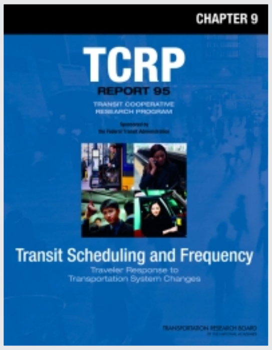

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TCRP REPORT 95

Traveler Response to Transportation System Changes

Chapter 9—Transit Scheduling and Frequency

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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions*, published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA; the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Special Notice

The Transportation Research Board, the National Research Council, the Transit Development Corporation, and the Federal Transit Administration (sponsor of the Transit Cooperative Research Program) do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the clarity and completeness of the project reporting.

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FOREWORD

By Staff, Transportation Research Board

TCRP Report 95: Chapter 9, Transit Scheduling and Frequency will be of interest to transit planning practitioners, educators, researchers, and professionals across a broad spectrum of transportation and planning agencies; MPOs; and local, state, and federal government agencies.

Information on traveler response and related impacts is presented in this chapter for scheduling changes made to conventional bus *and* rail transit, including changes in the frequency of service, hours of service, structuring of schedules, and schedule reliability. Frequency changes made together with fare changes are included.

The subject matter of this chapter—scheduling and frequency—covers a relatively specialized aspect of public transit operations. Chapter 10, "Bus Routing and Coverage," broadens the coverage of conventional bus operations, as does Chapter 4 for express bus services, and Chapters 7 and 8 for urban rail systems. All aspects of demand responsive and ADA (Americans with Disabilities Act) services are covered in Chapter 6; this includes matters of "scheduling" (dispatching) and service quantity.

The overarching objective of the *Traveler Response to Transportation System Changes Handbook* is to equip members of the transportation profession with a comprehensive, readily accessible, interpretive documentation of results and experience obtained across the United States and elsewhere from (1) different types of transportation system changes and policy actions and (2) alternative land use and site development design approaches. While the focus is on contemporary observations and assessments of traveler responses as expressed in travel demand changes, the presentation is seasoned with earlier experiences and findings to identify trends or stability, and to fill information gaps that would otherwise exist. Comprehensive referencing of additional reference materials is provided to facilitate and encourage in-depth exploration of topics of interest. Travel demand and related impacts are expressed using such measures as usage of transportation facilities and services, before-and-after market shares and percentage changes, and elasticity.

The findings in the *Handbook* are intended to aid—as a general guide—in preliminary screening activities and quick turn-around assessments. The *Handbook* is not intended for use as a substitute for regional or project-specific travel demand evaluations and model applications, or other independent surveys and analyses.

The Second Edition of the handbook *Traveler Response to Transportation System Changes* was published by USDOT in July 1981, and it has been a valuable tool for transportation professionals, providing documentation of results from different types of transportation actions. This Third Edition of the *Handbook* covers 18 topic areas, including essentially all of the nine topic areas in the 1981 edition, modified slightly in scope, plus nine new topic areas. Each topic is published as a chapter of TCRP Report 95.

To access the chapters, select "TCRP, All Projects, B-12" from the TCRP website: http://www4.national-academies.org/trb/crp.nsf.

A team led by Richard H. Pratt, Consultant, Inc. is responsible for the *Traveler Response to Transportation System Changes Handbook*, *Third Edition*, through work conducted under TCRP Projects B-12, B-12A, and B-12B.

REPORT ORGANIZATION

The *Handbook*, organized for simultaneous print and electronic chapter-by-chapter publication, treats each chapter essentially as a stand-alone document. Each chapter includes text and self-contained references and sources on that topic. For example, the references cited in the text of Chapter 6, "Demand Responsive/ADA," refer to the Reference List at the end of that chapter. The *Handbook* user should, however, be conversant with the background and guidance provided in *TCRP Report 95: Chapter 1, Introduction*.

Upon completion of the *Report 95* series, the final Chapter 1 publication will include a CD-ROM of all 19 chapters. The complete outline of chapters is provided below.

Handbook Outline Showing Publication and Source-Data-Cutoff Dates

	U.S. DOT Publication		TCRP Report 95	
General Sections and Topic Area Chapters (TCRP Report 95 Nomenclature)	**First Edition**	**Second Edition**	**Source Data Cutoff Date**	**Estimated Publication Date**
Ch. 1 – Introduction (with Appendices A, B)	1977	1981	2003[a]	2000/03/04[a]
Multimodal/Intermodal Facilities				
Ch. 2 – HOV Facilities	1977	1981	1999	2000/04[b]
Ch. 3 – Park-and-Ride and Park-and-Pool	—	1981	2003[c]	2004[d]
Transit Facilities and Services				
Ch. 4 – Busways, BRT and Express Bus	1977[e]	1981	2003[c]	2004[d]
Ch. 5 – Vanpools and Buspools	1977	1981	1999	2000/04[b]
Ch. 6 – Demand Responsive/ADA	—	—	1999	2000/04[b]
Ch. 7 – Light Rail Transit	—	—	2003	2004[d]
Ch. 8 – Commuter Rail	—	—	2003	2004[d]
Public Transit Operations				
Ch. 9 – Transit Scheduling and Frequency	1977	1981	1999	2000/04[b]
Ch. 10 – Bus Routing and Coverage	1977	1981	1999	2000/04[b]
Ch. 11 – Transit Information and Promotion	1977	1981	2002	2003
Transportation Pricing				
Ch. 12 – Transit Pricing and Fares	1977	1981	1999	2000/04[b]
Ch. 13 – Parking Pricing and Fees	1977[e]	—	1999	2000/04[b]
Ch. 14 – Road Value Pricing	1977[e]	—	2002–03[f]	2003
Land Use and Non-Motorized Travel				
Ch. 15 – Land Use and Site Design	—	—	2001–02[f]	2003
Ch. 16 – Pedestrian and Bicycle Facilities	—	—	2003	2004[d]
Ch. 17 – Transit Oriented Design	—	—	2003[d]	2004[d]
Transportation Demand Management				
Ch. 18 – Parking Management and Supply	—	—	2000–02[f]	2003
Ch. 19 – Employer and Institutional TDM Strategies	1977[e]	1981[e]	2003	2004[d]

NOTES:
[a] Published in TCRP Web Document 12, *Interim Handbook* (March 2000), without Appendix B. The "Interim Introduction," published in Research Results Digest 61 (September 2003), is a replacement. Publication of the final version of Chapter 1, "Introduction," as part of the TCRP Report 95 series, is anticipated for 2004.
[b] Published in TCRP Web Document 12, *Interim Handbook*, in March 2000. Available now at http://www4.nas.edu/trb/crp.nsf/All+Projects/TCRP+B-12. Publication as part of the TCRP Report 95 series is anticipated for the second half of 2004.
[c] The source data cutoff date for certain components of this chapter was 1999.
[d] Estimated.
[e] The edition in question addressed only certain aspects of later edition topical coverage.
[f] Primary cutoff was first year listed, but with selected information from second year listed.

CHAPTER 9 AUTHOR AND CONTRIBUTOR ACKNOWLEDGMENTS

TCRP Report 95, in essence the Third Edition of the "Traveler Response to Transportation System Changes" Handbook, is being prepared under Transit Cooperative Research Program Projects B-12, B-12A, and B-12B by Richard H. Pratt, Consultant, Inc. in association with the Texas Transportation Institute; Jay Evans Consulting LLC; Parsons Brinckerhoff Quade & Douglas, Inc.; Cambridge Systematics, Inc.; J. Richard Kuzmyak, L.L.C.; SG Associates, Inc. (BMI-SG as of June 2003); Gallop Corporation; McCollom Management Consulting, Inc.; Herbert S. Levinson, Transportation Consultant; and K.T. Analytics, Inc.

Richard H. Pratt is the Principal Investigator. Dr. Katherine F. Turnbull of the Texas Transportation Institute assisted as co-Principal Investigator during initial Project B-12 phases, leading up to the Phase I Interim Report and the Phase II Draft Interim Handbook. With the addition of Project B-12B research, John E. (Jay) Evans, IV, of Jay Evans Consulting LLC was appointed the co-Principal Investigator. Lead Handbook chapter authors and co-authors, in addition to Mr. Pratt, are Mr. Evans (initially with Parsons Brinckerhoff); Dr. Turnbull; Frank Spielberg of SG Associates, Inc. (BMI-SG); Brian E. McCollom of McCollom Management Consulting, Inc.; Erin Vaca of Cambridge Systematics, Inc.; J. Richard Kuzmyak, initially of Cambridge Systematics and now of J. Richard Kuzmyak, L.L.C.; and Dr. G. Bruce Douglas, Parsons Brinckerhoff Quade & Douglas, Inc. Contributing authors include Herbert S. Levinson, Transportation Consultant; Dr. Kiran U. Bhatt, K.T. Analytics, Inc.; Shawn M. Turner, Texas Transportation Institute; Dr. Rachel Weinberger, Cambridge Systematics (now of Nelson/Nygaard); and Dr. C. Y. Jeng, Gallop Corporation.

Other research agency team members contributing to the preparatory research, synthesis of information, and development of this Handbook have been Stephen Farnsworth, Laura Higgins and Rachel Donovan of the Texas Transportation Institute; Nick Vlahos, Vicki Ruiter and Karen Higgins of Cambridge Systematics, Inc.; Lydia Wong, Gordon Schultz, Bill Davidson, and Andrew Stryker of Parsons Brinckerhoff Quade & Douglas, Inc.; Kris Jagarapu of BMI-SG; and Laura C. (Peggy) Pratt of Richard H. Pratt, Consultant, Inc. As Principal Investigator, Mr. Pratt has participated iteratively and substantively in the development of each chapter. Dr. C. Y. Jeng of Gallop Corporation has provided pre-publication numerical quality control review. By special arrangement, Dr. Daniel B. Rathbone of The Urban Transportation Monitor searched past issues. Assistance in word processing, graphics and other essential support has been provided by Bonnie Duke and Pam Rowe of the Texas Transportation Institute, Karen Applegate, Laura Reseigh, Stephen Bozik, and Jeff Waclawski of Parsons Brinckerhoff, others too numerous to name but fully appreciated, and lastly the warmly remembered late Susan Spielberg of SG Associates.

