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Reducing the Energy Requirements of Suburban Transit Services by Route and Schedule Redesign

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ABSTRACT

Reducing energy consumption has become an increasingly important concern of transit planners and managers in recent years. Energy consumption may be reduced by improved scheduling of vehicles, reduced deadheading, and laying out more efficient routes. This paper investigates several ways of redesigning an existing transit service to reduce its energy requirements without reducing service quality substantially. Bellevue, a suburban area within King County, Washington, is used as the study area in this investigation. A 13-route existing transit service in Bellevue is simulated and then redesigned to reduce its energy requirements while still providing a comparable level of service. The generation and evaluation of seven alternate designs was accomplished with an interactive graphic computer program called the Transit Network Optimization Program. Results from the "best" design indicate that the energy requirements of the existing system could be reduced by about 56 percent without a substantial reduction of the level and quality of service in the study area.

Most transit agencies are currently under substantial financial pressure and depend heavily on governmental aid to meet many of their operating costs. Consequently, cost reduction techniques, particularly those that relate to energy costs, are receiving more attention. In recent years energy costs have become a fast-growing and large component of operating costs. Because of fluctuating prices and uncertainty about availability, reducing energy consumption has become an important concern of both planners and managers of transit systems. Energy consumption may be reduced by improving the scheduling of vehicles, reducing deadheading, and laying out more efficient routes. The optimal scheduling of vehicles is constrained by minimum headway requirements and deadheading by the location of bus bases. Transit routes may often be shifted to some limited extent to save energy. The objective of this study is to determine how much energy might be saved by designing more energy-efficient route structures and schedules. An interactive graphic computer program, the Transit Network Optimization Program (TNOP), is used to generate and evaluate alternative designs quickly and easily.

TNOP can be used to design and evaluate the performance of alternative fixed-route, fixed-schedule bus and rail transit systems. Through interactive computing, TNOP helps transit planners generate and evaluate a wide range of design alternatives and to compare their performance characteristics. Typically, planners are able to find higher performance designs by providing transit services that more closely match actual origin-destination travel patterns. Seattle Metro Transit decided to explore the applicability of TNOP to this question and this study was designed to evaluate TNOP's usefulness as a planning tool for the transit industry. Initially TNOP was used to simulate the existing transit service in the study area. Then a search for alternative designs that were more energy efficient but still gave high performance was conducted.

DESCRIPTION OF STUDY AREA

The area chosen for this study is the city of Bellevue, located in a suburban area of King County, Washington. Bellevue is located between Lake Washington and Lake Sammamish, about 6 miles east of Seattle (Figure 1) (1,pp.1-41). The city of Bellevue has the second largest population in urban King County and is the fourth largest city in Washington State. It has an area of 24.5 square miles. Bellevue is a major employment center for the Puget Sound region. It is also a major commercial center that is well linked to established transportation corridors.

Bellevue had a total population of 73,711 in 1980 and has had an average annual growth rate of 3.5 percent. The median family income is $24,000 (1978), which is higher than the King County average. The total number of people employed in the city was 41,000 in 1980, which is more than the number of workers who reside within its corporate limits. This area is reasonably well served by bus transit.

DATA PREPARATION

The data base for TNOP consists primarily of a base network, a demand matrix (trip table), and vehicle data (2,3).

Network Data

The development of the base network consisted of collecting land-use, economic, and existing street and highway information. From this a node-link network was developed for the study area. External nodes (nodes outside the study area) were connected to the study area network by major arterials or expressways. The Bellevue base network that resulted is shown in Figure 2. It consists of 231 nodes and 344 two-way bus links. Nodes 1 through 20 are external nodes. They are shown much closer to the study area than they actually are for map design purposes. Freeways are represented by thick dashed lines. Table 1 gives the major network nodes and the areas represented by them.

Demand Matrix

In 1982 an on-board survey was conducted by Metro in Bellevue. The survey was limited to 13 routes that either originate in or pass through downtown Bellevue. A total of 3,173 self-administered questionnaires was distributed to all bus riders during 173 inbound trips on Eastside routes and 31 trips on two van routes. Information about the origins and destinations of the trips was coded to 180 geographic zones.

Transformation of the demand matrix from a 180-zone system to a TNOP zone system was carried out (4). Using this information, an origin-destination (O-D) matrix (trip table) in TNOP format was constructed for use in this study.

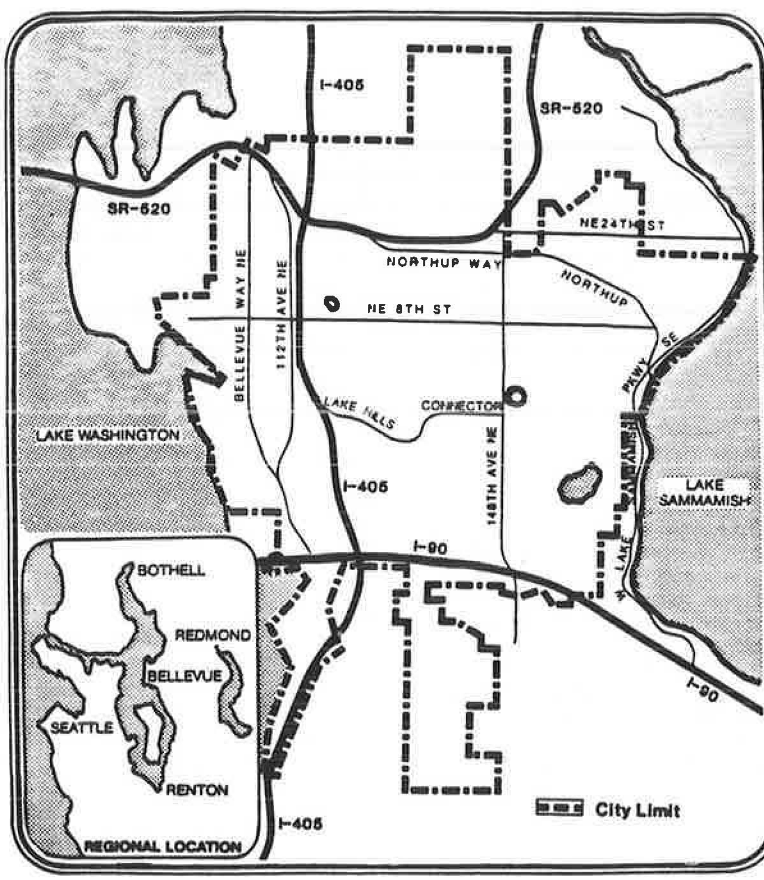

FIGURE 1 Study area—Bellevue, Washington.

