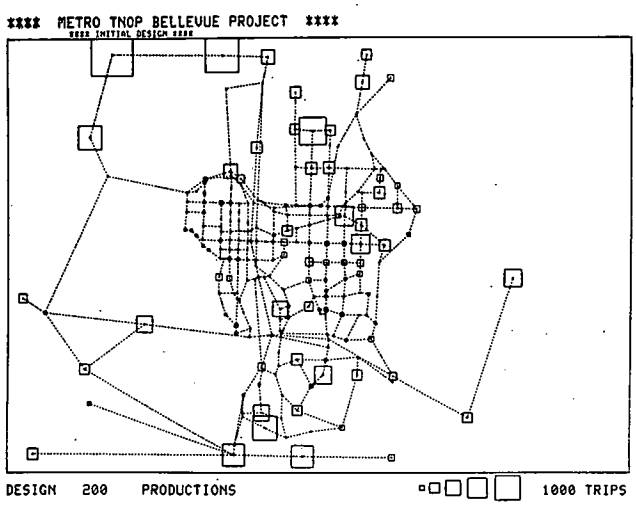


Figure 3. Metro TNOP Bellevue project.

provided that the total walk time from the node to the bus route was less than 10 minutes.

The 16 routes were interactively entered into TNOP, together with the route attributes shown in Figure 4. Routes 6 through 13, 15, and 16 were designed as feeder routes and were assigned school buses. The remaining routes were designed to connect external nodes to Bellevue locations and were assigned Metro buses.

The next step was to have TNOP assign trips to these 16 routes and evaluate the design. The resulting performance measures for this initial design (200) are shown in Figure 5. Only 23,840 trips were assigned out of 38,602. This 62 percent assignment is low considering that the objective is to assign all the trips.

## Modifications to Increase Performance

The next step was to modify the initial design. From the TNOP output, the number of trips that are not assigned along with their origins and destinations are known. From this the planner can determine which important O/Ds have not been connected by bus routes. By examining this information, it was determined that the initial transit network should be modified by adding five more routes as well as some new pedestrian links.

LINE PARAMETERS

| LINE NO. | MODE | HEAD WAY | VEHICLE NO. | | TYPE | LINE LENGTH | TRAVEL TIME | COST |
|---|---|---|---|---|---|---|---|---|
| 1 | B | 5.0 | 18 | 5 | ARTICULATED BUS | 42580 | 77.4 | 1293 |
| 2 | B | 5.0 | 26 | 5 | ARTICULATED BUS | 55400 | 111.8 | 1796 |
| 3 | B | 5.0 | 22 | 5 | ARTICULATED BUS | 50260 | 95.4 | 1559 |
| 4 | B | 5.0 | 18 | 5 | ARTICULATED BUS | 40300 | 74.2 | 1266 |
| 5 | B | 5.0 | 18 | 4 | 40-FOOT BUS | 41000 | 75.4 | 1274 |
| 6 | B | 5.0 | 7 | 3 | SCHOOL BUS | 12560 | 29.8 | 584 |
| 7 | B | 5.0 | 8 | 3 | SCHOOL BUS | 9890 | 31.0 | 570 |
| 8 | B | 5.0 | 7 | 3 | SCHOOL BUS | 8880 | 28.3 | 504 |
| 9 | B | 5.0 | 14 | 3 | SCHOOL BUS | 18140 | 59.7 | 1015 |
| 10 | B | 5.0 | 8 | 3 | SCHOOL BUS | 10510 | 34.7 | 583 |
| 11 | B | 5.0 | 14 | 3 | SCHOOL BUS | 18320 | 59.7 | 1019 |
| 12 | B | 5.0 | 8 | 3 | SCHOOL BUS | 10190 | 34.6 | 575 |
| 13 | B | 5.0 | 7 | 3 | SCHOOL BUS | 8430 | 30.5 | 493 |
| 14 | B | 5.0 | 30 | 4 | 40-FOOT BUS | 70920 | 126.8 | 2154 |
| 15 | B | 5.0 | 14 | 3 | SCHOOL BUS | 16710 | 57.2 | 984 |
| 16 | B | 5.0 | 20 | 3 | SCHOOL BUS | 27510 | 86.0 | 1484 |

Figure 4. Transit line attributes.

OVERVIEW STATISTICS

| | | | |
|---|---|---|---|
| DESIGN | | 200 | |
| NO.OF LINES: | RAIL | 0 | |
| | BUS | 16 | |
| | TOTAL | 16 | |
| ROUTE LENGTH: | RAIL | 0 | (KM ) |
| | BUS | 364 | (KM ) |
| | TOTAL | 364 | (KM ) |
| TOTAL TRIP DEMAND | | 38602. | |
| NO. OF ASSIGNED TRIPS | | 23840. | |
| NO. OF UNASSIGNED TRIPS | | 14762. | |
| AVERAGE SEATING & STANDING ROOM UTILIZATION: | RAIL | 0.0 | ( % ) |
| | BUS | 95.8 | ( % ) |
| | TOTAL | 95.8 | ( % ) |
| PASS.-KM (=SUM OF TRIP LENGTHS) | | 453100. | |
| PASS.-HRS (=SUM OF TRIP TIMES) | | 20300. | |
| AV. TOTAL TRIP TIME | | 44.5 | (MIN) |
| AV. TOTAL WAIT TIME | | 5.7 | (MIN) |
| AV. TOTAL TRANSFER TIME | | 0.5 | (MIN) |
| AV. TOTAL WALK TIME | | 0.4 | (MIN) |
| AV. TOTAL TRAVEL TIME | | 51.1 | (MIN) |
| NO. OF TRANSFERS | | 31600. | |

Figure 5. Overview statistics.

