POTENTIAL DEMANDS FOR DEMAND-SCHEDULED BUS SERVICES

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•DURING the past few years there has been considerable interest in demand-scheduled bus systems (DSB) as a potential urban transportation mode. This system consists of buses running on city streets with routes adjusted to meet the demands of new riders as well as to serve the needs of passengers already on the bus.

A potential passenger calls the bus company and gives his origin and destination. The bus company examines the buses available and the destinations of on-board passengers and then assigns the new passenger to a bus. The bus is contacted and assigned a new routing so that the new passenger as well as those already on the bus can be picked up and discharged. The system is shown in Figure 1.

There are clearly two objectives for this type of bus service: first, to maximize the level of service to the passengers and second, to minimize the costs of operation and control of the bus system. A great deal of research has been carried out in recent years by M. I. T. (1, 2), Northwestern University (3, 4), and General Motors (5) on the operating and control characteristics required to optimize a DSB system given the capital and operating costs and a predetermined level of demand.

This paper describes research at the University of Waterloo on the supply portion of DSB system. It is clear that the supply portion of a DSB system is not a predetermined variable but is a function of the operating characteristics of the DSB system being considered. For a complete optimization then, both the demand and the supply characteristics for DSB must be considered together. In the consideration of the demand for DSB typical potential operating characteristics for DSB systems were taken from previous research results.

The DSB system has been proposed in two basic operating modes—the one-to-many and the many-to-many. The former is exemplified by trips to a rail head (one destination) from many dispersed trip origins. The second type of service is from any origin in the city to any other destination. The research for this paper was limited to considering the many-to-many operating mode for DSB (7).

STUDY PROCEDURE

The study was carried out in six distinct phases.

1. Decision made to study the demand of DSB.
2. Study area selected (Kitchener-Waterloo); road and transit networks for 1965 and 1968 prepared on a generalized cost basis; minimum cost, district-to-district trees, and district-to-district work-trip matrices for 1965 and 1968 (only partial matrix for 1968) prepared.
3. Criterion developed for traffic model characteristics and selection.
4. Model calibrated to 1965 data and tested with 1968 data.
5. Demand simulated for DSB for different operating characteristics of DSB and also tests made of sensitivity of the results to assumed behavioral parameters.
6. Results, discussion, and conclusions generalized.

STUDY LOCATION

As with most transportation problems the results can only relate to a specific location, and then these results can be generalized. The study location was the urban area

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comprising the cities of Kitchener and Waterloo in Ontario. Total population in 1965 was 119,000. Travel data were available from a 3 percent random sample traffic survey in 1965 and a specialized cluster sample in 1968 of 3,500 household days. The area was divided into 29 districts as shown in Figure 2. The 1965 road and bus networks are shown in Figure 3.

The study was limited to work trips, and Table 1 gives the work-trip characteristics for the study area in 1965. Data for 1968

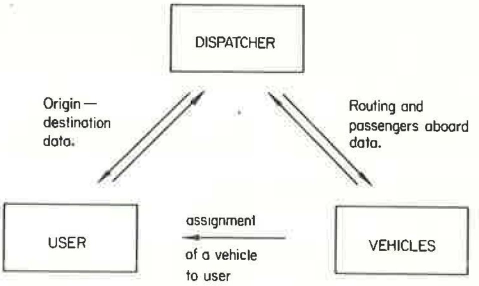

Figure 1. Conceptual operation of a DSB.