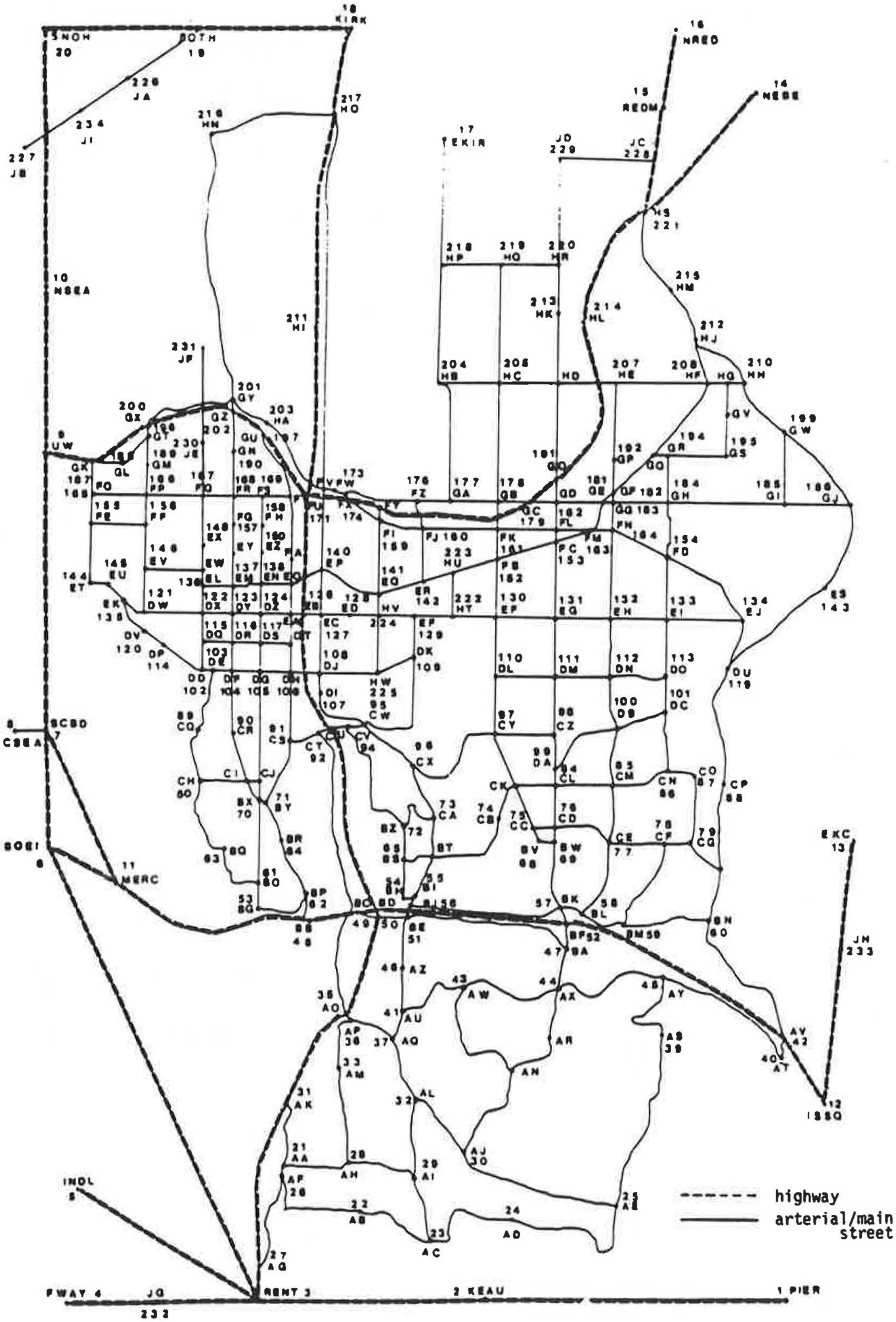

FIGURE 2 Bellevue network.

Vehicle Data

The vehicle data include information about the different types of vehicles available for use, their capacity, and their operating costs (per kilometer and per hour).

All the data prepared for the study area were verified before proceeding to the design work. The base network was verified by plotting it and comparing it with the map used for digitization. The demand matrix was verified by using the desire line option of TNOP for several well-known nodes. This procedure was also assisted by generating and examining maps of the productions or attractions. These

TABLE 1 Important Bellevue Network Nodes

Node No.	Node Name (TNOP Code)	Area Represented
1	PIER	Pierce County
2	KEAU	Kent and Auburn
3	RENT	Renton
4	FWAY	Federal Way
5	INDL	Industrial Area
6	BOEI	Boeing
7	SCBD	Seattle CBD
8	CSEA	Central Seattle
9	UW	University District
10	NSEA	North Seattle
11	MERC	Mercer Island
12	ISSQ	Issaquah
13	EKC	East King County
14	NEBE	Northeast of Bellevue
15	REDM	Redmond
16	NRED	North of Redmond
17	EKIR	East of Kirkland
18	KIRK	Kirkland
19	BOTH	Bothell
20	SNOH	Snohomish
57	BK	Park-and-Ride Lot
62	BP	Park-and-Ride Lot
116	DR	Bellevue Transfer Center
191	GS	Park-and-Ride Lot

graphics help the planner check the reasonableness and validity of the data.