Special thanks go to all involved for supporting the cooperative process adopted for topic area chapter development. Members of the TCRP Project B-12/B-12A/B-12B Project Panel, named elsewhere, are providing review and comments for what will total over 20 individual publication documents/chapters. They have gone the extra mile in providing support on call including leads, reports, documentation, advice, and direction over what will be the eight-year duration of the project. Four consecutive appointed or acting TCRP Senior Program Officers have given their support: Stephanie N. Robinson, who took the project through scope development and contract negotiation; Stephen J. Andrle, who led the work during the Project B-12 Phase and on into the TCRP B-12A Project Continuation; Harvey Berlin, who saw the Interim Handbook through to Website publication; and Stephan A. Parker, who is guiding the entire project to its complete fruition. Editor Natassja Linzau is providing her careful examination and fine touch. The efforts of all are greatly appreciated.

Continued recognition is due to the participants in the development of the First and Second Editions, key elements of which are retained. Co-authors to Mr. Pratt were Neil J. Pedersen and Joseph J. Mather for the First Edition, and John N. Copple for the Second Edition. Crucial support and guidance for both editions was provided by the Federal Highway Administration's Technical Representative (COTR), Louise E. Skinner.

In the *TCRP Report 95* edition, John (Jay) Evans is the lead author for this volume: Chapter 9, "Transit Scheduling and Frequency."

Participation by the profession at large has been absolutely essential to the development of the Handbook and this chapter. Members of volunteer Review Groups, established for each chapter, reviewed outlines, provided leads, and in many cases undertook substantive reviews. Though all members who assisted are not listed here in the interests of brevity, their contribution is truly valued. A Chapter 9 review was undertaken by Review Group member William G. Allen, Jr., and Gary Hufstedler stepped in to provide an additional outside review and associated contributions.

Finally, sincere thanks are due to the many practitioners and researchers who were contacted for information and unstintingly supplied both that and all manner of statistics, data compilations and reports. Though not feasible to list here, many appear in the "References" section entries of this and other chapters.

CHAPTER 9—TRANSIT SCHEDULING AND FREQUENCY

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9 – Transit Scheduling and Frequency

OVERVIEW AND SUMMARY

Information on traveler response and related impacts is presented in this "Transit Scheduling and Frequency" chapter for scheduling changes made to conventional bus *and* rail transit, including changes in the frequency of service, hours of service, structuring of schedules and schedule reliability. Frequency changes made together with fare changes are included. This chapter does not, however, cover transit routing and coverage changes. They are covered in other chapters as detailed at the end of this introduction.

Within this "Overview and Summary" section:

- "Objectives of Scheduling and Frequency Changes" outlines reasons for such actions.
- "Types of Scheduling and Frequency Changes" lists and defines the scheduling changes and combinations addressed in this chapter.
- "Analytical Considerations" covers methods used in quantifying response to schedule changes, limitations of available research, and cautions that thus apply to its use.
- "Traveler Response Summary" highlights the travel demand findings for scheduling and frequency changes. The recommended approach to using either the "Traveler Response Summary," or the material which follows, is to do so only after first reading the initial three subsections of this "Overview and Summary" for background.

Following the four-part "Overview and Summary," greater depth and detail are provided:

- "Response by Type of Strategy" describes the travel demand effects of scheduling changes in terms of service or headway elasticities, ridership, and other measures.
- "Underlying Traveler Response Factors" examines the role of the different components of travel time as well as considerations such as physical, operating and economic conditions.
- "Related Information and Impacts" presents subtopics such as mode versus route choice effects, peak versus off-peak response, and environmental and cost considerations.
- "Case Studies" expands on one multi-faceted demonstration project and three other instances of extensively analyzed frequency changes.

The subject matter of this chapter, scheduling and frequency, covers a relatively specialized aspect of public transit operations. Chapter 10, "Bus Routing and Coverage," broadens the coverage of conventional bus operations, as does Chapter 4 for express bus services, and Chapters 7 and 8 for urban rail systems. All aspects of demand responsive and ADA (Americans with Disabilities Act) services are covered in Chapter 6, even matters of "scheduling" (dispatching) and service quantity.

Objectives of Scheduling and Frequency Changes

Scheduling and frequency modifications are among the most common service changes that transit operators make to improve service effectiveness. Both cost effectiveness and service quality are primary goals to be served, with appropriate trade-offs. A cost effectiveness operating objective where transit use is high is to adjust capacity to demand, for adherence with passenger loading standards and productive distribution of service. A related objective applicable in all circumstances is to increase transit vehicle and crew utilization efficiency. The overriding service quality objectives of scheduling and frequency changes are to minimize overall passenger trip time and enhance convenience.

The resulting traveler response is of concern whichever the perspective — cost savings or service enhancement. A better understanding of the response of riders to frequency changes should result in design of more effective service modifications (Miller and Crowley, 1989).

Scheduling and frequency most particularly affect that aspect of transit service quality which is the waiting time patrons encounter and perceive in making a transit trip. Individual changes may have the objective of reducing wait time at the start of a transit trip, or minimizing wait time if a transfer between two vehicles is required. Scheduling changes may be made to increase the ease of passenger comprehension of the schedule. Related actions may have the objectives of improving the reliability of the service, reducing both real and perceived passenger wait times, and lowering passenger anxiety. These service quality objectives support the goals of providing a more attractive service, increasing transit ridership, and shifting travel out of low occupancy autos.

Types of Scheduling and Frequency Changes

Scheduling and frequency changes generally involve the manipulation of service hours and headways, and details of transit vehicle arrival and departure timing. Such changes are, in effect, a specialized form of transit service improvement or reduction that involves no alteration of coverage or routing. The following general types of changes are discussed further within this chapter:

Frequency Changes. This strategy involves increasing or reducing the number of scheduled transit vehicle trips to provide an increase or decrease in service frequency. Headways and passenger wait times are correspondingly shortened or lengthened.[1] Such changes may be concentrated in the peak or off-peak periods, or may apply overall.

Service Hours Changes. Under this strategy the span of service is increased or decreased by lengthening or shortening the service day during which service is provided, or by adding or eliminating days of service, such as Sunday operation. The hours during which taking transit is

[1] Service frequency is the number of buses or trains per hour or day, while the headway is the time interval between buses or trains. Passengers arriving randomly will, if the transit service is reliable, have a waiting time which averages one half the headway.

an option are correspondingly increased or constrained, and the likelihood of being stranded without service is likewise affected.

Frequency Changes with Fare Changes. Frequency changes (and service hours changes) are often implemented in conjunction with fare changes. Pairing frequency reductions with fare increases is a common approach to transit deficit reduction, while increased frequency may be implemented together with decreased fares to up ridership and enhance value received by the consumer.

Combined Service Frequencies. This approach is the outcome of offering a combination of different transit services to address diverse needs of patrons, while concurrently providing service frequency options to selected markets. For example, overlaying express service onto local service on the same street provides service tailored to passengers making both long and short trips. At the same time, for trips that can be made by boarding and alighting where both service types stop, this approach provides the option of either taking the next bus or waiting for the preferred service.

Regularized Schedules. This strategy uses rescheduling to obtain regularized service frequency and associated benefits. Regularized schedules can result in easy-to-remember departure times, matches with regularly scheduled activities, or better coordination at transfer points. Timed transfers minimize transfer wait times and, therefore, reduce total travel times for multi-route passengers.

Reliability Changes. Reliability of service is an issue allied with scheduling. Lack of reliability can take the form of deviations from scheduled arrival and departure times, transit vehicle or train trips missed altogether, or both. Correction reduces passenger wait time, delay and uncertainty.

Rescheduling and frequency adjustments are often included as elements of more extensive transit service modifications. Such combinations are, in the main, discussed in Chapter 10, "Bus Routing and Coverage."

Analytical Considerations

Changes in both individual transit route headways and more broadly based service levels, major aspects of scheduling and frequency, lend themselves to impact quantification using elasticities to describe the response of transit ridership. Elasticities are convenient and useful in this regard, but whether case-specific or generalized, require caution in their interpretation and application (see also Chapter 1, "Introduction," under "Use of the Handbook" — "Concept of Elasticity"). Results of service frequency changes are often not fully distinguishable from the effects of other concurrent service alterations, such that empirically derived elasticities and like measures frequently reflect the influence of other actions.

Similar to the situation in other transit service change topics, much of the more detailed information on scheduling and frequency change effects is old. Available recent findings, however, do suggest that basic relationships between transit service level changes and impacts on ridership are remaining stable over time. Although there are long term social and economic trends that have altered the usage of public transit, interpretation of older data on response to scheduling and frequency changes is not complicated by shifts in travel patterns in the way that raises special concern for evaluation of strategies with a strong spatial component, such as routing changes or system reorientation.

The "unlinked trip" system of reporting transit usage, which counts each boarding whether at the start of a trip or at a transfer point, does not cause problems for interpretation of most scheduling and frequency changes. It does, however, severely complicate evaluation of those timed transfer strategies which involve introduction of routes which terminate at the timed transfer "pulse point," as compared to use of through routing at the "pulse point." Any action which forces transfers increases the unlinked trip count without necessarily increasing the number of transit passengers. Only with *linked* trip survey data or transfer rate information can such service changes be satisfactorily evaluated.

The environment within which a transit service change takes place will affect the results, and this places a special burden on the analyst seeking to judge the transferability of traveler response findings from one situation to another. The handful of cases where local economic conditions have been reported tend to suggest that response to frequency improvements in particular may be significantly affected by the state of the local economy. This and other possible effects of the operating environment are discussed further in the "Underlying Traveler Response Factors" section.