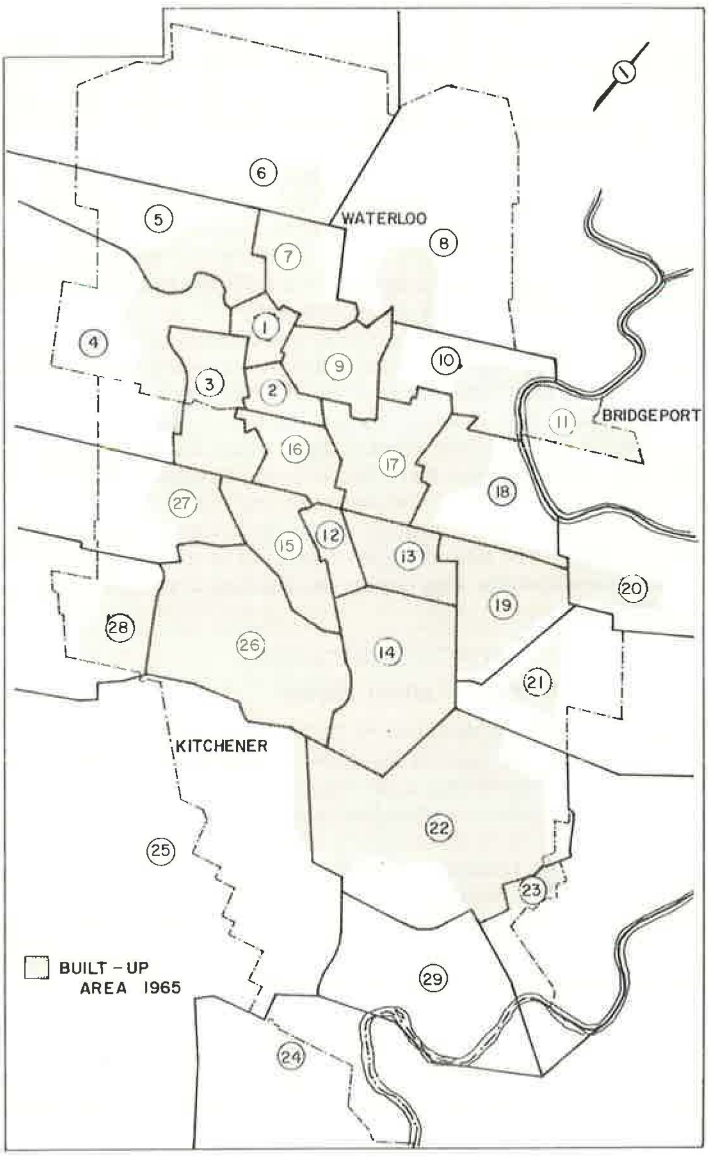

Figure 2. Study area district.

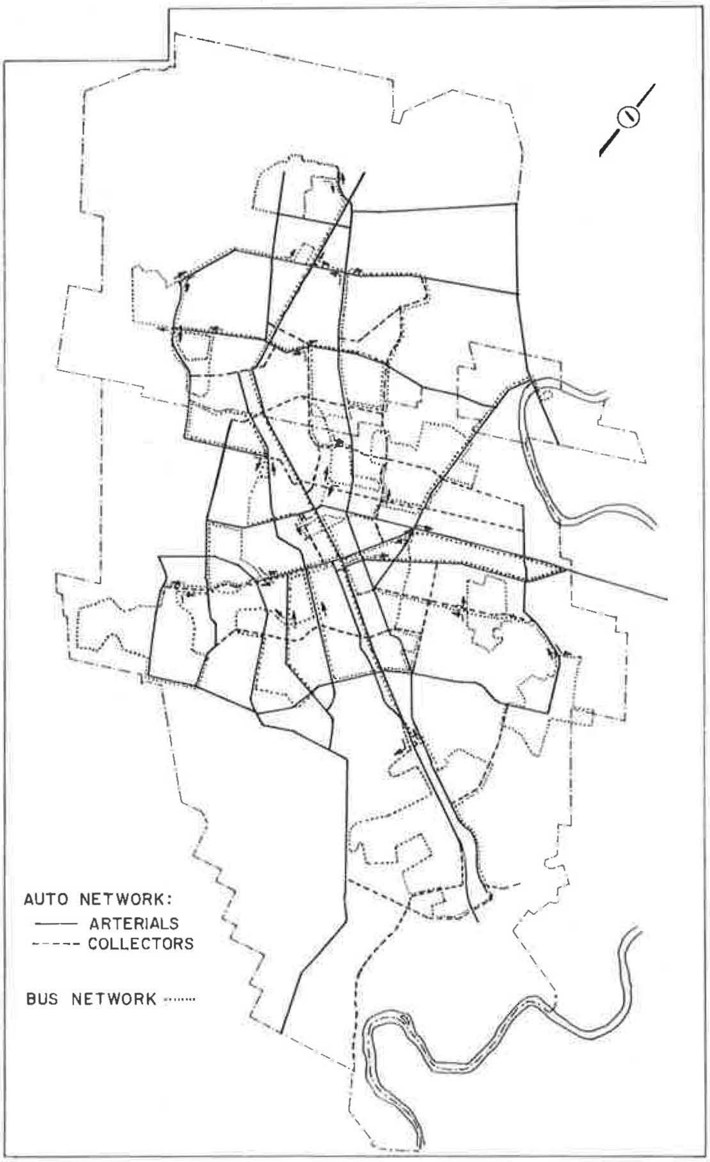

Figure 3. 1965 automobile and transit networks in study area.