CALIBRATION OF LINK TRAVEL TIME

In many cases there may not be enough data about the actual time on the links. It is important to have correct link travel times because they influence the assignment process and therefore the load on each transit line. For this study actual link travel times were not available, so the link file was constructed with posted 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 was derived from this procedure that was used to convert actual into TNOP travel times. Using this factor, the link file was modified to incorporate the more realistic travel times.

METHODOLOGY

The methodology used for the energy efficiency study consists of the following steps:

Step 1: Simulate the operation of the existing 13 routes included in the Metro survey.

Step 2: Evaluate the design representing the existing system. Some of the measures to be checked on are (a) number of unassigned trips, (b) average use, (c) total route length, (d) total vehicle-kilometers, (e) average total trip time, (f) average total wait time, (g) average total transfer time, (h) average total walk time, (i) number of transfers, and (j) total operating costs per hour.

Step 3: If any of the measures do not reflect the true condition of the existing system, the cause must be ascertained and corrections made before going to the next step.

Step 4: Study the weaknesses of the existing system--for example, too many lines covering a route, many long routes, or inadequate connection to main nodes. Try to match the productions and attractions using trip desire line graphics. Check the line capacity provided and the loadings on the lines. See if there is excess line capacity available.

Step 5: Sketch the new route system over the network on a sheet of paper. Try to cover all the important O-D nodes. Define the lines for computer input and assign the trips.

Step 6: Evaluate the new design using the measures discussed previously. The number of trips unassigned may be equal to or less than those of the existing system. If the number of unassigned trips is more, the new system does not serve all the nodes served by the existing system. The design has to be modified until the objective is reached. The design also has to meet the headway and other con- straints present in the existing system.

Step 7: There is no direct way to calculate the energy used by the transit service in a TNOP design. The energy can, however, be calculated from the total number of vehicle-kilometers. In many cases the average total trip time, wait time, transfer times, and number of transfers may be higher in the proposed design than in the existing system. The amount by which they may exceed present levels depends on the objectives.

ANALYSIS

In this section the analysis and the results of the energy-efficiency study are presented. A total of seven alternative designs was developed. The existing and the proposed system of routes are discussed in the following sections.

Existing System

The existing system has 13 routes, which were surveyed by Metro. These routes were simulated using TNOP. The base network used in this design is shown in Figure 3. A graphic overview of all lines is shown in Figure 4. The overview statistics for this design are given in Table 2. The total route length is 387 km (242 miles). Nineteen of 549 trips are not assigned. This may be due to rounding off errors because assignment messages did not indicate any unassigned trips. The average use of this design is only 6.9 percent, which is due to the high frequency of buses used in spite of the low demand. Table 3 gives transit line statistics. The headways used in this design are the actual headways used in the morning peak period in the existing system. Other statistics, such as average total trip time and wait time, appear to be reasonable. The total operating cost per hour is $5,683. Note that line 8 of Table 3 has an asterisk, denoting that maximum loading on one of the links on the route exceeds the total capacity by seven passengers. In all other cases the total capacity is more than the maximum loading. This is one of the reasons for the low average use. The only data available to validate the simulation of the existing network were travel times between transfer stops and the total demand using the routes. These were examined and it was found that the simulated values matched the observed values well.

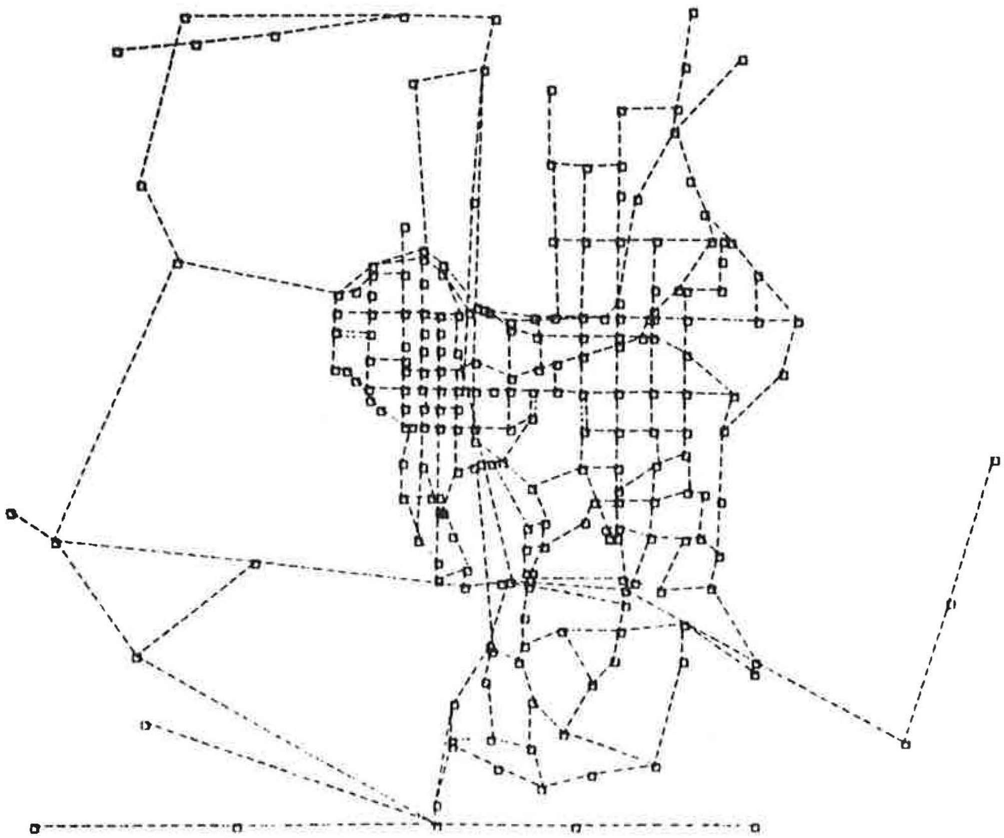

FIGURE 3 Base network (design 200).