Additional guidance on using the generalizations and examples provided in this Handbook is offered in the "Use of the Handbook" section of Chapter 1. Please note that throughout the Handbook, because of rounding, figures may not sum exactly to totals provided, and percentages may not add to exactly 100.

Traveler Response Summary

The traveler response to service frequency changes varies substantially. Ridership increases proportionately exceeding the frequency increases they are related to have been observed, reflecting an elasticity in excess of +1.0, but not often. Circumstances where frequency improvements failed to attract new ridership at all are also reported. The average response to frequency changes, including both increases and decreases, approximates an elasticity of +0.5 as measured in terms of response to service quantity.[2] Extremely limited information suggests that the hours service is offered can be as important as frequency.

There are underlying patterns that relate to at least some of the widely varying circumstances and results attending individual transit service modifications. Ridership is typically most sensitive to frequency changes when the prior service was infrequent, such as hourly or half-hourly, and when the transit line involved serves middle and upper income areas. Where transit headways are already short, and particularly when lower income service areas are involved, ridership tends to be less affected by frequency changes and may be more sensitive to fare changes. Otherwise, ridership is typically more responsive to frequency changes than fares. There is normally a higher sensitivity to frequency changes on the part of off-peak riders than there is by peak period ridership.

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[2] A service elasticity of +0.5 indicates a 0.5 percent increase (decrease) in ridership in response to each 1 percent service increase (decrease), calculated in infinitesimally small increments. An elastic value is +1.0 or greater and indicates a demand response which is more than proportionate to the change in the impetus. Elasticities reported in this chapter are thought to all be either mid-point arc or log arc elasticities, which are very similar, and if not are almost certainly from other closely equivalent computations (see "Use of Handbook" — "Concept of Elasticity" in Chapter 1, "Introduction," and Appendix A, "Elasticity Discussion and Formulae").

Recent frequency elasticity observations have tended to group around either +0.3 or +1.0. Those that are grouped around +1.0 are suburban systems that have undertaken carefully planned, comprehensive expansion programs, in an atmosphere of good public image and a growing or at least stable economy. A majority but not all of those grouped around +0.3 are central city urban systems.

The greatest concern expressed by transit riders is with dependability of service and with midday and evening service frequencies. When service is reliable, passengers make their actual waits at the transit stop less than random arrivals would imply. Waiting times are more severely affected by service irregularities than might be apparent on the basis of operating data averages, and in addition, riders have been shown to be more sensitive to unpredictable delay than predictable time requirements.

Easy to remember departure times and readily available schedules appear to be significant contributors to achieving a favorable user perception of the wait for low and medium frequency transit service. Limited but consistent examples of ridership gains in response are reported. Timed transfer service design seems to improve rider satisfaction, but patronage effects are indeterminate given presently available data.

Frequency changes affecting individual transit lines typically cause diversion of riders to or from other transit services when alternatives are available, such that the impact on overall transit usage is not as much, and sometimes far less, than the effect on individual route ridership. Frequency and headway elasticities are thus often, in a sense, "inflated" by this phenomenon. On the other hand, the highest observed sensitivities to frequency increases have been in circumstances where diversion from other transit services is not an issue.

In business districts significant numbers of people who previously walked may be attracted by frequency improvements. In general, however, one out of every two or three new riders drawn to transit service by frequency improvements would otherwise have driven an auto, as is the case with transit fare reductions.

RESPONSE BY TYPE OF STRATEGY

Bus Frequency Changes

Increased bus frequency normally attracts increased patronage, and vice versa but with wide variation in results. It has been suggested that available observations do not support a single numerical relationship between service frequency and patronage changes (Holland, 1974). Indeed, measured in terms of service quantity, elasticities calculated for the more recently reported frequency changes group either around an elasticity of +0.3 or around +1.0, the threshold of elastic response. Nevertheless, both historical and more recent elasticities of bus service changes exhibit a service elasticity *average* that is on the order of +0.5. There is not enough information to address whether there are differences in proportionate response between increases and decreases in service, though it happens that none of the highest elasticities reported pertain to service decreases.

The substantial variations in reported ridership responses are attributable in part to the widely varying circumstances attending individual bus route and system headway changes. The variables involved include the pre-existing level of transit service, the geographic and demographic environment, and the time period of the day or week. There is evidence that some of these variables affect ridership response in a predictable way, especially pre-existing frequencies and time of day (Holland, 1974; Mayworm, Lago and McEnroe, 1980). Complexities are added by the frequent presence of concurrent actions (such as fare changes or service extensions), and by other aspects of the operating environment, examined in the "Underlying Traveler Response Factors" section. (Combined impacts of concurrent actions may provide opportunities, it should be noted, for obtaining desired outcomes.)

Another confounding factor is that some ridership changes in response to frequency changes reflect primarily diversion of riders from one route to another (route choice), rather than diversion from one mode to another (mode choice, such as between auto and transit). The sensitivity of overall transit usage to route frequency changes is less than would be indicated by route level elasticities derived where significant shifting among routes has occurred (Miller and Crowley, 1989). Elasticities "inflated" by passengers who merely shifted routes are among those reported in the literature and used in drawing generalizations. Nevertheless, in essentially none of the recent observations of service frequency elasticities in excess of +1.0 is route shifting a significant factor, although there are certainly other influences at work.

Historical Data

The Mass Transportation Commission of the Commonwealth of Massachusetts performed a variety of mass transit service improvement and fare reduction experiments in the early 1960s that provide what is still the most extensive quasi-experimental data set available on individual transit route frequency change impacts. Full coverage of the experiments is provided in the case study "Mass Transportation Demonstration Projects in Massachusetts." Mid-point arc headway elasticities calculated from individual Massachusetts demonstration project results (Mass Transportation Commission et al., 1964) are presented in Table 9-1 along with other reported 1960s and 1970s headway elasticity findings (Holland, 1974; Mayworm, Lago and McEnroe, 1980). Note that headway elasticities are negative.[3]

The median headway elasticity among those derived from the Massachusetts experiments is -0.4, or -0.6 omitting depressed urban areas. There are indications that due to data limitations, these elasticities may have somewhat understated the long term potential for ridership gains in the study area.[4] The other pre-1980 elasticities reported in Table 9-1 (and Table 9-6 "Fare and Service Elasticities") average -0.5 (expressed as headway elasticities).

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[3] The measure "headway elasticity" indicates the percentage change in ridership observed or expected in response to a 1 percent change in the headway. The negative sign indicates that the effect operates in the opposite direction from the cause. Thus a headway elasticity of -0.50, for example, indicates that a 1 percent decrease in headway has caused or is expected to cause a 0.50 percent gain in ridership. (See also footnote 2, under "Overview and Summary" — "Traveler Response Summary.") Service elasticity and headway elasticity are both used to express the degree of transit ridership response to frequency changes. Those calculated by the authors of this Handbook and presumably all other sources have been derived using arc elasticity formulae that give the same elasticity value (except for sign) for both service — expressed in bus trips, miles or hours — and headway.

[4] There are several reasons these elasticities may be somewhat understated. For one thing, the Massachusetts experiments were short — 3 to 12 months in duration. Also, the elasticities were calculated on the basis of revenue, "before" ridership data not having been reported. In cases where smaller fares were changed for shorter trips, there may have been more of a ridership increase than revenue increase, because indications are that service improvements attract proportionately more short trips than long trips.

Table 9-1 Bus Route or Small System Headway Elasticities Observed in the 1960s/70s

Route / Service Territory	Headway Elasticity	Months After Implementation
Massachusetts Demonstrations[a]		
Boston-Milford suburban route (new headway approx. hourly)	-0.4	10-12
Uxbridge-Worcester suburban route (new headway hourly)	-0.2	7-9
Adams-Williamstown city route (new headway approx. hourly)	-0.6	1-3
Pittsfield city route (raised from 3 to 8 round trips daily)	-0.7	1-3
Pittsfield city route (raised from 10 to 15 round trips daily)	-0.6	1-3
Newburyport-Amesbury (depressed area) city route (new headway 30 min. peak/60 min. midday)[b]	-0.4	6-8
Fall River (depressed area) city service (overall 20 percent service increase)	nil	4-6
Fitchburg-Leominster city route (new afternoon headway 10 min., to match morning)[b,c]	-0.3	6-8
Boston downtown distributor, Phase 1 (new midday headway 5 min., to match peak)[c]	-0.8	5-7
Boston downtown distributor, Phase 2 (new headway 4 min. base, 8 min. midday)[c]	-0.6	8-10
Boston rapid transit feeder route (new midday headway 5 min., to match peak)[c]	-0.1	4-6
Other Contemporary Findings		
Detroit city route (new headway 2 min. peak, 3.5 min. midday)	-0.2	—
Chesapeake, VA, suburban service (new headway 35 to 42 min.)	-0.8	—
Stevenage, England (peak period/off-peak; new headway 5 min.)	-0.4/-0.3	—
Madison, WI, circulator routes (Saturday/Sunday; new headway 20/30 minutes)	-0.2/-0.6	—

Notes:
[a] Mid-point arc elasticity calculated on the basis of revenue.
[b] Includes impact of minor route extension.
[c] Approximate elasticity computed for full service day by using an unweighted average of peak and off-peak (or morning and afternoon) headway improvements.

Sources: Massachusetts Demonstrations — Mass Transportation Commission et al. (1964).
Massachusetts elasticity calculations — Pratt, Pedersen and Mather (1977).
Other Findings — Holland (1974), Mayworm, Lago and McEnroe (1980).