This design resulted in 89 percent of all trips being assigned, which is a significant improvement. However, 15 of 21 routes were overloaded, some of them more than 100 percent, which resulted in a high average use of 73.8 percent. These routes are so overloaded that more capacity has to be provided on each route. Because the minimum headway of 5 minutes cannot be lowered, additional capacity can only be provided by adding more routes.

The final design (300) has 25 transit routes. The summary statistics in Table 1 show that 98.7 percent of trips have been assigned to this system, which is close to the objective of assigning all the demand. However, 18 of 25 routes were still overloaded, with a 78 percent average use.

At this stage it was decided to lower the minimum headway constraint to provide more buses to meet the demand for service because this design is so overloaded. The headways of all the routes were reduced and the assignment executed. The results are given in Table 1. The average use has now been reduced to 49.8 percent, which is a significant improvement. The average total wait time is 3 minutes instead of 4.5 minutes in the previous design. There is an increase of 460 transfers (1 percent); this may be due to the reduction of headways on some of the routes, which increases their ability to attract trips from other routes. Seven routes are still overloaded in this design, but because the situation

Table 1. Summary of Bellevue designs.

| Description | Demand Level (%) | | | | |
|---|---|---|---|---|---|
| | 100 | 100[a] | 75 | 75[a] | 50 |
| 1. Design number | 300 | 400 | 100 | 200 | 100 |
| 2. Number of routes | 25 | 11 | 15 | 13 | 16 |
| 3. Route length (km) | 557 | 244 | 297 | 254 | 307 |
| 4. Number of assigned trips | 38,100 | 15,650 | 30,050 | 17,460 | 19,898 |
| 5. Percent of trips assigned | 98.7 | 41 | 95 | 55 | 100 |
| 6. Average seating and standing utilization (percent) | 49.8 | 47.8 | 56.7 | 52.9 | 54.3 |
| 7. Average total trip time (min) | 40.8 | 36.8 | 37.3 | 37.2 | 36.3 |
| 8. Average total wait time (min) | 3.0 | 3.5 | 2.8 | 3.6 | 3.8 |
| 9. Average total transfer time (min) | 0.6 | 0.1 | 0.4 | 0.8 | 0.1 |
| 10. Average total walk time (min) | 0.5 | 1.1 | 1.2 | 0.8 | 1.2 |
| 11. Average total travel time (min) | 44.9 | 41.5 | 41.7 | 42.4 | 41.4 |
| 12. Number of transfers | 50,960 | 21,660 | 39,430 | 20,710 | 249,710 |
| 13. Total number of vehicles | 651 | 285 | 440 | 282 | 320 |
| 14. Total vehicle kilometers | 13,938 | 5,574 | 8,789 | 5,728 | 6,232 |
| 15. Operating cost/hour | 46,063 | 19,091 | 28,880 | 18,819 | 21,039 |

[a]With vehicle constraint.

handled in this project is of an emergency nature some overloads must be allowed.

The primary problem with this design is that 651 buses are required, compared to 280 available, including 70 school buses. Thus it does not seem feasible to attempt to carry 100 percent of the demand, unless a significant number of additional buses can be used.

## VEHICLE CONSTRAINED DESIGN

The next step was to develop a route design that would attempt to maximize the number of riders served, given the vehicle availability constraint. The desire line (Figure 2) and production map (Figure 3) and an attraction map, all displayed by TNOP, are useful in developing routes to maximize ridership. Only the major external origins and destinations were included, as it was already known from previous designs that too many buses would be required to serve everyone.

This design (400) resulted in 11 routes being used. As the data in Table 1 indicate, this design required 285 buses--only five more than available. The drawback, however, is that only 41 percent of the demand has been served. Thus, given the number of vehicles available, including school buses, more than 50 percent of the total work and school trips must still use automobiles or vanpools.

## CONCLUSION

One application of using TNOP for energy contingency planning has been described. There were two other energy-related elements in this project. One was a similar contingency planning study in Federal Way, another suburban Metro service area. The other was an energy efficiency study in Bellevue in which TNOP was used to redesign existing service to make it more energy efficient, while still serving the same transit demand. This later study resulted in a design which theoretically saves 56 percent of the route-miles used by the existing system.

Based on the experience from this project, it may be concluded that TNOP can be used to assist in the preparation of energy contingency plans, given the availability of good transit origin and destination trip data. The interactive features of TNOP allow for rapid examination and comparison of many alternatives to generate high performance designs in a relatively short time.

## REFERENCE

1. N. Janarthanan and J. Schneider. Contingency Planning for Transit Services During a Gasoline Shortage Emergency Using the Transit Network Optimization Program (TNOP). Dept. of Civil Engineering, University of Washington, Seattle, 1983.