Proposed Energy-Efficient Design

In this section the proposed energy-efficient system of routes, which will satisfy all the demand in the system but will reduce the operating costs with the least increase in total travel time and number of transfers, is presented. Six designs were generated before the final design was reached. The TNOP design numbers are 300 through 800. Designs 300 to 500 are preliminary designs. Design 600 is the proposed design. Designs 700 and 800 are extensions of design 600.

The main weaknesses of the existing system were identified before the new network was designed, and

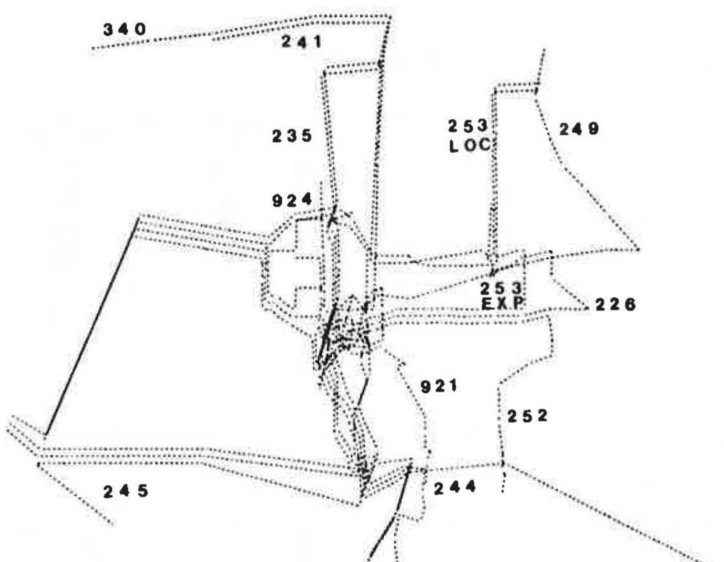

FIGURE 4 Graphic overview of bus lines (design 200).

TABLE 2 Overview Statistics (Design 200)

DESIGN	200	
NO.OF LINES: RAIL	0	
BUS	13	
TOTAL	13	
ROUTE LENGTH: RAIL	0	(KM)
BUS	387	(KM)
TOTAL	387	(KM)
TOTAL TRIP DEMAND	549.	
NO. OF ASSIGNED TRIPS	530.	
NO. OF UNASSIGNED TRIPS	19.	
AVERAGE SEATING & STANDING ROOM UTILIZATION: RAIL	0.0	(%)
BUS	6.9	(%)
TOTAL	6.9	(%)
PASS.-KM (=SUM OF TRIP LENGTHS)	9000.	
PASS.-HRS (=SUM OF TRIP TIMES)	420.	
AV. TOTAL TRIP TIME	40.8	(MIN)
AV. TOTAL WAIT TIME	6.0	(MIN)
AV. TOTAL TRANSFER TIME	0.3	(MIN)
AV. TOTAL WALK TIME	0.5	(MIN)
AV. TOTAL TRAVEL TIME	47.6	(MIN)
NO. OF TRANSFERS	160.	

VEHICLE REQUIREMENTS AND OPERATING COSTS

DESIGN 200

VEHICLE TYPE	NUMBER	VEH.KM	COST/KM	COST/H	OP.COST/H
TOTAL RAIL VEHICLES	0	0			0.
VAN	4	42	1.83	44.00	253.
40-FOOT BUS	85	1725	0.98	44.00	5430.
TOTAL BUS VEHICLES	89	1767			5683.
TOTAL VEHICLES	89	1767			5683.

they are as follows: (a) overlapping of routes, (b) extremely long routes, and (c) too much line capacity compared to the demand.

The proposed system was aimed at reducing vehicle-kilometers by avoiding overlapping routes. Transfer points were created at important locations, such as downtown Bellevue and the Eastlake and Overlake park-and-ride lots. These transfer stops were connected to each other and to all important origins and destinations.

Preliminary designs 300 and 400 had a system of 10 routes with different structures. Design 300 assigned 93 percent of trips with 550 transfers, and design 400 assigned 95 percent of trips with 560 transfers. Design 500, which incorporated improvements to designs 300 and 400, assigned 97 percent of trips with 490 transfers. Figure 5 shows the routes of design 500. The overview statistics of design 500 are given in Tables 4 and 5. Table 6 gives a comparison of four designs (200 through 500). Note that in design 500 vehicle requirements have been reduced by more than 50 percent compared to design 200 (existing system), but the number of transfers and the average total trip time have increased considerably.

TABLE 3 Transit Line Statistics (Design 200)

DESIGN 200

LINE	VEH.TYPE	NUMBER VEH'S	ROUTE LENGTH	ROUTE TIME	HEAD-WAY	OPERATING COSTS/HR
1	40-FOOT BUS	7	61800	152	25	453
2	40-FOOT BUS	9	75580	177	25	573
3	40-FOOT BUS	6	61000	168	35	367
4	40-FOOT BUS	4	91800	201	60	266
5	40-FOOT BUS	3	56580	120	60	188
6	40-FOOT BUS	3	58900	124	60	190
7	40-FOOT BUS	4	31840	93	30	239
8	40-FOOT BUS	3	42800	117	45	188
9	40-FOOT BUS	6	62140	137	30	386
10	40-FOOT BUS	30	61160	156	6	1920
11	40-FOOT BUS	10	113240	254	30	661
12	VAN	2	12540	47	30	134
13	VAN	2	16680	58	60	119

DESIGN 200

LINE	VEH. TYPE	HEAD-WAY	CAPACITY SEAT	STAND	TOTAL	LOADINGS MAX	AV.	UTIL.	
1	40-FOOT BUS	25	120	60	180	74	24	13.3	
2	40-FOOT BUS	25	120	60	180	23	6	3.3	
3	40-FOOT BUS	35	85	43	128	8	2	1.6	
4	40-FOOT BUS	60	50	25	75	17	3	4.0	
5	40-FOOT BUS	60	50	25	75	31	13	17.3	
6	40-FOOT BUS	60	50	25	75	33	10	13.3	
7	40-FOOT BUS	30	100	50	150	41	19	12.7	
8	40-FOOT BUS	45	66	34	100	107	41	41.0	*
9	40-FOOT BUS	30	100	50	150	16	5	3.3	
10	40-FOOT BUS	6	500	250	750	97	27	3.6	
11	40-FOOT BUS	30	100	50	150	31	7	4.7	
12	VAN	30	24	0	24	10	3	12.5	
13	VAN	60	12	0	12	9	2	16.7	