Differentiation by Service Level

A 1980 exploration of the causes of headway elasticity variations utilized a data set produced from essentially the same case studies as those listed in Table 9-1, but designed to give non-Massachusetts sites somewhat more emphasis. Separate calculations were made, where possible, of peak and off-peak headway elasticities. These, along with all-day elasticities, produced 23 separate mid-point arc elasticity values. The resulting headway elasticity averages, stratified by original bus service level, are listed in Table 9-2. The results clearly indicate a greater sensitivity to frequency changes for cases where the prior service was infrequent. The average headway elasticity for all observations was -0.44, or -0.47 including only those seven observations pertaining to all weekday hours, peak and off-peak (Lago, Mayworm and McEnroe, 1981). (For stratification by time period, see "Temporal Ridership Patterns" under "Related Information and Impacts".)

Table 9-2 Bus Route Headway Elasticities Stratified by Original Service Level

Original Service Level (Headway)	Number of Observations	Arc (Mid-point) Elasticity	Standard Deviation
Less than 10 minutes	7	-0.22	±0.10
10 to 50 minutes	6	-0.46	±0.18
Greater than 50 min.	10	-0.58	±0.19
All observations	23	-0.44	±0.22

Source: Lago, Mayworm and McEnroe (1981).

More Recent Experience

Observations of frequency change results and corresponding arc elasticities from the 1980s and 1990s are summarized in Table 9-3, followed by brief descriptions of selected examples. All but two of these elasticities are computed on the basis of service quantity rather than headway, and thus have positive rather than negative signs, but are otherwise comparable to the elasticities in Tables 9-1 and 9-2. The elasticities reported in Table 9-3 (along with post-1980 bus elasticities from Table 9-6 "Fare and Service Elasticities") average slightly above +0.5 (expressed as a service elasticity).[5]

The results for systemwide evaluations are of special interest. They tend to reflect change in overall transit usage, without being confounded by route-specific effects, which may reflect shifts from one route to another without a corresponding change in transit mode share. The Santa Clarita and Charlottesville examples are perhaps the most free of confounding route choice effects, although the Santa Clarita example does have service hours enhancements mixed with the frequency improvements.

[5] Updated indication that elasticities for individual routes with intermediate to infrequent service tend toward the upper values of the normal range is offered by Dallas Area Rapid Transit (DART) crosstown route service elasticities in the range of +0.9 to +1.0 for both peak and off-peak frequency increases (Hufstedler, 2004). The type of route may be an additional factor in the rider response.

Table 9-3 Bus Service Elasticities for Frequency Changes Observed in the 1980s/90s

Transit System or Route	Time Span	Headway Change (Minutes)	Service Measure	Arc Elasticity	Notes and Comments
Vancouver, WA to Portland, OR	1980	Mixed, e.g., 19-23 to 10-15; AM peak	Peak buses	+0.33 (all hours)	See description below
Charlottesville [VA] Transit System	1980-1981	From 60 to 30 in peak periods	Vehicle miles	+0.33 (all hours)	See description below
Mt. Pleasant bus route, Toronto, ON	Sept.-Nov. 1987	From 10 to 15 in peak periods and 15 to 30 evening	Headway	-0.47 pk. -0.29 off-peak	See description below and case study
Tasta to central Stavanger, Norway	early 1990s	From 30 to 15	Headway	-0.26	Headway measure gives negative sign
Santa Clarita [CA] Transit (local fixed route system)	1992/93 - 1997/98	Primarily 60 to 30 with service hours enhancements	Service (bus) hours	+1.14 (all hours)	See description below and case study
Foothill Transit, L.A., CA (system)	1993-96	Various, plus new weekend service	Service hours	+1.03 (all hours)	Frequency upped on all lines
Community Transit (Snohomish County system, WA)	1994-96	Primarily 60 to 30 plus new services as well	Service hours	Over +1.0 (see notes)	Confounding factors include U of W "U-Pass" introduction
Santa Monica, CA Big Blue Bus system	1996-98	Various, plus some new service	Service hours	+0.82 (all hours)	See description below
Lincoln Blvd. route Santa Monica, CA	March - Sept. 1998	20 to 10 (40 to 10 on link to LAX)	Service hours	+0.97	6AM-6PM; see description below

Note: Elasticities are log arc formulation, except Toronto is mid-point arc.

Sources: Vancouver, WA — Public Technologies (Sept., 1980); Charlottesville, VA — SG Associates and Transportation Behavior Consultants (1982); Toronto — Miller and Crowley (1989); Norway — Lunden (1993); Santa Clarita — Kilcoyne (1998a and b) and Santa Clarita Transit (1993-1998); Foothill Transit and Community Transit — Stanley, 1998; Santa Monica — Catoe (1998); all elasticity calculations except Toronto by Handbook authors.

Individual Examples

The more recent U.S. service elasticity experience with a frequency emphasis begins with a Service and Methods Demonstration (SMD) project in effect from late 1979 to mid-1980. To promote transit on the route connecting Vancouver, Washington, with downtown Portland, Oregon, the Vancouver transit operator decreased average headway during peak periods and extended operating hours. Starting in February 1980, the number of morning buses was increased from 10 to 14, decreasing the headway of 19 to 23 minutes to between 10 and 15 minutes. The number of afternoon buses was increased from 6 to 15, and the hours of service were expanded from 6:18 PM to 9:33 PM. Service was extended along two branches to provide a feeder component. Daily ridership increased from 1,400 to over 1,700 (Public Technologies, Sept., 1980). Attributing the ridership increase to the added number of buses, the Handbook authors calculate a resulting log arc service elasticity of +0.33.

A system that has focused local bus service expansion primarily on frequency and service hours enhancements is Santa Clarita Transit, serving outlying suburbs of Los Angeles. Local service revenue hours were increased by 66 percent and miles by 99 percent in the five years from FY 1992-93 through FY 1997-98. Service improvements, accompanied by limited route adjustments and extensions, featured expanded weekday and Saturday service hours, addition of Sunday service, and effectively a doubling of frequencies on a majority of routes. The affected routes originally had only hourly service with some 30-minute combinations. Local ridership growth, 120 percent, has exceeded the service growth. The corresponding bus hours log arc elasticity is +1.14, and the bus miles elasticity is even higher (Kilcoyne, 1998a and b; Santa Clarita Transit, 1993-1998; elasticity calculations by Handbook authors). Population growth was modest during this period. The case study "Frequency and Service Hours Enhancements in Santa Clarita, California" provides further background and details.

A contrasting experience is offered by Charlottesville, Virginia. There the hourly service frequency was doubled in peak periods, extensive route restructuring was undertaken, and two new routes were added. While daily vehicle miles increased 110 percent, ridership went up a modest 28 percent over a one year period, exhibiting a service miles log arc elasticity of +0.33. The failure of ridership to increase in proportion to service was ascribed to a largely fixed market consisting primarily of transit dependents. However, it was also reported that the 6 to 21 year old buses were unreliable and that for several restructured routes, the original pattern had generated better ridership. Service was returned to an hourly headway and a design close to the original configuration (SG Associates and Transportation Behavior Consultants, 1982; elasticity calculation by Handbook authors).

Another Los Angeles area system undertaking frequency enhancement is Santa Monica Municipal Bus Lines. In March 1998 the "Big Blue Bus Line" upped the 6:00 AM to 6:00 PM frequency on its Lincoln Boulevard route, which connects the Los Angeles International Airport (LAX) with downtown Santa Monica, from a 20 to a 10 minute headway. Simultaneously, frequency on the relatively new route extension connecting with the LAMTA cross-county Green Line Light Rail was upped from a 40 to a 10 minute headway. Peak and midday route performance was 66.1 boardings per service hour before the changes. This performance statistic was already back up to 64.5 after five months, equivalent to a service elasticity of approximately +0.97. The Lincoln Boulevard route has benefited from diversion of ridership, via the Green Line, from LAMTA bus services connecting Los Angeles with oceanfront communities. It has also been the beneficiary of new travel agency advertisements identifying the Lincoln Boulevard route as a means of getting from LAX to Santa Monica and area attractions.

Rather than being an anomaly, the Lincoln Boulevard improvements are part of a Big Blue Bus Line expansion that has increased service by 23 percent systemwide since 1996. Guided by public input, and a goal of system simplicity, this service increase has been about 90 percent frequency enhancements and 10 percent routing adjustments. Boardings per service hour were 65 in 1996 and 63 in 1998, indicating a log arc service elasticity of +0.82. The response to service expansion is thought to have been enhanced by a major image building campaign and benefited from a rebounding local economy (Catoe, 1998; elasticity calculations by Handbook authors).

A panel survey of transit riders in suburban Toronto was used to study response to changes in headway on the Mt. Pleasant Road trolleybus route. Peak-period mid-point arc headway elasticities for the route were determined to be higher in this case (-0.47) then off-peak headway elasticities (-0.29) (Miller and Crowley, 1989). This result — higher peak than off-peak elasticities — is not typical. It may reflect the circumstance that the "off-peak" service reduction involved evening service only. Midday service was unchanged and omitted from the elasticity calculations. Of more import is the shifting among transit routes demonstrated by this study (see both "Mode Shifts and Sources of New Ridership" under "Related Information and Impacts" and the case study "Mt. Pleasant Bus Route Service Reduction in Toronto — Panel Survey" for further information).

For additional estimates of service elasticities, based primarily on time-series data, refer to the "Frequency Changes with Fare Changes" subsection.

Sensitivity Indicators

It may be concluded that response to bus service frequency improvements tends to be greatest when the prior frequency was less than three buses or so per hour (Pratt and Bevis, 1971), when the route involved serves middle and upper income areas (Holland, 1974), when the travel market involved is predominantly comprised of trips short enough that walking is an option, and when other factors are favorable (see "Underlying Traveler Response Factors" — "Physical, Operating and Economic Environment"). The response to service frequency changes is apparently least when the service modifications primarily affect lower income areas, when the prior service was relatively frequent, and when the travel market served is characterized by long trips.

Train Frequency Changes

Aside from providing new facilities or lower fares, fixed rail systems are for the most part restricted to scheduling and frequency changes as a form of service improvement. The available quasi-experimental data on passenger response are mostly in the realm of commuter rail operation. Described in terms of the factors identified above as influencing response to bus frequency changes, commuter rail lines typically serve middle and upper income areas. Although they have relatively long time intervals between trains, they also predominantly serve long trips. Thus an average or somewhat above average response to service changes might be expected if there is a correlation between bus and commuter rail service impact.

