Panel Survey Approach to Measuring Transit Route Service Elasticity of Demand

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This paper presents the results of a pilot test of a panel survey procedure designed to determine transit service elasticities of demand under a range of operating and demographic conditions. This procedure consists of surveying a randomly selected panel of potential transit users within a given study area, both before and after a transit service change occurs, and then using the observed changes in transit usage by this panel of users to impute service elasticity characteristics. A total of 76 panelists were recruited from existing users of the test route by interviewers stationed at transit stops located within the study area, representing a net recruitment success rate of 72 percent. Each panelist was required to complete "trip record sheets" for 2 weeks before and 2 weeks after the service change. The attrition rate over the course of the survey period with respect to panelist participation in the survey was quite low, with 75 percent of the panel (57 out of 76) still active in the panel after the 4 record-keeping weeks. Ridership on the test route declined by 17 percent (1.3 trips per week per person) in response to a 50 percent increase in peak-period headway (and up to a 100 percent increase in off-peak headways). 53.8 percent (0.7 trips per week per person) of this ridership loss, however, shifted to alternative routes rather than to competing modes, resulting in a net loss in system patronage of 0.6 trips per week per person or 6.8 percent of the "before" period ridership in the study area. These changes translate into an aggregate headway elasticity on the test route of approximately −0.4, whereas the elasticity of total transit ridership in the service area with respect to headway changes on the test route is of the order of −0.1.

"Service elasticity of demand" refers to the elasticity of transit ridership with respect to changes in transit service headway (or frequency). The relevance of service elasticity of demand to transit planning activities is clear: one of the most common actions available to a transit operator in its attempts to improve service efficiency and effectiveness is to alter service frequencies on selected routes. It follows directly that the better the likely responses of the traveling public to such changes are understood, the more effectively such changes can be designed and implemented. The purpose of this paper is to describe an experimental procedure for determining service elasticities of demand and to present the results of a "pilot test" of this procedure. The procedure consists of surveying a randomly selected panel of potential transit users within a given study area, both before and after a transit service change occurs, and then using the observed changes in transit usage by this panel of users to impute service elasticity characteristics.

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BACKGROUND

Despite the importance of service elasticity of demand to transit planning, little solid, quantitative service elasticity data are available. Mayworm et al. summarize the empirical experience in North America and Great Britain as of 1980 and construct average bus demand elasticities with respect to headways of −0.37 for peak periods (±0.19, based on three cases), −0.46 for off-peak periods (±0.26, based on nine cases), and −0.47 for all-hours service (±0.21, based on seven cases) (*1*). Disaggregate mode-choice models also provide some insight into the sensitivity of travelers to transit headways in that they indicate that transit out-of-vehicle travel time (which depends, among other factors, on route headways) is typically weighted by travelers 1.5 to 3.5 times more heavily than in-vehicle travel time (*2,3*). Finally, various manuals on transit ridership analysis discuss the use of service elasticities without providing strong empirical evidence concerning relevant elasticity values to use, beyond quoting the Mayworm et al. results cited here (*4,5*).

Three major reasons exist for this relative lack of insight into transit service elasticities. The first is that—unlike fare changes, which are systemwide in their effect—service frequency changes are applied on a route-by-route basis. Thus, a single, systemwide elasticity is not observable, nor is it even a very meaningful concept. Second, the accurate measurement of "before" and "after" ridership at the route level is a very complex and expensive task, principally because of the relatively large temporal variations that exist in transit ridership at the route level, as well as uncertainty concerning how long it takes route ridership levels to adjust to a change in service frequency. And, third, service frequency changes are typically made in an "uncontrolled environment" within which other service changes may be simultaneously introduced, the impact on parallel or cross routes is not monitored, and changes in route ridership on "control" routes are not observed. The result in such cases is that even if a change in ridership on the route in question can be observed with reasonable accuracy, the proportion of this change that is a net change in *system* ridership and, of this, the amount attributable to the service frequency change, is difficult to determine.

These observations clearly indicate the need for a carefully designed experimental procedure, in which as many factors affecting ridership as possible are either controlled (i.e., held constant) or explicitly measured (so that the effect of changes in these factors can be explicitly accounted for), as well as in which all types of ridership responses (mode shifts, route shifts, changes in trip rates, etc.) are directly measured.