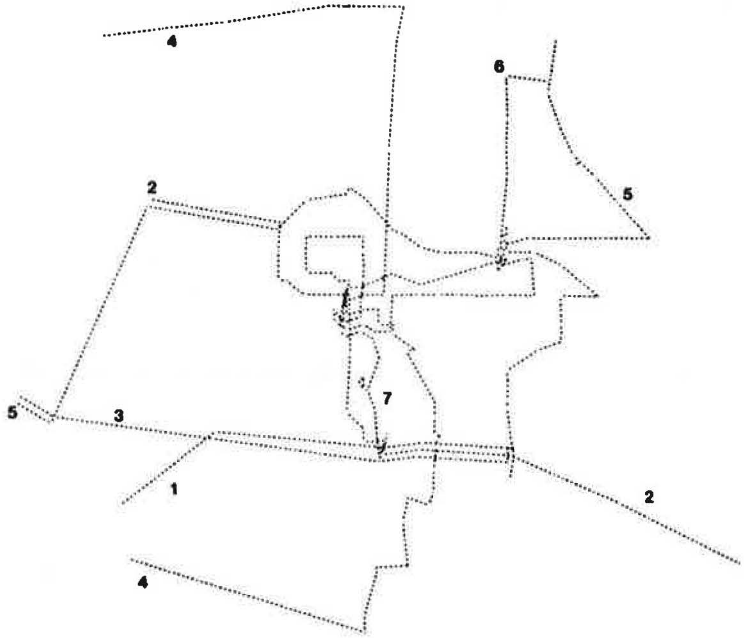

FIGURE 5 Graphic overview of bus lines (design 500).

TABLE 4 Overview Statistics (Design 500)

DESIGN		500	
NO.OF LINES:	RAIL	0	
	BUS	7	
	TOTAL	7	
ROUTE LENGTH:	RAIL	0	(KM)
	BUS	349	(KM)
	TOTAL	349	(KM)
TOTAL TRIP DEMAND		549.	
NO. OF ASSIGNED TRIPS		530.	
NO. OF UNASSIGNED TRIPS		19.	
AVERAGE SEATING & STANDING ROOM UTILIZATION:	RAIL	0.0	(%)
	BUS	16.1	(%)
	TOTAL	16.1	(%)
PASS.-KM (=SUM OF TRIP LENGTHS)		9900.	
PASS.-HRS (=SUM OF TRIP TIMES)		510.	
AV. TOTAL TRIP TIME		45.9	(MIN)
AV. TOTAL WAIT TIME		9.7	(MIN)
AV. TOTAL TRANSFER TIME		1.9	(MIN)
AV. TOTAL WALK TIME		0.5	(MIN)
AV. TOTAL TRAVEL TIME		58.0	(MIN)
NO. OF TRANSFERS		490.	

VEHICLE REQUIREMENTS AND OPERATING COSTS

DESIGN 500

VEHICLE TYPE	NUMBER	VEH.KM	COST/KM	COST/H	OP.COST/H
TOTAL RAIL VEHICLES	0	0			0.
40-FOOT BUS	42	818	0.98	44.00	2650.
TOTAL BUS VEHICLES	42	818			2650.
TOTAL VEHICLES	42	818			2650.

TABLE 5 Transit Line Statistics (Design 500)

DESIGN 500

LINE	VEH.TYPE	NUMBER VEH'S	ROUTE LENGTH	ROUTE TIME	HEAD-WAY	OPERATING COSTS/HR
1	40-FOOT BUS	6	62260	144	30	386
2	40-FOOT BUS	5	55880	130	30	330
3	40-FOOT BUS	3	40760	76	30	212
4	40-FOOT BUS	12	116780	298	30	757
5	40-FOOT BUS	7	70500	160	30	446
6	40-FOOT BUS	6	41980	138	30	346
7	40-FOOT BUS	3	20500	62	30	172

TABLE 6 Global Design Comparison (Designs 200, 300, 400, and 500)

DESIGN:		200	300	400	500
NO. OF LINES:	RAIL	0	0	0	0
	BUS	13	10	10	7
	TOTAL	13	10	10	7
VEHICLE REQUIREMENTS:	RAIL	0	0	0	0
	BUS	89	39	42	42
	TOTAL	89	39	42	42
TOTAL OPERATING COSTS:	($)	5700	2400	2600	2600
NO. OF VEHICLE-KM:	RAIL	0	0	0	0
	BUS	1767	717	791	818
	TOTAL	1767	717	791	818
PER CENT OF TRIPS ASSIGNED:		96.54	92.90	94.72	96.54
NO. OF PASSENGER-KM.:		9000	9600	9900	9900
AVERAGE TOTAL TRIP TIME:	(MIN)	47.6	54.8	57.7	58.0
NO. OF TRANSFERS:		200	600	600	500

In design 600 the attempt was to reduce the average total travel time and the number of transfers. This design has seven routes, which are plotted in Figure 6. The base network for all the designs discussed here is the same as that of design 200 (the existing system). Table 7 gives the overview statistics. In design 600 the route length has been reduced to 301 km from 394 km in design 500. The average seating and standing use has been increased to 16.6 percent from 16.1 percent in design 500. The average total trip time has been reduced by 4.4 min and the average total wait time by 1.9 min. The number of transfers has been reduced from 490 (design 500) to 310. The reduction in transfers was achieved mainly by restructuring the routes. This was aided by examining trip desire line displays and studying the transfer movements at all transfer stops using TNOP menu item 63. The total number of buses required by this design is 40. Note that this design used a headway of 30 min, the maximum allowed. Table 8 gives the transit line statistics and it may be seen that all the lines except line 7 have a headway of 30 min. In addition, all these lines have more capacity than required by maximum loading. Table 9 gives a comparison of design 600 and the existing system (design 200). The proposed design, design 600, has six fewer routes, 49 fewer vehicles, and a savings of $2,200 per hour. The average total trip time has been increased by 6.0 min and the number of transfers by 100.