Commuter Rail Demonstrations

Listed in Table 9-4 are the ridership impacts of demonstration project service changes in three Northeast applications. Marketing activities were involved in all cases, as were certain off-peak fare incentives in the Boston experiments. Fares were *increased* in the Philadelphia demonstration (Mass Transportation Commission et al., 1964; Southeastern Pennsylvania Transportation Authority, 1971). The computed service elasticities range from +0.5 to +0.9, which indeed reflect average to above average sensitivity to service levels. (Further detail on the Boston experiences is provided in the case study "Mass Transportation Demonstration Projects in Massachusetts.")

In the Philadelphia demonstration, average trip length increased by 5.8 percent (Southeastern Pennsylvania Transportation Authority, 1971), resulting in a mid-point arc elasticity with respect to passengers miles of +1.6. One interpretation is that long commuter rail trips may be more sensitive to service levels than shorter trips; another is that the longer trips may have involved travel on services with poorer initial frequencies.

Table 9-4 Commuter Rail Demonstration Project Impacts and Overall Service Elasticities

Location	Railroad	Demonstration Phase	Increase in Service	Increase in Ridership	Implied Arc Elasticity
Philadelphia	Reading	Final	9.2%	8.6%	+0.9
Boston	Boston & Maine	2	77%	37.5%	+0.6
Boston	New Haven	2	26%	11.5%	+0.5

Note: Mid-point arc elasticities; calculated disregarding effects of fare changes and marketing.

Sources: Philadelphia Demonstration — Southeastern Pennsylvania Transportation Authority (1971); Massachusetts Demonstrations — Mass Transportation Commission et al. (1964); elasticity calculations — Pratt, Pedersen and Mather (1977).

The longer commuter rail lines in Boston were likewise associated with greater traveler response to headway changes than the shorter lines.[6] In Boston, it was also specifically observed that the ridership response was greater for the lines with the poorer pre-demonstration service levels (Mayworm, Lago and McEnroe, 1980). Table 9-5 presents a summary by original service level of commuter-rail elasticities estimated from the five-corridor demonstration in the Boston area in 1962-64 (Lago, Mayworm and McEnroe, 1981).

Table 9-5 Individual Commuter Rail Service Elasticities from the Boston Area Demonstration

Original Service Level (Headway)	Number of Observations	Arc (Mid-point) Elasticity	Standard Deviation
10 to 50 minutes	11	-0.41	±0.13
Greater than 50 minutes	4	-0.76	±0.10
All observations	15	-0.50	±0.20

Source: Lago, Mayworm and McEnroe (1981).

Results obtained in the New York City area, although not directly comparable, appear to be consistent with the primary Philadelphia and Boston findings (Tri-State, 1966). Overall, these data tend to suggest that commuter rail patronage responses to frequency changes are in the same general realm as bus ridership responses on routes with similar demographics and original service frequencies.

Rail Rapid Transit (Metro)

In contrast to commuter rail, time series based estimates by London Transport indicate that rail rapid transit, in the instance of the London Underground, has a lower sensitivity to frequency changes than bus. As presented under "Frequency Changes with Fare Changes," the

[6] These limited observations are not in direct conflict with the apparently greater sensitivity of short versus long bus trips to headway changes. Very short trips via bus are an alternate to the walk mode and this is not the case with any normal length commuter rail trip.

Underground exhibits a miles operated service elasticity of +0.08, just under half that for London buses (London Transport, 1993). This general relationship is as would be expected, given the much higher overall service levels typical of rail rapid transit. This being only one observation, however, it provides insufficient evidence to safely generalize that rail rapid transit service elasticities will average on the order of half those for bus frequency changes, even though a comparable conclusion can reasonably be reached for fare elasticities.

Service Hours Changes

Service hours changes are quite distinct from frequency changes, but their effect is not often identified separately. For example, a significant part of improvements undertaken by Santa Clarita Transit in California from 1992 to 1998 consisted of service hours expansions; later weekday and Saturday operating hours and addition of Sunday service. Yet frequency enhancements were a larger part of the added bus hours of service. The one impact assessment conclusion that can be reasonably drawn is that both types of actions must have contributed substantially to the outstanding ridership response, reflected in a service elasticity of +1.14 (see "Bus Frequency Changes" and the case study "Frequency and Service Hours Enhancements in Santa Clarita, California").

Additional perspective is provided by a package of suburban transit service enhancements initiated in 1994-95 by New Jersey Transit (NJT). Out of 40 projects, including 15 involving expansion or introduction of evening and weekend service, 23 were retained after the trial period. The success rate for evening and weekend service enhancements was well above the 40-project average.

One successful NJT example was bus Route 59, connecting Newark and Elizabeth and extending to the smaller city of Plainfield through wealthier suburbs. Saturday service hours were expanded and Sunday service, discontinued over two decades before, was restored with hourly headways between 8:00 AM and 6:00 PM. After two years the route was attracting some 1,100 boardings on a typical Sunday, compared to 5,700 on weekdays and 3,100 on Saturdays. About 45 passengers per Sunday one-way trip were served at a farebox recovery ratio of 46.8 percent. Another successful example involved commuter rail service on the Main/Bergen County line. Two trips were added on Saturday, two more were extended, and six round trips were added to Sunday service. The annual ridership for this additional weekend service was 73,473 after two years, with a farebox recovery ratio of 52 percent (Michael Baker et al., 1997).

Extended evening service may, on peak-period-only commuter routes, consist of as little as one trip added after the evening rush hour to serve stragglers. A classic example was documented in the early days of bus service to the new town of Reston, Virginia. A bus was added in 1970 to pick up late passengers in downtown Washington between 7:00 and 7:26 PM. Ridership on the bus varied between 15 and 20 passengers per trip, but more than 80 new riders were attracted to the system. These riders needed the assurance that they would not be stranded at their workplace by a late meeting or other delay (Furniss, 1977).[7]

[7] Two newer instances have been reported of general ridership increase upon introducing evening or weekend service. Whatcom Transportation Authority obtained a significant increase in a time of static ridership by introducing a single evening route connecting Western Washington University with other major generators in its Bellingham service area (Elmore-Yalch, 1998). In Dallas a group of suburban shuttles exhibited a discernible *weekday* ridership increase, to 4,400 weekday riders in total, in response to introduction of Saturday service that carried 1,400 riders (Hufstedler, 2004).

Frequency Changes with Fare Changes

Frequency Versus Fare Sensitivities

Results of urban transit frequency changes implemented in connection with fare changes suggest that either type of change may have the greater impact depending on circumstances. Statistical analysis covering two years of fare and service changes in greater Dallas revealed greater sensitivity to fares than service in the center city, and the converse in the suburbs, for both suburban express and local services (Allen, 1991). The added ridership attracted by an experimental bus frequency increase of approximately 25 percent in Fitchburg, Massachusetts, was effectively nullified by a 25 percent fare increase (Mass Transportation Commission et al., 1964). Additional background and findings on the Dallas fare and service changes are provided in the case study "Fare and Frequency Changes in Metropolitan Dallas."

The direct comparisons between observed fare and service elasticities shown in Table 9-6 for Dallas, San Diego and London, developed using time series data, are thought to reflect primarily service frequency adjustments as contrasted to routing and coverage changes. An exception is "San Diego...(all bus routes)," which is shown for comparison.

Table 9-6 Fare and Service Elasticities for Dallas, San Diego and London

	Fare Elasticity	Service Elasticity	Service Measure
Dallas (1985-1987)			
urban bus (DTS)	-0.35	+ 0.32	bus revenue miles
suburban express bus	-0.26	+ 0.38	
suburban local	-0.25	+ 0.36	
San Diego (1972-1975)			
(all bus routes)	(-0.51)	(+0.85)	bus miles
established bus routes	-0.67	+ 0.65	
London (1971-1990)			
bus	-0.35	+ 0.18	operated miles
Underground (Metro)	-0.17	+ 0.08	

Sources: Allen (1991); Goodman, Green and Beesley (1977); London Transport (1993).

When results for frequency changes with fare changes are taken in conjunction with other frequency, fare and service change results, additional conclusions may be inferred. Ridership appears likely to be more sensitive to fare changes than frequency changes where frequency levels are high. Conversely, response to service changes is almost always greater than to fare changes of similar magnitude where service levels are low and especially when new routing, coverage or express service is involved. (See Chapter 10, "Bus Routing and Coverage," under "Response by Type of Service and Strategy" — "Service Changes with Fare Changes," and also Chapter 4, "Busways, BRT and Express Bus" — "Underlying Traveler Response Factors" — "Service Coverage and Frequency.")

Mutually Reinforcing Fare and Frequency Changes

Fare increases together with service reductions obviously lead to ridership loss at the same time as they offer cost savings potential. In the District of Columbia, institution of a 25¢ Metrorail to bus transfer charge and an increase of approximately 70 percent in elderly and disabled and other reduced fares, along with service reductions, led to a bus ridership decline of 11 percent on weekdays and 14 percent on weekends averaged over the first 2 full months. Corresponding bus revenues were up by 6 percent on weekdays, but down 3 percent on weekends. Two-thirds of the bus ridership loss was attributed to the service reductions, which included route eliminations and consolidations in addition to frequency reductions (Washington Metropolitan Area Transit Authority, 1995).

Dallas fare increases approaching 50 percent, coupled in the same year with a 16 percent decrease in service, mostly frequency reductions, were accompanied by a 16.5 percent ridership loss and a 20 percent revenue gain. Part of the loss was attributed to a local economic downturn. Three previous years of service increases, initiated with a 29 percent base fare reduction, had afforded almost a 50 percent ridership gain (Allen, 1991). (See also the case study "Fare and Frequency Changes in Metropolitan Dallas.")