are similar except the population had increased to 137,000 and the percentage of work trips by transit had decreased to about 8 percent. For purposes of the traffic model, a generalized cost of travel was used (Table 1). The generalized cost of travel used for 1965-68 was the following (6):

$$\text{Automobile trip cost} = (1/O)[(P/2) + C_a \cdot d_1] + K\,[T_1 + 60\,(d_1/V_1] \quad (1)$$

and

$$\text{transit trip cost} = F + K\,[T_2 + 60\,(d_2/V_2)] \quad (2)$$

where

O = average occupancy, 1.50;

P = parking cost per day (in CBD only, 50 cents);
C_m = out-of-pocket driving cost per vehicle mile, 4 cents;
K = time cost per minute, cents;
T_1 = automobile trip walking and waiting time (non-CBD, 1 min, and CBD, 3 min);
d_1, d_2 = trip length (miles from the networks, 1 for automobile and 2 for transit);
V_1, V_2 = speed, mph, from the networks;
T_2 = transit trip walking, waiting, and transfer time (walking rate 2.5 mph and waiting times ½ headway); and
F = fare (1965, 13 cents per trip, and 1968, 20 cents per trip).

TABLE 1

1965 SOCIOECONOMIC AND TRANSPORTATION CHARACTERISTICS OF STUDY AREA

Characteristic	Amount
Population	119,000
Average annual household income, $	4,000 to 9,313
Automobiles owned per person	1 per 3.2
Daily home-to-work trips	34,432
Work trips by transit, percent	14
Transit routes, miles	53
Main automobile routes, miles	320
Automobile work trips	
Length, mi	2.32
Time, min	9.17
Cost, cents	29
Transit work trips	
Length, mi	2.51
Time, min	33.06
Cost, cents	82

The values used in the generalized cost function were average estimates taken from the literature. It was thought that, because the travel model would be calibrated to both these costs and the same costs used in the analysis, the estimates were of sufficient accuracy. Also the model calibration resulted in a good fit for both the trip distribution function and the modal-split function. This gave added confidence in the costs used.

The generalized transit cost for a zone without bus service was taken to be $3.00 (taxi ride).

TRAVEL MODEL

In the problem definition phase several criteria for the traffic models to estimate demand levels for DSB were developed:

1. The model should perform trip distribution and modal split and be compatible with new modes of transport;
2. The model must be practical for the computer and computer time available (IBM 360-175);
3. The model should be able to reproduce the 1965 survey data, and then the calibrated model should reproduce the 1968 survey data; and
4. The model variables must be compatible with the data available.

Several models were examined for their suitability, including conventional models (17), disutility models (8, 11), probabilistic models (9, 10), discriminate analysis (12, 13, 14), and entropy maximizing models (15, 16).

Wilson's model (18) was selected on the basis of the criteria. It does trip distribution and modal split at the same time. Through the generalized cost function it can deal with new modes of transport, and the data and computer requirements were met.

Wilson's model is of the following form:

$$T_{ij}^{kn} = A_i^n B_j O_i^n D_j e^{-\beta^n C_{ij}^k} \qquad (3)$$

where

T_{ij}^{kn} = number of trips between i and j by mode k by person type n;

$A_i^n = 1/\sum_j \sum_{k \epsilon y(n)} B_j D_j e^{-\beta^n C_{ij}^k}$;

$$B_j = 1/\sum_i \sum_n \sum_{k \epsilon y(n)} A_j^n O_i^n e^{-\beta^n C_{ij}^k};$$

O_i^n = number of trip origins (productions) in zone i by persons of type n;
D_j = number of trip destinations (attractions) in zone j;

$y(n)$ = set of modes available to persons of type n;

C_{ij}^k = generalized cost ("general measure of impedence") of traveling from zone i to zone j by mode k; and

β^n = parameter that determines the mean of the trip length distribution (in cost terms) for persons of type n.

The equation is subject to the following three constraints:

1. $T_{i*}^{*n} = O_i^n$;
2. $T_{*j}^{**} = D_j$; and
3. $T_{**}^{*n} C_{**}^{*} = C^n$.