PANEL SURVEY APPROACH

One obvious approach to measuring changes in a transit route's ridership is to conduct a set of ridership counts before and after the service change. This approach, however, is extremely limited in the information that it generates, very labor-intensive if sufficient observations for statistical reliability are to be gathered, and subject to a wide variety of uncontrolled factors that may well confound the results obtained. The net result of these limitations is that the riding count approach is neither a very reliable nor cost-effective approach for measuring transit service elasticities [for further discussion of this issue, see Miller (*6*)].

A second approach involves the random selection of a representative panel of residents within the test route catchment area and monitoring the before and after usage levels of the panel members through the use of a diary survey. Relative to the ridership count approach, the panel survey approach has the following advantages:

- The survey cost-effectively collects travel information for all service periods.
- The survey readily collects information concerning mode and transit route for each trip made. Hence, both route-shift and mode-shift effects can be identified.
- A wide range of socioeconomic characteristics of each trip maker can be obtained. Hence, differences in elasticities among different groups of people can be examined.
- Further, because each individual within the panel is explicitly identified and "tracked" during the test period, considerable control over the test is possible. In particular, virtually every factor affecting transit route usage can be controlled in the panel survey approach. In addition, population movements into and out of the test area will not have an impact on the panel survey results.

The panel survey approach thus provides controlled and detailed information concerning travel responses to a transit service change. The only major limitation of the approach is that it depends on each panel member recording his or her trip information over a potentially lengthy test period. There are clearly limits, however, in people's willingness to fill out questionnaires over long time periods. The success of such a panel survey depends on simplifying the respondents' task to make their participation over an extended period as painless as possible. In addition, recruitment and sustained commitment depend on the provision of appropriate incentives to each panelist to join the panel in the first place and then to continue to participate fully in the panel throughout the course of the survey. In this study two such incentives were used:

- A lottery ticket to encourage participation in the initial interview at the transit stop.
- Financial incentives to encourage continued participation in the survey. This involved entering all active panel members in a weekly cash lottery.

PANEL SURVEY DESIGN AND EXECUTION

The Mt. Pleasant Road trolley bus route (Route 74) in the City of Toronto was chosen as the study test route (see Figure 1). This route was viewed as a nearly ideal candidate for the pilot test since it had long been considered a candidate for service reduction, independent of the needs of this study; it has a well-defined, almost entirely residential, catchment area; and the resident population of the study area is relatively homogeneous. Based on Toronto Transit Commisssion analysis of the route's service requirements, the following changes in service headways were implemented on October 18, 1987, as part of a regular board period change:

- Peak-period headways were increased 50 percent from 10 to 15 min.
- Early evening (7 to 9 p.m.) headways were increased 100 percent from 15 to 30 min.
- Midday and late evening headways were left unchanged at 15 and 20 min.

The survey panel members were recruited by interviewers located at test route stops who intercepted passengers while they waited for the arrival of a bus. Panel recruitment occurred during 3 days of the week immediately before the first week of the survey. A total of 78 out of 121 persons interviewed (64 percent) agreed to participate in the survey. Many of the "refusals" recorded actually represent a failure to complete the interview before the next bus arrived. If these incomplete interviews are subtracted from the total (along with people who were rejected for reasons such as they knew that they would soon be moving out of the study area), then the acceptance rate becomes 78 out of 108 or 72 percent.

Each panel member was given a booklet at the time of recruitment that contained "trip record sheets" for each weekday for the 4 weeks that the panel member was to record his or her trips made to and from home, along with instructions on how to fill out these sheets. Each trip record sheet was designed so that the panelist merely had to "tick" the box corresponding to the time of day, trip purpose, and trip mode for each trip that began or ended at home. Figure 2 provides an example of one side of a trip record sheet for trips beginning at home for Monday, November 9, 1987 (the other side of this sheet contained a similar form for recording the trips made that ended at home for this same day). The 4 weeks for which trip records were to be kept began on Monday, September 28, October 5, November 9, and November 16, respectively, with the first 2 weeks occurring before the Mt. Pleasant route service change on October 18, and the second 2 weeks occurring after this change. The timing of the 2 "before" weeks was chosen so as to avoid the Thanksgiving holiday Monday (October 12), and the timing of the 2 "after" weeks was chosen to provide as long an "adjustment period" as possible (in this case, 3 weeks), without overly extending the survey duration. Four addressed, stamped envelopes were provided to each panelist, and the panelist was requested to mail the five trip record sheets for each week of the survey in one of these envelopes at the end of each week of recording.