Timetable optimization has been executed for this design. Table 10 gives the cyclic terminal departure times for all the lines. Transfer delay distribution before and after timetable optimization is shown in Figures 7 and 8. Note that transfer delay has been reduced from 4,589 to 3,306 min, a considerable reduction of 28 percent.

The energy consumed on transit routes is directly proportional to the total number of vehicle-kilo-

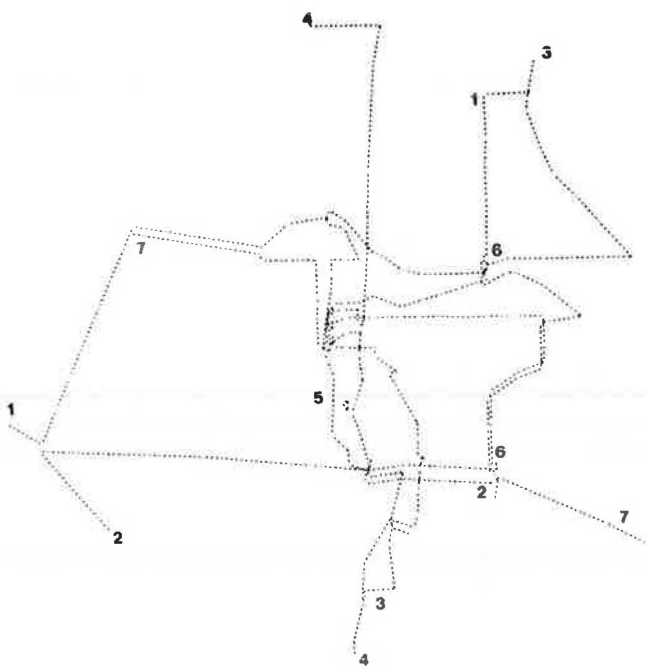

FIGURE 6 Graphic overview of bus lines (design 600).

TABLE 7 Overview Statistics (Design 600)

DESIGN			600
NO.OF LINES:	RAIL		0
	BUS		7
	TOTAL		7
ROUTE LENGTH:	RAIL		0 (KM)
	BUS		301 (KM)
	TOTAL		301 (KM)
TOTAL TRIP DEMAND			549
NO. OF ASSIGNED TRIPS			540
NO. OF UNASSIGNED TRIPS			9
AVERAGE SEATING & STANDING ROOM UTILIZATION:		RAIL	0.0 (%)
		BUS	16.6 (%)
		TOTAL	16.6 (%)
PASS.-KM (=SUM OF TRIP LENGTHS)			9600
PASS.-HRS (=SUM OF TRIP TIMES)			480
AV. TOTAL TRIP TIME			43.9 (MIN)
AV. TOTAL WAIT TIME			7.8 (MIN)
AV. TOTAL TRANSFER TIME			1.5 (MIN)
AV. TOTAL WALK TIME			0.4 (MIN)
AV. TOTAL TRAVEL TIME			53.6 (MIN)
NO. OF TRANSFERS			310

VEHICLE REQUIREMENTS AND OPERATING COSTS

DESIGN 600

VEHICLE TYPE	NUMBER	VEH.KM	COST/KM	COST/H	OP.COST/H
TOTAL RAIL VEHICLES	0	0			0.
40-FOOT BUS	40	771	0.98	44.00	2516.
TOTAL BUS VEHICLES	40	771			2516.
TOTAL VEHICLES	40	771			2516.

TABLE 8 Transit Line Statistics (Design 600)

DESIGN 600

LINE	VEH.TYPE	NUMBER VEH'S	ROUTE LENGTH	ROUTE TIME	HEAD-WAY	OPERATING COSTS/HR
1	40-FOOT BUS	6	62140	140	30	386
2	40-FOOT BUS	4	53760	100	30	282
3	40-FOOT BUS	8	63740	197	30	477
4	40-FOOT BUS	6	66020	146	30	393
5	40-FOOT BUS	3	23680	70	30	178
6	40-FOOT BUS	3	17480	55	30	166
7	40-FOOT BUS	10	65640	166	20	633

DESIGN 600

LINE	VEH. TYPE	HEAD-WAY	CAPACITY SEAT	STAND	TOTAL	LOADINGS MAX	AV.	UTIL.
1	40-FOOT BUS	30	100	50	150	93	30	20.0
2	40-FOOT BUS	30	100	50	150	81	24	16.0
3	40-FOOT BUS	30	100	50	150	49	20	13.3
4	40-FOOT BUS	30	100	50	150	40	12	8.0
5	40-FOOT BUS	30	100	50	150	19	7	4.7
6	40-FOOT BUS	30	100	50	150	46	10	6.7
7	40-FOOT BUS	20	150	75	225	197	63	28.0

TABLE 9 Global Design Comparison (Designs 200, 600, 700, and 800)

DESIGN:		200	600	700	800
NO. OF LINES:	RAIL	0	0	0	0
	BUS	13	7	7	7
	TOTAL	13	7	7	7
VEHICLE REQUIREMENTS:	RAIL	0	0	0	0
	BUS	89	40	31	28
	TOTAL	89	40	31	28
TOTAL OPERATING COSTS:	($)	5700	2500	1900	1700
NO. OF VEHICLE-KM:	RAIL	0	0	0	0
	BUS	1767	771	580	523
	TOTAL	1767	771	580	523
PER CENT OF TRIPS ASSIGNED:		96.54	98.36	98.36	98.36
NO. OF PASSENGER-KM.:		9000	9600	9600	9600
AVERAGE TOTAL TRIP TIME: (MIN)		47.6	53.6	53.6	53.6
NO. OF TRANSFERS:		200	300	300	300