C^n is the total expenditure on transport by persons of type n, and * denotes summation over that particular subscript or superscript.

It is observed that the modal split is given directly by the trip distribution function. A recent application of the model in Manchester, England, is documented (18). A_i^n and the B_j are solved by an iterative process, and the model is calibrated over the β^n. Person types, n, can be defined by income class, car ownership, and so forth. Initially the model was calibrated for the whole of the study area. Later the model was calibrated for each district (n = district population) on the basis of district income.

During the calibration procedure one change was made in the form of the model. β^n was replaced by a linear function of cost, i.e., instead of $e^{-\beta^n C_{ij}^k}$, we have $e^{-(\beta^n - \alpha^n C_{ij}^k)}$ C_{ij}^k. This was found necessary to fit the Kitchener-Waterloo data. This form of the function is supported by the recent work of one of the authors in London, although the function may not be linear. This change in the model has the advantage that the calibrated model fits for both trip distribution and modal split. In previously reported work (18) two values of β^n were required, one for trip distribution and one for modal split. (Recent conversations with Professor Wilson suggest that this formulation implies a logarithmic perception of travel costs similar to human perception of other stimuli.)

Further details of the model calibration are found in another report (7). Only a few indicative results of the calibration are presented here.

Figure 4 shows for automobile and transit trips the trip cost distributions for the survey and Model 1. Model 1 used only one person type, and the fitted impedance function was $e^{-(4.5 - 1.0 C_{ij}^k)}$, where C_{ij}^k is the generalized cost in dollars.

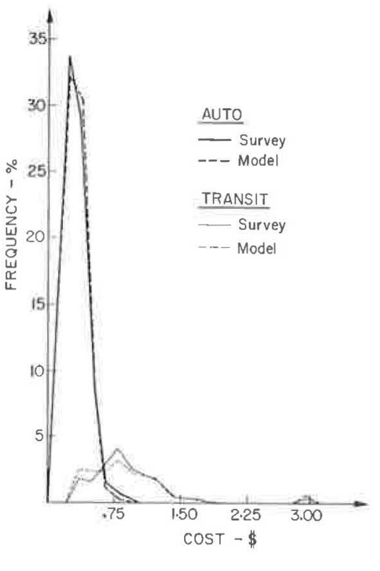

Figure 4. Cost distribution of 1965 automobile and transit work trips.

One sensitivity check of the results and the model parameters was made. The parameters of the fitted impedance function estimated a 14.6 percent work-trip bus usage for the whole study area. With everything else constant, one of the impedance function parameters was changed to 3.75 instead of 4.5. The results were an estimated 13.8 percent work-trip bus usage. Thus the model results are not sensitive to the models' fitted parameters (i.e., 0.75/4.5 > 0.8/14.6).

For testing purposes and with the 1968 cluster data, Model 2 was developed from the 1965 data where each district was taken as a person type n. Two characteristics were used for each district: (a) the average household income and (b) distance from the CBD (either less than or more than 6,000 ft). The latter generally measured higher density and older areas of the city. The impedance function for Model 2 for distances less than 6,000 ft from CBD was $e^{-(\beta - \alpha C_{ij}^{k}) C_{ij}^{k}}$. For distances more than 6,000 ft from CBD, $\beta = -5.0 + 0.002\,I$, $\alpha = -1.15 + 0.0005\,I$, $\beta = 9.4 + 0.002\,I$, and $\alpha = -3.1 + 0.0005\,I$, where I = average annual household income.

Little confidence can be placed in the parameter values of Model 2 because the data were very limited. The fit of Model 2 to the 1965 data was judged to be as good as but no better than that of Model 1. Of course, the ability of Model 2 to forecast was better because it included income effects directly.

For validation purposes the calibrated models were applied to the 1968 cluster sample. The accuracy with which the model predicted the survey data is given in Table 2. Model 2 was used and adjusted to the incomes of the cluster samples. It should be remembered that from 1965 to 1968 transit patronage in the study area decreased from 14 to 8 percent. Data given in Table 2 indicate that the model is able to forecast transit patronage very well under these rapidly changing conditions.