Each panelist was contacted by telephone once for each of the 4 survey weeks. The objectives of these contacts were to ensure that the panelist was actively filling out the survey

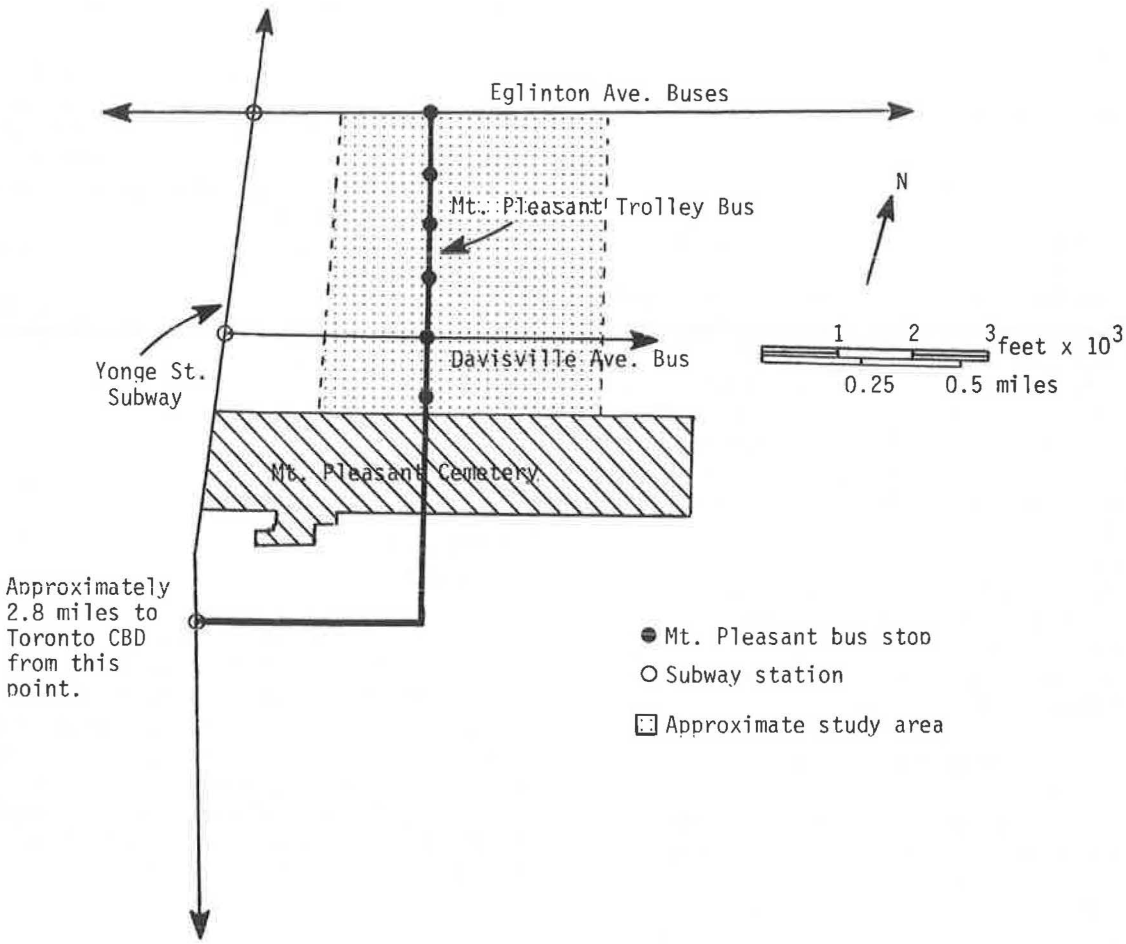

FIGURE 1 Study area.

forms, to obtain additional information about the panelist's socioeconomic characteristics, and to ascertain whether anything unusual happened to the panelist during the week (e.g., was sick or away on business) or whether anything had happened to alter the panelist's characteristics (e.g., changed jobs) that would have affected the panelist's trip-making propensities. All panelists who reported that they were filling out the trip record sheets for the given week were eligible for a cash lottery. Six winners were selected from this group each week and sent checks for the amount won. One $50 and five $10 prizes were awarded each week.