Commuter Rail

Indications are that the typical commuter railroad patron is much more influenced by service frequency than by fares, although findings are not entirely consistent. The first phase of 1960's era Boston & Maine demonstrations included both fare decreases (28 percent) and service increases (77 percent). Overall Phase 1 patronage rose 27 percent, but the increase on two individual lines which received only fare reductions was a mere three percent. Although most fares were raised in Phase 2, ridership continued upward. The experience on Boston area lines of the New Haven Railroad was comparable (Mass Transportation Commission et al., 1964), and an 11 percent fare increase as part of the Philadelphia area Reading Company demonstration similarly failed to erase positive patronage response to service frequency improvement (Southeastern Pennsylvania Transportation Authority, 1971).

On the other hand, cross-sectional model adjustment based on time series data from Maryland's MARC Brunswick line suggested that 1993-94 log arc fare elasticity may have been on the order of -0.70, 25 percent higher than the modeled sensitivity to a frequency improvement focused outside the peak. This is a corridor with highly competitive travel options. Evidence from the other two MARC lines was inconclusive (Parsons Brinckerhoff et al., 1994, unpublished worksheets).

Combined Service Frequencies

Some transit service improvement actions involve deployment of buses to serve a given street or closely defined corridor in an operating mode differing from the pre-existing or alternative service. Overlaying express bus routes on existing local routes is an example. In such cases it cannot strictly be said that the frequency of service has been changed in proportion to the new bus runs, and some riders may not benefit from the new service. Other riders, however, obtain increased options with additional amenities such as express speed.

Express Service Options

In situations where the provision of new or expanded express bus service has resulted in increased overall frequency of service from residential areas to the central business district (CBD), ridership increases have exhibited service elasticities on the order of +0.9. These findings suggest that where express service is appropriate, a combination of increased service and express runs may attract additional patronage — possibly half again as much — as would a similar bus trip increase applied to local service alone. Further detail on frequency changes with express service is contained in Chapter 4, "Busways, BRT and Express Bus."

Transfer Versus No Transfer

When differing services are coordinated to provide a useful combined frequency, some passengers appear governed in the choice of their transit trip by the departure and arrival times, and others appear governed by the other characteristics of the service offered. In rural England, a study was made of local transit travel under circumstances of combined frequency. Riders were offered hourly service alternating between a through trip and a trip requiring one transfer. If departure/arrival time governed, 50 percent of the riders would be expected to use the transfer service. If other trip characteristics governed, none of the riders would be expected to use it. In actual practice 24 percent elected to use the service requiring the transfer (Tebb, 1977).

In Oslo, Norway, surveyed riders were found willing to accept longer journey times to avoid transfers. Regular riders indicated willingness to accept 8-10 minutes more journey time or to pay NOK 2.25 (about $0.33 at the time) in order to avoid switching to a waiting vehicle. In cases where a 5-minute wait for the next connection was required, passengers were found willing to accept a 14 minute increase in journey time or to pay NOK 4.00 to avoid the transfer (Stangeby, 1993).

Regularized Schedule

Minimizing Passenger Wait Times

A number of travel demand analyses have shown that while the average wait for local, often irregularly scheduled bus service can be adequately described for travel estimation purposes as one-half the headway, the average wait for commuter rail service cannot (Parsons Brinckerhoff et al., 1994). The wait for commuter trains is apparently perceived by the potential commuter as being some lesser amount. Readily available schedules and long-term dependability of service, allowing one to minimize wait at the station, are presumably major factors in this favorable perception of commuter rail scheduling. (This phenomenon is further discussed in Chapter 8, "Commuter Rail." See the "Underlying Traveler Response Factors" section in particular.)

With the right kind of systematic, easy to remember and well-advertised bus schedule, effects similar to those in rail might be possible to engender (Pratt and Bevis, 1971). Hard information on actual response to provision of easily remembered departure times is extremely scarce, although anecdotal evidence is reported of appreciable gains in ridership when schedules have been reorganized to give simple "clockface" timings, for example, where buses always arrive at 10 minutes, 30 minutes and 50 minutes after each hour (Webster and Bly, 1980).

It is notable that many successful restructurings of small city bus service and midday commuter service have employed "clockface" scheduling as one aspect of the overall design (Dueker and Stoner, 1972; Dueker and Stoner, 1971; Mass Transportation Commission et al., 1964; Tri-State, 1966). The case study "A Combined Program of Improvements with Fare Changes in Iowa City," in Chapter 10, "Bus Routing and Coverage," describes an example.

A documented case involving Omnitrans in Riverside, California, entailed both route and schedule restructuring. The restructuring was accomplished in the Fall of 1995 within the constraint that total bus service hours not be increased by more than 4 percent. Ridership increased by 20.4 percent over the prior year. Route restructuring focused on enhancing direct travel. The schedule restructuring emphasized consistency and ease of transfer, in addition to providing increased frequency on heavily traveled routes within the service hours constraint. All schedules were standardized to be on 15-, 30- or 60-minute on-the-hour headways (Stanley, 1998).[8]

Minimizing Transfer Times

Transfer centers are a popular means of facilitating suburban and smaller city transit service as well as making transfers between routes more convenient. While transfer centers can make it easier to institute scheduling enhancements such as coordinated transfers, they are often created for other reasons.

In a survey conducted by the Institute of Transportation Engineers of 10 transit transfer centers throughout the United States, only 3 indicated that increasing ridership was a primary objective of the facility. Common objectives were to provide a rest area for operators, enhance the public's image of transit, provide a civic facility, aid downtown development or revitalization, provide riders with protection from weather and a better waiting environment, reduce the potential for accidents, and enhance passenger convenience. Half the centers reported that they had no impact on transit ridership, while the other half had positive ridership impacts (Hocking, 1990).

While the presence of a transfer center may make it easier to operate coordinated transfer schedules, also known as timed-transfers, it is the interplay between route design and scheduling that is crucial. The timed-transfer concept utilizes timed connections at a point where routes are focused in order to minimize the wait time and irregularity involved in the transfer between lines. The connecting transit routes must be designed within route running time parameters that facilitate timed-transfer scheduling. Route length, traffic conditions and passenger activity determine run time, and run time determines ability to make a complete bus trip and still maintain timed-transfer meets and bus layover time requirements.

To serve fringe areas in a timed-transfer system, a trunk line generally operates with a regular service frequency throughout the day and connects with local timed-transfer lines at a transit center located in the suburban community. This technique eliminates the need to dedicate transit equipment of each suburban route to the costly run between the suburban center and downtown. In smaller cities all routes may be local timed-transfer routes focused on a downtown center and perhaps one or two other activity nodes. The timed-transfer especially benefits passengers who must use more than one bus line to complete their trips.

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[8] For an example and discussion of a strong favorable response to doubling an evening peak period "clockface" feeder bus schedule to match the "clockface" schedule of the rail line served, for benefit of riders returning home, see Chapter 7, "Light Rail Transit," under "Related Information and Impacts" — "Mode of Access and Egress to Rail Service" — "Feeder Service Effects."

Timed-Transfer Findings

In Portland, Oregon's Westside community, two transit centers were used as part of a network redesign. A timed-transfer system was successfully implemented in the summer of 1979. Departure times from the transit centers were consistent throughout each day. A high degree of service reliability could be maintained, and schedule efficiency was improved. Ridership in both the peak and off-peak periods increased significantly. By the spring of 1980, daily ridership had increased 40 percent to 13,808. The new service influenced travel patterns. Local trips and non-work trips accounted for the largest increases. In certain areas, local trips increased by 138 percent, and non-work trips increased by 68 percent. Travel to downtown Portland increased by 12 percent. However, it is important to note that the 1979 gasoline shortage occurred during the changes (Kyte, Stanley and Gleason, 1982; Charles River Associates, 1997).

In other studies of timed-transfer networks, direct ridership impacts were less apparent. The Urban Mass Transit Administration, in 1983, reviewed the design and cost effectiveness of timed-transfer networks in Ann Arbor, Michigan, and Boulder, Colorado. Large increases in unlinked trips (bus boardings) for the systems were found. However, the study could not determine the extent to which the increases were caused by actual new ridership as compared to the increased transfer boardings inherent in certain timed-transfer designs (Newman, Bebendorf and McNally, 1983).

In a study of the Tidewater region in Norfolk, Virginia, improvements in the perceptions of riders were found to be the principal impact of the implementation of a timed-transfer system. From 1989 to 1991, an elaborate multiple hub system was put in place to reduce the required operating subsidies. The resulting service had between two and six routes meeting at a location. Between 40 and 45 percent of bus trips involved a transfer. Of surveyed riders, the majority felt service quality was improved with the implementation of the timed-transfer system, 77 percent felt schedules had improved, and 71 percent experienced decreased travel times. Over two-thirds thought the reliability of service increased. A decrease in ridership was attributed to several factors unrelated to timed transfer, including fluctuation in the resident military population, so it was difficult to determine the ridership response to the timed-transfer system (Charles River Associates, 1997; Rosenbloom, 1998).

Transit Reliability Changes

A service improvement even more fundamental than schedule enhancement is the achievement of reliability, so that whatever schedules are established are adhered to. Unreliable transit service may result from either environmental factors alone, or in combination with inherent factors. Environmental factors include fluctuating traffic conditions, traffic signals, variations in boarding/alighting demand and availability of drivers and vehicles. Inherent factors aggravate initial deviations from scheduled headways. Platooning, for example, results when late vehicles encounter increased passenger loads at subsequent stops, producing additional delay, while following or early vehicles encounter decreased loads, causing them to be further ahead. Dependable service avoids the reductions in effective frequency that accrue from missed runs, platooning of vehicles, and other unplanned deviations from schedules (Abkowitz, 1978).