DEMAND FOR DSB

The analysis to estimate the demand response of the Kitchener-Waterloo population toward the DSB was performed directly with Model 2 by simply varying the value of the different parameters of the cost function relevant to the DSB system. In all cases, the range of the parameters used was taken from representative values in the literature. It was assumed that the DSB system was in existence in 1965 and that it was also the only transit system available at the time. The DSB travel times were varied from 1.5 to 3.0 × automobile times. This ratio of the DSB travel time to that of the automobile is referred to as the travel time ratio (TTR).

At the same time, waiting time was introduced into the cost function. This represents the approximate time that a user would have to wait to be picked up by a vehicle. The values used were 2, 3, or 4 min.

Finally a range of fares of 30 to 60 cents was used for the DSB service. In addition, for some analysis a modal attribute or attraction benefit of up to 15 cents was assigned to the DSB system. That is, in making their modal choices patrons would perceive DSB as being 15 cents cheaper per trip than the generalized cost would suggest. The basis for this perceived benefit was that the model was calibrated to a regular bus system and DSB has door-to-door service, smaller vehicles, a more personalized service, and so forth. Thus it is conceivable that such a service would be perceived as better than the fare and travel time alone would indicate.

Clearly the value of such a modal attribute cannot be measured until an actual DSB is put into operation. For this analysis a modal attribute of 15 cents for DSB is taken to be the upper limit estimate of possible ridership for the service.

TABLE 2
RESULTS OF VALIDATION TESTS ON 1968 DISTRICT DATA

District	Percent by Transit		Mean Travel Cost (dollars/trip)			
			Automobile		Transit	
	Survey	Model 2	Survey	Model 2	Survey	Model 2
3	8.18	5.48	0.255	0.238	0.840	0.829
6	0.00	0.63	0.268	0.262	—	—
8	3.03	5.49	0.300	0.350	1.085	1.193
9	1.89	2.32	0.231	0.231	0.785	0.820
13	7.63	4.48	0.247	0.213	1.260	0.560
14	16.42	10.00	0.268	0.250	0.860	0.649
17	0.97	0.44	0.304	0.168	0.670	0.745
19	8.56	6.39	0.351	0.284	0.868	0.694
21	2.69	0.22	0.352	0.264	1.146	1.047
22	1.27	0.20	0.385	0.266	2.050	1.228
26	9.38	7.24	0.297	0.285	0.813	0.714
28	0.00	0.71	0.405	0.331	—	—

TABLE 3

ESTIMATED 1965 TRANSIT WORK TRIPS

District	Income (dollars)	Number of Transit Users		Percent by Transit	
		Bus—Survey	DSB—Model 2	Bus—Survey	DSB—Model 2
1	4,423	43	203	9.0	42.6
2	5,300	128	241	15.5	29.2
3	6,764	217	268	9.9	12.2
4[a]	8,194	0	55	0.0	3.6
5	9,313	26	5	7.4	1.4
6	6,344	263	152	23.8	13.8
7	6,558	234	175	17.1	12.7
8[a]	7,417	0	92	0.0	6.2
9	7,063	136	176	7.8	10.0
10[a]	8,385	0	12	0.0	3.8
11	6,600	33	46	6.9	9.6
12	4,379	373	236	48.1	30.0
13	5,433	354	239	16.7	11.2
14	5,957	559	286	14.8	7.6
15	4,305	257	346	16.5	22.2
16	5,034	233	154	20.6	13.6
17	5,240	389	289	15.8	12.1
18	6,763	315	163	24.1	12.5
19	6,132	476	409	17.3	14.9
20[a]	6,000	0	11	0.0	17.2
21[a]	5,417	0	110	0.0	24.7
22	6,148	565	574	14.4	14.6
23	4,500	51	36	48.6	34.3
24[a]	4,000	0	7	0.0	38.9
25[a]	4,000	0	33	0.0	34.0
26	5,589	737	1,050	16.5	23.6
27	6,158	93	121	12.4	16.1
28	8,022	0	22	0.0	3.4
29[a]	6,000	0	17	0.0	14.7

Note: Travel-time ratio = 2.5, fare = 30 cents, waiting time = 4 min.
[a]Not directly served by bus service in 1965.

In a similar fashion, the modal forecast of ridership can be considered to be a conservative estimate of ridership because the special attributes of DSB are not directly included in the analysis.