TABLE 10 Cyclic Terminal Departure Times

LINE	MODE	HDWY.	TERMINAL 1			TERMINAL 2			NO.OF
				DEPART.	LAYOVER		DEPART.	LAYOVER	VEHICLES
1	B	30.0	CSEA	0.0	20.2	JC	0.0	20.2	6
2	B	30.0	BOEI	0.0	10.1	BK	0.0	10.1	4
3	B	30.0	REDM	0.0	21.4	RENT	0.0	21.4	8
4	B	30.0	BOTH	0.0	17.1	AF	0.0	17.1	6
5	B	30.0	BK	15.0	9.8	GY	0.0	9.8	3
6	B	30.0	BK	15.0	17.7	GO	0.0	17.7	3
7	B	20.0	ISSQ	0.0	17.1	UW	0.0	17.1	10

meters. The total number of vehicle-kilometers for designs 600 (proposed design) and 200 (existing system) are 771 and 1,767, respectively. Therefore, design 600 saves 996 vehicle-kilometers, a reduction of 46 percent, which would result in savings in energy. This vehicle-kilometer estimate does not take deadheading kilometers into account. It may be concluded that design 600 can save approximately 56 percent of the energy being used by the existing system.

Because design 600 used a maximum headway of 30 min, the line capacity provided in six of seven lines was more than required. An analysis has been made to determine the effect of changing the maximum policy headway to 45 and 60 min in the peak period. Designs 700 and 800 were generated on the basis of design 600. The route structure is the same as that of design 600. The transit line attributes were modified and the trips were assigned.

Maximum allowable headways of 45 min for design 700 and 60 min for design 800 were assumed. Table 10 gives global design comparisons of designs 200, 600, 700, and 800. The number of trips assigned, passenger-kilometers, average total trip time, and transfers remained at the same level on design 600. There was no change in the average total trip time among designs 600, 700, and 800, even though the headways are different. The reason was the use of logarithm of wait time in the trip assignment menu. By shifting the minimum headway from 30 to 45 and 60 min, a savings of 67 and 70 percent over the energy used by the existing system could be obtained.

CONCLUSIONS

This study was designed to investigate the potential for achieving energy savings by restructuring the routes and service of an existing system. It was also used to test the effectiveness and ability of TNOP to simulate the existing system as well as to assist in the design of more energy-efficient transit services. The study used O-D data collected by Metro's on-board survey of 13 routes in the Bellevue area. Initially TNOP was used to simulate the existing system and was able to do so satisfactorily. Based on this, more energy-efficient designs were generated for 30-, 45-, and 60-min headways. Encouraging results have been obtained by making changes in the route structure and service attributes to better match the current demand pattern. The route changes involved were simple. Overlapping routes were removed. Three routes were left unchanged. Three other routes were extended to reach more locations. One other route has the same origin and destination but uses a different path. Table 11 gives a

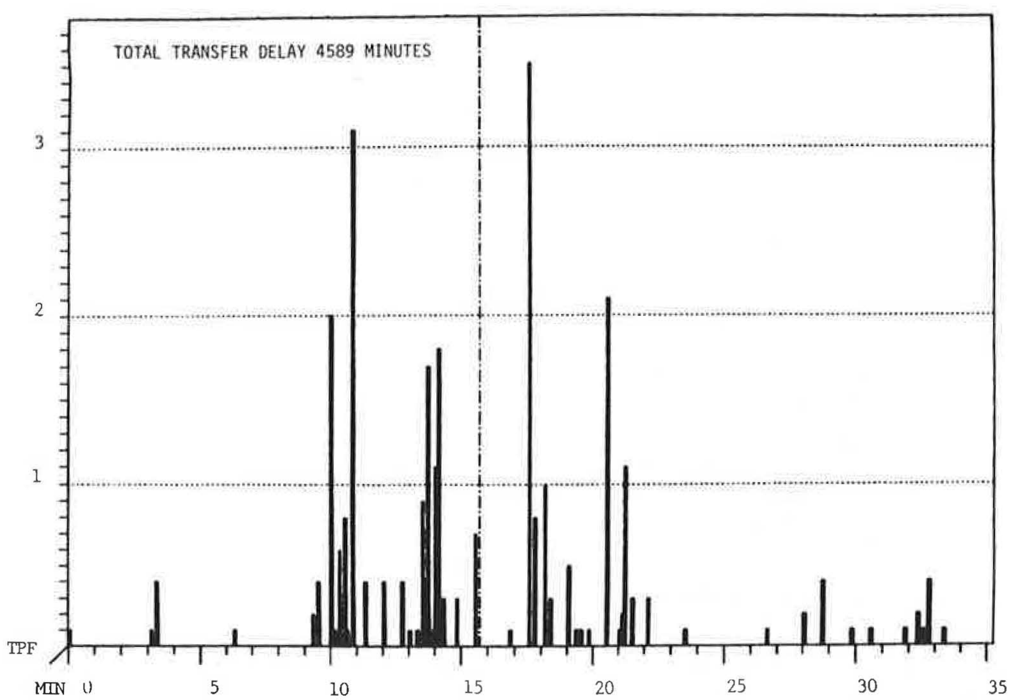

FIGURE 7 Before timetable optimization.