The overall completion rate for the 4 weeks of the survey is 75 percent. Subtracting those panelists who dropped out because of sickness, moving out of the neighborhood, and changing jobs, the completion rate is 57 out of 70 or 81.4 percent. Further, if one focusses on those panelists who could be contacted by telephone during the course of the survey, the completion rate is 55 out of 61 or 90.2 percent. In contrast, the completion rate among those panelists who could not be contacted by telephone (either because they refused to provide a number or the number was recorded incorrectly) was 2 out of 8 or 25 percent.

ANALYSIS OF SURVEY RESULTS

Table 1 presents a summary of the trip-making behavior of the panel over the duration of the survey. It shows the average one-way (i.e., to or from home) trips per week per person, by mode, for each week of the survey, as well as for the 2 "before" weeks (Weeks 1 and 2) and the 2 "after" weeks (Weeks 3 and 4) combined. These averages represent "net" trip rates, in that days or weeks in which "unusual" events (e.g., sickness, vacation, etc.) resulted in "unusual" trip patterns have been factored out, thus allowing variations in observed trip rates to be unambiguously attributed to the change in transit service. Average mode splits are also shown.

Two key points to note from this table are

- Average weekly rides per person on the Mt. Pleasant bus declined from 7.5 to 6.2 trips per week (a 17 percent decrease). This translated into a decline in the Mt. Pleasant route's modal share from 70.5 percent to 61.7 percent (a 12.5 percent decrease in modal share).
- The percentage of all trips made by panelists on any transit route, however, declined by only 1.7 percent, from

DIARY FOR TRIPS **BEGINNING** AT HOME

MONDAY, NOVEMBER 9, 1987

	TRIPS TO WORK				TRIPS TO SCHOOL				"OTHER PURPOSE" TRIPS TO: "Downtown"				"Local Area"				Other Dest'ns			
	TTC Route First Used				TTC Route First Used				TTC Route First Used				TTC Route First Used				TTC Route First Used			
Time Left Home	Mt. Pleasant	Davisville	Eglinton	"Other Modes"	Mt. Pleasant	Davisville	Eglinton	"Other Modes"	Mt. Pleasant	Davisville	Eglinton	"Other Modes"	Mt. Pleasant	Davisville	Eglinton	"Other Modes"	Mt. Pleasant	Davisville	Eglinton	"Other Modes"
2:00 a.m. - 5:59 a.m.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
6:00 a.m. - 8:59 a.m.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
9:00 a.m. - 2:59 p.m.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
3:00 p.m. - 6:59 p.m.	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
7:00 p.m. - 2:00 a.m.	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
TOTAL TRIPS	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120

FIGURE 2 Sample trip record sheet.

TABLE 1 AGGREGATE TRIP RATES AND MODE SPLITS

	Week 1	Week 2	Week 3	Week 4	Weeks 1 + 2	Weeks 3 + 4
Weekly trips						
All modes	11.0 (2.9)	10.3 (3.1)	10.0 (2.2)	10.2 (2.8)	10.6 (3.0)	10.1 (2.5)
All transit	8.9 (2.8)	8.6 (2.3)	8.2 (2.8)	8.2 (2.8)	8.8 (2.6)	8.2 (2.8)[a]
Mt. Pleasant bus	7.7 (3.3)	7.2 (2.9)	6.3 (3.1)	6.0 (3.4)	7.5 (3.1)	6.2 (3.2)[a]
No. of observations	58.0	52.0	48.0	45.0	110.0	93.0
Mode splits (%)						
Transit/Total	81.3 (24.0)	84.2 (22.4)	82.1 (26.8)	80.5 (25.4)	82.7 (23.5)	81.3 (26.3)
Mt. Pleasant/Tot	70.5 (30.2)	70.4 (29.9)	63.7 (31.0)	59.5 (33.4)	70.5 (30.2)	61.7 (32.4)[a]
Mt. Pleasant/Tr.	86.6 (21.8)	83.6 (23.6)	77.6 (26.8)	73.9 (30.4)	85.2 (22.8)	75.8 (28.8)[a]
No. of observations (1 + 2)	58.0	51.0	48.0	44.0	109.0	92.0
No. of observations (3)	58.0	51.0	46.0	44.0	109.0	90.0

[a]Statistically significant at 95% confidence level.