For a fare of 30 cents, a travel-time ratio of 2.5 (x automobile-travel times), and a waiting time of 4 min, the forecast by Model 1 of the percentage of 1965 work trips by DSB for the entire study area was 14.4 percent or approximately equal to the bus patronage for that year. The ridership on both systems is given in Table 3. Clearly they are not directly comparable. As indicated, eight districts in 1965 were not served by bus routes. However, the general pattern is as expected. DSB patronage for the journey to work has the same pattern as bus patronage in 1965. The average expansion factor for the 1965 survey was 25; therefore, many survey figures represent only one or two observations.

Table 4 gives for the entire study area the percentage of work trips for the 1965 forecast by DSB under different waiting times and travel-time ratios. In each case the distribution of demand is similar to that given in Table 3. As data given in Table 4 indicate, the level of ridership was not sensitive to the waiting time but was very sensitive to the travel-time ratio.

Table 5 gives the predicted level of DSB patronage for a constant travel-time

TABLE 4

PERCENTAGE OF 1965 WORK TRIPS BY DSB FOR VARYING TRAVEL-TIME RATIOS AND WAITING TIMES

Travel-Time Ratio	2.0-Min Wait	3.0-Min Wait	4.0-Min Wait
1.5	23.69	22.58	21.53
1.6	22.73	21.67	20.65
1.7	21.82	20.79	19.82
1.8	20.95	19.96	19.02
1.9	20.12	19.17	18.27
2.0	19.33	18.41	17.55
2.25	17.50	16.67	15.89
2.5	15.88	15.13	14.41
2.75	14.43	13.75	13.10
2.0	13.14	12.52	11.93

Note: Fare = 30 cents.

ratio of 2.5 and varying fares. Sensitivity of patronage to waiting time is low. Sensitivity of patronage to fares is high and of the same order as the sensitivity to travel-time ratio.

Table 6 gives and Figure 5 shows the estimated patronage for DSB, with a waiting time of 3 min for a range of travel-time ratios and fares. Also shown as a set of dotted curves is the upper limit (UL) estimate of patronage, based on a perception of DSB special attributes being worth 15 cents. The shaded area shown in Figure 5 represents the bus system in Kitchener-Waterloo during 1965-68, which had a travel-time ratio of 3.6.

TABLE 5

PERCENTAGE OF 1965 WORK TRIPS BY DSB FOR VARYING FARES AND WAITING TIMES

Fare (cents)	2.0-Min Wait	3.0-Min Wait	4.0-Min Wait
30	15.88	15.13	14.41
45	11.06	10.55	10.06
60	7.78	7.43	7.10

Note: Travel-time ratio = 2.5.

Figure 5 shows clearly that for a DSB system to attract as much patronage as the existing bus system it would have to have a travel-time ratio of 2.5 or 3.0 and a fare of 30 to 40 cents. The system selected would depend of course on the trade-off between fares and travel-time ratios on the operational side of the DSB analysis. On the demand side, Figure 5 shows that for levels of patronage of 15 to 25 percent on DSB very low fares and high travel-time ratios would be required. In general, previous research (2, 4, 8) has indicated that feasible DSB systems would have travel-time ratios of more than

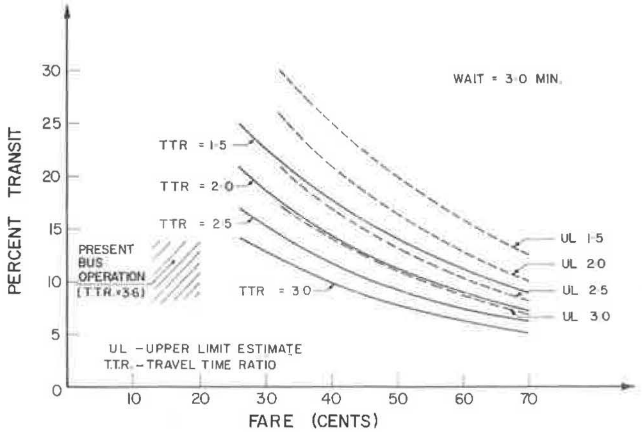

Figure 5. 1965 DSB ridership versus fare and travel-time ratio.

TABLE 6

PERCENTAGE OF 1965 WORK TRIPS BY DSB FOR VARYING FARES AND TRAVEL-TIME RATIOS

Fare (cents)	Travel-Time Ratio				Upper Limit			
	1.5	2.0	2.5	3.0	1.5	2.0	2.5	3.0
30	22.58	18.41	15.13	12.52	—	—	—	—
45	15.79	12.85	10.55	8.74	22.58	18.41	15.13	12.52
60	11.08	9.03	7.43	6.18	15.79	12.85	10.55	8.74
75	—	—	—	—	11.08	9.03	7.43	6.18

Note: Waiting time = 3.0 min.