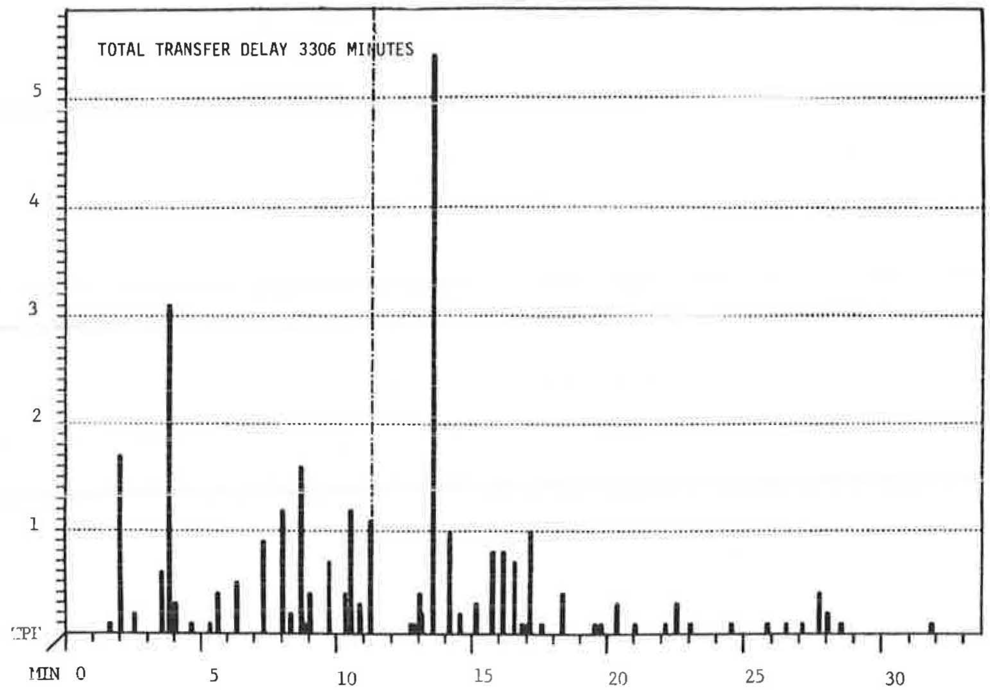

FIGURE 8 After timetable optimization.

TABLE 11 Comparison of the Performance of the Existing and Proposed Designs

Performance Measure	Existing Design	Proposed Design	% Change
A. Less Is Better			
Route length (km)	387	301	- 22.0
Number of routes	13	7	- 46.0
Passenger-kilometers	8900	9600	+ 8.0
Passenger-hours	420	480	+ 14.0
Average total trip time (min.)	40.8	43.9	+ 8.0
Average wait time (min.)	6.0	7.8	+ 30.0
Average walk time (min.)	0.5	0.4	- 20.0
Average travel time (min.)	47.6	53.6	+ 12.6
Number of transfers	160	310	+ 93.8
Transfers per passenger	0.3	0.57	+ 90.0
Number of vehicles	89	40	- 55.1
Vehicle kilometers	1767	771	- 56.4
Operating cost per hour ($)	5683	2516	- 55.7
Total transfer delay (min.)	2180	3306	+ 51.7
Average cost/vehicle kilometer ($)	3.22	3.26	+ 1.2
Average cost/passenger hour ($)	13.53	6.89	- 49.1
B. More Is Better			
Average utilization (%)	6.9	16.6	+241.0
Per cent trips assigned	96.5	98.4	+ 1.1
Trip time/travel time	0.86	0.82	- 4.7

comparison of different performance measures for the existing design (design 200) and the proposed design (design 600).

The data in Table 11 indicate that, for 16 performance measures, "less is better." The proposed design is better in 7 of these 16 categories and worse in 9. However, most of these impairments are small and of little consequence. Transfers and transfers per passenger are sharply up and this is an undesirable result. But, this impairment has to be traded off with the sharp drop in operating costs for the system. In the "more is better" category, a large increase in average use was obtained and this result, when added to the lower costs, mitigates the burden of more transfers and the somewhat longer travel times associated with the proposed design. In some situations this trade-off would be done differently and TNOP allows the planner to quickly estimate the cost of reducing the volume of transfers by increasing the cost of the service provided.

The proposed design (design 600) saves approximately 56 percent of the energy used by the existing system. The total fuel costs for the entire Metro system amounted to $7.3 million for 1982. The Bellevue area uses about 23 percent of the service provided by the entire Metro system. If the energy-efficiency study were extended to the whole of Bellevue and if a savings of 50 percent were found, approximately $900,000 could be saved every year (i.e., 11 percent of Metro's 1982 fuel bill). If similar results could be found in other suburban parts of the transit system, even more significant fuel cost savings could be obtained. Restructuring the routes and service in developed areas such as the inner city and the middle city may not yield similar levels of savings because of various constraints such as heavy automobile congestion and the difficulty of moving routes that have been in place for 40 years or longer. Nevertheless, an examination of an inner city area should be conducted to determine how much energy might be saved by a more efficient route and schedule design. From this study it may be concluded that suburban areas appear to be good locations for obtaining substantial energy savings payoffs through restructuring the routes and service level of an existing system.

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Montgomery County, Pennsylvania, Turnpike Express Bus Study

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ABSTRACT

A summary of the methodology, analysis, evaluation, and findings of a bus study that was conducted to assess the feasibility of park-and-ride and express bus service within the Pennsylvania Turnpike corridor is presented. Some of the fastest developing commercial and industrial areas in the Philadelphia metropolitan area are within this corridor, including many high-technology industries. A special traffic demand estimation method, which requires a special coding procedure and uses an existing traffic assignment model, was developed. This demand estimation technique reduces the computer cost of simulation, allows the use of the regional modal split and transit assignment models without recalibration, and produces accurate transit ridership estimates within the detailed study area for the routes under study. The evaluation of the promising express bus alternatives for the Pennsylvania Turnpike indicated that the subsidy for circumferential express bus routes is rather large because the patronage is generally small, even for growing and congested circumferential urban corridors.

The Pennsylvania Turnpike and US-202 Expressway describe a circumferential transportation corridor through Philadelphia's northern and western suburbs. The corridor includes a 31.4-mile segment of the turnpike between Valley Forge (Exit 24) and the Delaware Valley (Exit 29) interchanges and an 18-mile segment of US-202 Expressway from Valley Forge to the Town of West Chester, Pennsylvania. Some of the fastest developing commercial and industrial areas within the Delaware Valley region are adjacent to these two expressways. These areas include many high-technology industries, which are attracted by the access to national markets provided by the turnpike (see Figure 1) and the availability of large tracts of inexpensive land for commercial development. This growth in employment, coupled with suburban residential development, has increased traffic congestion and consequently decreased the level of