82.7 percent to 81.3 percent. Hence, the majority of the loss in Mt. Pleasant ridership represents a "route shift" to competing transit routes, rather than a "mode shift" to competing modes.

Table 2 presents "before" and "after" trip summary information for workers and students in one group and "others" in the other. Nonworkers in this sample (predominantly seniors) travel less than workers and their modal choices are virtually invariant between the "before" and "after" periods. This latter result presumably reflects the lack of flexibility that nonworkers have in their choice of both modes and routes. That is, this group generally appears to be truly "captive" to transit, and hence its only response to reduced service is either to continue to use transit despite the service reduction or else to not make the trip. This latter option may be reflected in a "before" to "after" trip rate reduction of 1.4 trips per week

TABLE 2 AGGREGATE TRIP RATES AND MODE SPLITS, WORKERS AND STUDENTS VS. NONWORKERS/STUDENTS

	Workers and Students		Nonworkers/Students	
	Weeks 1 + 2	Weeks 3 + 4	Weeks 1 + 2	Weeks 3 + 4
Weekly trips				
All modes	10.8 (2.8)	10.3 (1.9)	9.7 (4.7)	8.3 (4.6)
All transit	9.0 (2.5)	8.5 (2.6)	7.0 (3.2)	6.1 (3.3)
Mt. Pleasant bus	7.8 (3.1)	6.5 (3.2)[a]	5.0 (2.7)	4.3 (2.5)
No. of observations	98.0	81.0	12.0	12.0
Mode splits (%)				
Transit/Total	83.8 (23.1)	82.2 (26.8)	72.3 (25.7)	73.7 (21.5)
Mt. Pleasant/Tot	72.6 (29.5)	62.7 (32.5)[a]	51.1 (31.2)	52.5 (31.6)
Mt. Pleasant/Tr.	86.6 (22.5)	76.3 (29.0)[a]	70.6 (21.1)	71.2 (28.3)
No. of observations (1 + 2)	97.0	81.0	12.0	11.0
No. of observations (3)	97.0	79.0	12.0	11.0

[a]Statistically significant at 95% confidence level.

TABLE 3 SERVICE ELASTICITIES

		Elasticities[a]		
Trip Purpose	Time Period	Mt. Pleasant	Total Bus	All Modes Transit
Work/ school trips[b]	All periods	−0.40	−0.06	0.00
Non-work/ school trips[c]	All periods	−0.40	−0.40	−0.29
All purposes	Peak periods	−0.47	−0.15	−0.10
All purposes	Off-peak	−0.29	0.00	−0.10

[a]Computed using the formula $e_{D_x} = \{(D_2 - D_1)/(D_2 + D_1)\}\{(x_2 + x_1)/(x_2 - x_1)\}$, where $e_{D_x} = \{\Delta D/D_0\}/\{\Delta x/x_0\}$; ΔD = change in demand level, equal to $(D_2 - D_1)$; D_1, D_2 = "before" and "after" demand levels, respectively; D_0 = "reference" demand level, equal to $(D_2 + D_1)/2$; Δx = change in headway, equal to $(x_2 - x_1)$; x_1, x_2 = "before" and "after" headways, respectively; and x_0 = "reference" headway, equal to $(x_2 + x_1)/2$.
[b]Given that a majority of work/school trips occur during the morning and afternoon peak periods, it is assumed that the relevant headway for computing work/school trip service elasticity is the peak-period headway.
[c]It is assumed that the relevant headway for computing non-work/school trip service elasticity is the early evening period headway. This time period is clearly the relevant time period for workers and students, the majority of whom are away from home at work or school during the rest of the day. This time period would also appear to be the relevant one for non-workers/students given that most round trips by panelists in this group either began or ended during this time period.

for nonworkers (a 14.4 percent reduction) compared with a 0.5 trips per week reduction for workers/students (4.6 percent).