Attitudinal studies of commuters in Baltimore and Philadelphia early on found "arrival at intended time" to be perceived as the second most important travel attribute for work trips. Only "arrival without accident" was judged by respondents to be more important out of over 35 attributes listed. Similar surveys in Boston and Chicago placed "arrival at intended time" above travel time, waiting time and cost measures. For non-work trips reliability was judged not as important, although it still ranked eighth on the list (Golob et al., 1970; Paine et al., 1967).

Effects on Wait Time

Increased reliability results in actual transit vehicle arrival times occurring in a tighter distribution around the scheduled time. The range of actual vehicle arrival times at the beginning and end of a trip, and at transfer points, determines the wait time, the overall travel time and the likelihood of missed connections and late arrivals that a rider faces. Maintenance of on-time service has a positive effect on riders and ridership because patrons experience less waiting, decreased travel time, fewer missed connections, more on-time arrivals at their destinations, and reduced uncertainty overall.

Waiting times, even for a frequent service, are affected more substantially by service irregularities than the average headway achieved would indicate. Passengers of frequent services arrive more or less continually at the transit stop. Consequently, a larger number of passengers are adversely affected by long unscheduled gaps between buses and trains than are benefited by corresponding short gaps. Table 9-7 lists the percentage of passenger wait time in excess of the optimum

Table 9-7 Reliability Impacts on Wait Time for Individual New York City Bus Routes

NYCTA Bus Route	Waiting Time Index	Wait in Excess of Optimum (%)
B46	0.58	+72%
M7	0.58	72
B35	0.62	61
M4	0.65	54
BX41	0.68	47
M3	0.69	45
M16	0.66	52
M2	0.72	39
Q32	0.68	47
M34	0.68	47
M11	0.77	30
BX55	0.79	26
BX28	0.81	23
M79	0.82	22
BX30	0.95	5

Note: The Waiting Time Index is the minimum average wait (assuming passengers arrive without reference to the schedule), divided by the actual average wait (calculated using the same assumption). The Wait in Excess of Optimum is the actual average wait less the minimum average wait, divided by the minimum average wait, and expressed as a percentage.

Source: N.Y. State Office of the Inspector General for the MTA as graphed in Henderson, Kwong and Atkins (1991), with excess wait calculations by the Handbook authors.

achievable with full schedule adherence, for 15 New York City Transit Authority bus routes. The passenger wait time is calculated on the basis of actual bus arrivals assuming random passenger arrivals (Henderson, Kwong and Atkins, 1991).

Schedule reliability is in fact demonstrated to save regular commuters even more time than the assumption of random passenger arrivals at the transit stop would indicate. A study of ten bus stops in London found that where bus arrival times were consistent, passenger waiting times tended to be less than that expected based on random arrivals. Passengers were benefiting by setting their arrival time to coincide with bus arrival times. Where service was inconsistent, waiting times more nearly approximated times based on random arrivals (Jolliffe and Hutchinson, 1975). Table 9-8 lists transit and passenger statistics for the bus stops with the most reliable and least reliable service of the 10 examined.

Table 9-8 Observed London Bus Headway Reliability and Passenger Wait Times

	Scheduled Headway	Observed Headway	Standard Deviation	Waiting Time for Random Arrivals	Observed Waiting Time
Stop with most reliable service	23.0	23.9	2.2	12.9	5.8
Stop with least reliable service	20.3	23.5	10.7	14.0	13.1

Source: Abkowitz et al. (1978).

Other work suggests an even greater effect if vehicle-miles are lost from an otherwise perfectly reliable service. On high frequency services, if 10 percent of the buses are cut randomly, average passenger waiting time will increase by 20 percent. For services with long headways, an even larger effect is predicted. Since passengers tend to schedule their arrival especially for infrequent services, a missing bus means waiting an entire extra headway interval (Webster and Bly, 1980).

Effects on Ridership

In general, the effects on ridership of lack of reliability will be even more pronounced than the increase in waiting time alone indicates. This effect is attributable to the uncertainty about if and when the next vehicle will arrive and consequent anxiety and annoyance to passengers. London Transport has estimated that elasticities with respect to "unplanned" service cuts (i.e., lost vehicle-miles) are some 33 percent larger than with respect to scheduled service cuts (Webster and Bly, 1980). Periodic equipment failures during initial operation of the BART rapid rail system in San Francisco led to public perceptions of undependability and are thought to have inhibited ridership in the early years (Peat, Marwick, Mitchell, 1975).

Virginia Railway Express (VRE) commuter rail service encountered severe reliability problems caused by track congestion and related delays after a July 1996 freight train derailment affecting both VRE lines. The aftermath of the derailment caused chronic delays for weeks, along with individual train cancellations. Riders were alienated despite a liberal ticket refund policy. At the same time a new set of commuting options was coming available with the opening of a Metrorail station and carpool lane extensions. In the months following the incident, VRE experienced a 32 percent decrease in ridership. For the year, although VRE had originally projected growth in ridership, the system actually faced a 16 percent loss (Finn, 1997). Further exploration of the effects on VRE and other commuter rail ridership of service reliability problems, changing conditions on parallel transportation facilities, and other external factors is found in Chapter 8, "Commuter Rail."

The impact of strikes on transit ridership was the subject of a time-series analysis of the effects of major incidents on ridership in Orange County, California, including the 1979 gasoline shortage and transit strikes of 1981 and 1986. The work underscores the long-term effects a prolonged strike can have on transit ridership. The gasoline shortage caused a temporary 20 percent increase in ridership which only lasted as long as the shortage. The 1981 6-week work stoppage caused a 20 percent decrease in ridership and a prolonged multi-year negative effect on ridership levels. A shorter work stoppage in 1986 caused a similar decrease, but ridership levels returned close to normal relatively quickly (Ferguson, 1991). For an analysis of impacts *during* a strike, see the case study "Impacts of a Bus Transit Strike in the San Francisco East Bay Cities," in Chapter 10, "Bus Routing and Coverage."

UNDERLYING TRAVELER RESPONSE FACTORS

Wait and Transfer Time Savings

Service frequency changes affect the time a transit patron must wait for service, both initially and at transfer points. Increasing the frequency reduces these wait times and makes transit a more attractive travel mode. Studies of urban travel behavior show that the travel time implications of travel alternatives are a highly important determinant of consumer choices. For urban area travel to and from work, overall travel time savings are valued at roughly one-third to one-half of the wage rate, on average. The value depends on the choice situation involved, such as mode choice and path choice. Non-work travel time savings are usually valued less (Charles River Associates, 1997).

Not all components of travel time are equal in value per minute as perceived by the trip maker. Time components of the complete trip that are often referred to as the "out-of-vehicle time" are the time spent getting to and from motorized transport or waiting for the vehicle to arrive or depart. These appear to be more onerous than the time actually spent in the vehicle, the so-called "in-vehicle time." Typically, reductions in out-of-vehicle times are more highly valued than reductions in in-vehicle times, and thus more strongly affect consumer choice of mode. This finding has important service design implications

Travel demand research done using various modeling techniques has for some time suggested that transit wait time, transfer time, and walk time lumped together as "out-of-vehicle time" may be at least on the order of twice as important in mode choice as an equal time spent in the transit vehicle (Quarmby, 1967; Shunk and Bouchard, 1970; Schultz, 1991). More recent modeling efforts, utilizing advanced techniques and protocols for more precise treatment of out-of-vehicle time components, are divided between identifying out-of-vehicle time as being twice as important or four times as important as in-vehicle travel time. In the roughly twice as important category (basing out-of-vehicle time importance on the first 4.5 or more minutes of waiting for the initial bus, journeying to or from work) are Houston at 2.58 times in-vehicle time, Portland at 1.25 times and Cleveland at 2.13 times (Barton-Aschman, 1993; Kim, 1998; Parsons Brinckerhoff, 1998). In the roughly four times as important category, using the same basis of comparison, are

Minneapolis-St. Paul at 4.36 times and Chicago (bus and rapid transit) at 3.41 times (Parsons Brinckerhoff, 1993 and 1999).

An examination of over 50 work purpose travel demand models from throughout the United States found each minute of transit wait time to average 2.12 times as important as a minute of in-vehicle travel time. Ranges were from 2.72 average for urban areas under 750,000 population to roughly 2.0 for larger cities, and from 2.48 average for 1990s models to about 2.0 for older models (U.S. Environmental Protection Agency, 2000).

Newer models often afford differentiation among the out-of-vehicle time components. This capability provides mixed indications, but as discussed further in Chapter 10, transfer wait is most often shown to be of greater importance than the overall initial wait. If transit service is reasonably reliable, passengers can reduce the impact of the initial wait time by adjusting their time of arrival to more closely coincide with the transit schedule. Transfer waits, in contrast, cannot be controlled by the passenger. (The several references to Chapter 10 in this discussion refer specifically to the "Running, Walk and Wait Time" subsection within the "Underlying Traveler Response Factors" section of Chapter 10, "Bus Routing and Coverage.")

Table 9-9 gives the relative weights on travel time exhibited by the Minneapolis-St. Paul mode choice model. In this model, the relative importance of transfer wait time must be taken together with the importance of the penalty associated with each transfer to judge the degree to which travelers view transferring as undesirable. (Transfer penalties are examined further in Chapter 10.) Similarly, the relative importance of initial (non-transfer) wait time must be judged by taking the values for the first 7.5 minutes together with the values for additional wait time (Parsons Brinckerhoff, 1993).

Table 9-9 Relative Importance of Minneapolis-St. Paul Model Travel Time Components

Trip Purpose	Running Time	Initial Wait (First 7.5 min.)	Initial Wait (Over 7.5 min.)	Transfer Wait Time	Added Penalty per Transfer
Home-Work	1.0	4.36	0.88	4.36	none
Home-Other	1.0	4.00	10.78	3.77	17.27
Non-Home Based, Work Related	1.0	4.00	4.00	2.50	27.28
Non-Home Based, Non-Work Related	1.0	4.00	7.63	1.58	121.05

Notes: All values are normalized to minutes of running (in-vehicle) time. Relative importance values of 4.00 (four times as important as running time) are assumed on the basis of the home-work model calibration results. All other relationships are "originally estimated" using the 1990 Minneapolis-St. Paul survey data.