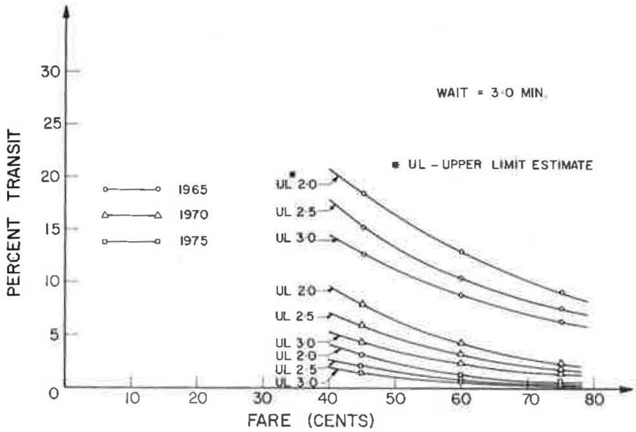

Figure 6. 1965, 1970, and 1975 DSB ridership versus fare and travel-time ratio.

TABLE 7

PERCENTAGE OF 1965, 1970, AND 1975 WORK TRIPS BY DSB FOR VARYING FARES AND TRAVEL-TIME RATIOS

Year	Fare (cents)	Upper Limit		
		2.0	2.5	3.0
1965	45	18.41	15.13	12.52
	60	12.85	10.55	8.74
	75	9.03	7.43	6.18
1970	45	8.03	5.87	4.38
	60	4.19	3.10	2.35
	75	2.29	1.73	1.33
1975	45	3.09	2.01	1.36
	60	1.12	0.75	0.53
	75	0.45	0.32	0.23

Note: Waiting time = 3.0 min.

2.5 and fares of more than 45 cents. This indicates a maximum DSB ridership for the study area work trips of 11 to 16 percent (Fig. 5). In general, then, one can conclude that the prospects for patronage for a DSB system in 1965 in Kitchener-Waterloo would not have been much different from the existing bus system, which had 14 percent ridership.

To examine the future prospects for DSB, we increased the income of the 1965 population of the study area 5 percent per year to 1970 and 1975 levels. Then Model 2 was used to estimate the DSB patronage. The upper limit estimate was used, and the results are given in Table 7 and shown in Figure 6. The resulting patronage is very low. If one keeps in mind that the existing bus patronage fell from 14 percent to 8 percent from 1965 to 1968, the figures seem more credible. This future analysis clearly demonstrates that DSB, unless it is heavily subsidized, will not be able to serve a significant portion of the transport demand in the future.

DISCUSSION OF RESULTS

The results for the study area indicate for even a heavily subsidized system a very low demand for DSB transportation system in the very near future. Because the Kitchener-Waterloo area is typical of North American cities, it is expected that similar results would be forthcoming in other cities, and that the results presented here could be used for other cities. Recent work at General Motors supports the range of ridership predicted.

With such a low level of ridership it would seem inappropriate for any public agency to invest in this type of system as its primary public transport system. In fact the results give some indication that a fixed-route bus system would provide the same levels of ridership at a lower cost. This was not tested directly in this study because only the demand was examined.

It seems clear from the demand model that the travel-time ratio of an alternative mode of public transport must be very close to one to ensure substantial level of ridership. Thus the DSB concept's main obstacle to success is its high travel-time ratio. If further development work on DSB is carried out, it should concentrate on operational methods of reducing the travel-time ratio.

CONCLUSIONS

1. A Wilson type of gravity model (15) with a modified impedance function is a satisfactory travel model for forecasting the demand for a DSB system;
2. For a DSB system (many-origins-to-many-destinations operation) with operating characteristics indicated from previous research, the demand for the journey to work would not be much greater for such a system than for a typical existing urban bus system;
3. The future work-trip patronage prospects for a DSB system are not good (DSB systems with travel-time ratios of 2.0 or less and fares of 45 cents per trip would, at the most, serve 3 percent of the journey-to-work trips for the study community, Kitchener-Waterloo, in the year 1975); and
4. The levels of patronage for DSB systems for nonwork trips were not estimated by the study.

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