Further analysis of the worker/student group indicates that nonwork/school travel for this group is far less dependent on transit than are work/school trips, with an aggregate "before" modal split of only 48.6 percent versus 88.3 percent for work/school trips. Further, nonwork/school travel is far more sensitive to the change in transit service, exhibiting a 43.2 percent decline in the Mt. Pleasant route's modal share (36.8 percent to 20.9 percent), compared with a decline of 14.0 percent (87.6 percent to 76.7 percent) for work/school trips. Finally, the shift in nonwork/school trip making generally involves a shift to other modes, because the loss of 0.3 trips per week (0.5 to 0.2) on the Mt. Pleasant route translates directly into an overall loss of 0.3 transit trips per week. The shift in work/school trips, however, is largely a route shift, in that the decline of 1.1 Mt. Pleasant route trips per week (7.4 to 6.3) results in an overall decline in transit usage of only 0.2 trips per week (8.4 to 8.2).

Table 3 presents estimates of arc elasticities for Mt. Pleasant bus ridership, total local transit usage, and total trip making by the panelists in this survey for work/school trips, nonwork/school trips, peak-period trips, and off-peak-period trips. As indicated by this table, Mt. Pleasant bus ridership is service inelastic (ranging from about −0.3 to −0.5 in value). The elasticity of total transit usage in the area with respect to service on the Mt. Pleasant bus is, as expected, even smaller (averaging about −0.1), although the nonwork/school total transit trip elasticity is identical to the Mt. Pleasant bus elasticity. The route headway elasticities of −0.29 to −0.47 compare favorably with other results cited in the literature (*1*). There is, however, virtually nothing in the literature that corresponds to the "total transit" or service area elasticity that also has been calculated here.

SUMMARY AND CONCLUSIONS

The results of the study demonstrate the feasibility of panel surveys for identifying the response of a small sample of riders to specific headway changes on one route. This method allows researchers to control for nonservice factors and to study the behavior of different groups of travelers (e.g., transit captives, workers, etc.). These pilot test results clearly indicate that it is possible to maintain a high percentage of panelists in a survey that involves recording trip-making behavior for 4 full weeks over a 2-month period. This result, of course, depends on the simple diary format adopted, the use of a fairly attractive incentive program, and active contact between the survey team and the panel members.

Route headway elasticities comparable to those reported elsewhere in the literature were found for the test route examined. The panel survey approach, however, also allows a "total transit" elasticity, which indicates the net change of ridership for the service area, to be computed. This net elasticity is generally much smaller in value than the route-level elasticity, at least for the case examined, which involved increasing headways in an area in which alternative transit routes were generally available for travelers' use. Generalization of the results obtained here obviously will require further surveys to identify ridership responses to different types of service changes in a variety of operating environments.

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REFERENCES

1. P. Mayworm, A. M. Lago, and J. M. McEnroe. *Patronage Impacts of Changes in Transit Fares and Services*, Report RR 135-1. UMTA, U.S. Department of Transportation, 1980.
2. P. R. Stopher, L. K. Tamny, K. L. Killough, and R. J. Schulte. *Mode-Choice Models, Networks, and Path Building*. Presented at the 65th Annual Meeting of the Transportation Research Board, Washington, D.C., 1986.
3. S. Algers and S. Widlert. Applicability and Stability of Logit Models in Sweden—Some Recent Findings with Policy Implications. In *Behavioural Research for Transport Policy*, VNU Science Press, The Hague, The Netherlands, 1986, pp. 173–192.
4. R. Menhard, G. Ruprecht, and I. Burns. *Route-Level Demand Models: A Review*. Report DOT-I-82-6. UMTA, U.S. Department of Transportation, 1982.
5. Roads and Transportation Association of Canada. Demand Models. In *Canadian Transit Handbook*, 2nd ed. Canadian Urban Transit Administration, Ottawa, Ontario, Canada, 1985, Chapter 6.
6. E. J. Miller. *Service Elasticity of Demand: A Study Design*. Final report to the Service Planning Department, Toronto Transit Commission. University of Toronto–York University Joint Program in Transportation, Toronto, Ontario, Canada, 1986.

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