Source: Parsons Brinckerhoff (1993).

Note that in the case of the Minneapolis-St. Paul model, the time over 7.5 minutes is not viewed as even as important as running time by work trip commuters. This outcome is presumably because commuters know the schedule and can avoid a long time at the bus stop. Conversely, travelers making trips likely to be less repetitive and more discretionary apparently find the longer waits increasingly onerous, as indicated by the "Initial Wait over 7.5 Minutes" values in Table 9-9 for home-other (non-work) trips and non-home based non-work related trips.

There is some indication that out-of-vehicle times tend to be more important for non-work travel than for work purpose travel, as suggested by the values in the Minneapolis-St. Paul model presented in Table 9-9 when taken together. The recent Portland, Oregon, mode choice model offers additional and straightforward evidence. In the Portland model, the various out-of-vehicle time components range from 1.25 to 2.46 times as important as running time for work trips (see Chapter 10), as compared to 2.67 times as important for non-work trips (Kim, 1998). This finding suggests that off-peak service design in particular needs to focus on minimizing out-of-vehicle times, either by lessening them or somehow mitigating their effect.

Transit wait time becomes more important when the trip is short and easily substituted for by another mode, typically walking. Commuters will opt for the other mode or walk to the destination rather than wait for an infrequent bus. In the downtown Chicago area, surveys showed travelers were more willing to walk than to wait for a special shuttle from the rail stations, because walking was an easy alternative (Kurth, Chang and Costinett, 1994). Mixed experiences with connecting peripheral parking to downtowns with bus shuttles exhibit similar phenomena (see Chapter 18, "Parking Management and Supply" — "Response by Type of Strategy" — "Peripheral Parking around Central Business Districts").

Physical, Operating and Economic Environment

The effects of waiting time are influenced by a number of external factors. One of these is the physical environment. For instance, protection from weather in wet, hot, or cold climates makes a difference in a rider's perception of waiting and transfer times. Seasonal variations in ridership can perhaps be attributed in part to differences in the waiting environment (Webster and Bly, 1980).

Circumstantial and anecdotal evidence suggest that image and the general operating environment may affect response to frequency improvements. A disappointing ridership response in Charlottesville, Virginia (elasticity of +0.33) occurred in the environment imposed by old and unreliable buses among other problems described under "Response by Type of Strategy" — "Bus Frequency Changes" — "More Recent Experience" (SG Associates and Transportation Behavior Consultants, 1982). In contrast, the outstanding responses to service hours and frequency enhancements in Santa Clarita and Santa Monica, California (elasticities of +1.14 and +0.82) were accompanied by aggressive marketing ranging from direct mail campaigns and free-ride coupons to image building keyed to a striking new bus paint design (Stanley, 1998; Catoe, 1998).

Economic conditions may likewise influence the extent of response to service frequency enhancements. The few cases where local economic conditions have been reported tend to suggest that poor economic environments may be associated with dampened ridership responses to frequency improvements, whereas a booming local economy may be a factor in heightened response (Mass Transportation Commission et al., 1964; Catoe, 1998). Even if there is not a direct impact on sensitivity to service improvements, superimposition of an average traveler response onto downward or upward trends will produce differing results. With respect to service frequency reductions, there is no consistent evidence concerning effect of economic conditions.

Looking to the future, the information made possible by Intelligent Transportation Systems (ITS) technologies offers potential for reducing rider uncertainty about wait times, holding out the possibility of making transit use more attractive even where reliability improvements are impractical. A completed trial application in London tied automatic vehicle location (AVL) monitoring with electronic signs at the 400 stops along 40 day and 12 night bus routes, giving passengers closely estimated wait times for approaching buses. Results of this "Countdown" system were sufficiently promising that fleetwide AVL implementation was programmed for the next 3 years, with provision of "Countdown" signs at all 4,000 bus stops over the next 10 years (London Transport, 1998). The information on expected wait time is reported to make passengers less anxious, to reduce their perception of the amount of wait time even though nothing else has changed, and to have a positive although probably modest effect on actual ridership. "Countdown" results are further explored in Chapter 11, "Transit Information and Promotion," under "Traveler Response by Type of Program" — "Real-Time Transit Information Dissemination" — "Results of Real-Time Train and Bus Arrival Information."

Other Considerations

A change in service hours introduces the issue of availability of service. Beyond the reach of operating hours there is simply no transit service available to the prospective customer.

When the service hours issue is how late after the PM peak period to operate, the potential for riders to be "trapped" without service when they have to work late or try to squeeze in an after work activity becomes a concern. Persons faced with such trip scheduling uncertainties may simply elect not to use transit at all, although provision of an evening "guaranteed ride home" program may mitigate the deterrence. Similar situations arise when there is no midday service, and a commuter is faced with an emergency need to return home.

When attendees were polled at a St. Louis public hearing, only 24 percent were concerned with obtaining improved rush hour service, while nearly all desired service improvements in other time periods (Holland, 1974). Commuters to New York City listed midday and evening service improvements, which involved both speed and service frequency, as the most important changes wrought by a demonstration project involving the New York Central Railroad (Tri-State, 1966).

Where and when transit service already exists, as is always the case when service frequency improvements are being considered, those who are most dependent on public transportation ("captives") are among the transit riders already being served. Thus the riders attracted by frequency improvements tend to be discretionary ("choice") transit riders, more prevalent among middle and upper income groups (Holland, 1974). This has recently been observed in the case of the Santa Monica "Big Blue Bus" frequency improvements examined under "Response by Type of Strategy" — "Bus Frequency Changes" — "More Recent Experience." The ridership increase has drawn especially on trip makers within the $40,000 to $50,000 household income range. Persons in this income bracket constitute some 20 percent of current Santa Monica Municipal Bus Line ridership (Catoe, 1998).

RELATED INFORMATION AND IMPACTS

Mode Shifts and Sources of New Ridership

When transit riders are attracted or repelled by transit service frequency increases or decreases, shifts between travel modes take place along with some occurrences of new trips or trips no longer taken. Such effects define the sources of new ridership when frequencies are improved. In available surveys of new riders attracted by increased service frequency, "trips not made previously," reflecting changes in trip frequency or destination choice that result in "new" trips, were apparently not identified. The percentage of such trips is probably comparable to the 10 to 20 percent reported in connection with combined fare and service increases. (See "Related Information and Impacts" — "Sources of New and Lost Ridership" in Chapter 12, "Transit Pricing and Fares," for the specific data and further discussion.)

Bus and commuter railroad riders attracted from other travel modes by increased frequency were, in various Massachusetts experiments, distributed among the prior modes as shown in Table 9-10 (Mass Transportation Commission et al., 1964):

Table 9-10 Prior Travel Modes of Transit Users Attracted by Increased Frequency

Bus Users Attracted by Various Massachusetts Bus Frequency Increases		Rail Users Attracted by Boston Area Commuter Rail Frequency Increases	
Prior Mode	**Percentage**	**Prior Mode**	**Percentage**
Own car	18 to 67%	Own car	64%
Carpool	11 to 29	Carpool	17
Train	0 to 11	Bus	19
Taxi	0 to 7		
Walking	0 to 11		

Source: Mass Transportation Commission et al. (1964).

When frequencies were reduced on the Mt. Pleasant Road trolley bus route (Route 74) in Toronto, Canada, choice of that particular route relative to all other possible travel options went down by 12.5 percent among panelists selected at bus stops prior to the change. However, choice of public transit as the selected travel mode went down only 1.7 percent. The indication was that in Toronto's relatively dense transit network, shifts among routes were dominant, with relatively little shifting to non-transit modes taking place. Overall trip rates for worker and student trips were relatively impervious to the service decrease, but reported non-worker and non-student trips by all modes dropped by 14 percent, suggesting travel foregone (Miller and Crowley, 1989). (See the case study "Mt. Pleasant Bus Route Service Reduction in Toronto — Panel Survey" for further detail.)

Temporal Ridership Patterns

The potential of transit frequency improvements for attracting additional ridership is demonstrably greatest percentagewise in the off-peak periods of the day. A likely reason, in part, is the typical existence of lesser service frequencies in the off-peak hours. Another likely factor is the off-peak prevalence of discretionary travel.

In the Detroit center city Grand River Avenue demonstration of the 1960s, off-peak elasticities were almost 100 percent above the peak hour headway elasticity of -0.13. In Virginia, the Chesapeake to Norfolk suburban service off peak elasticities were over 50 percent above the morning peak -0.58 elasticity. Bus headway observations previously discussed with respect to Table 9-2 are stratified in Table 9-11 by time period (Mayworm, Lago and McEnroe, 1980). This stratification also displays the existence of higher off-peak sensitivity to frequency improvements, although to a lesser degree than the individual instances cited first.

Table 9-11 Bus Headway Elasticities Stratified by Time of Day

Time Period	Number of Observations	Arc (Mid-point) Elasticity	Standard Deviation
Peak Hours	3	-0.37	±0.19
Off-peak Hours	9	-0.46	±0.26
Weekends	4	-0.38	±0.17
All Hours	7	-0.47	±0.21

Source: Mayworm, Lago and McEnroe (1980).

Only in the Stevenage, England, and Mt. Pleasant trolleybus of Toronto observations were elasticities observed or estimated to be lower in the off-peak than in the peak. Analytical issues affecting the Toronto off-peak estimate were previously noted.

Experimental train frequency increases on Boston & Maine service into Boston of 82 percent in the peak and 92 percent in the off-peak induced an 18 percent Phase 1 ridership increase in the peak and a 60 percent increase in the off-peak. In this experiment, "off-peak" was defined as including not only midday and evening trains and patronage, but also trains and patrons moving reverse to the predominant flow during the peak hours. The experiment did not employ off-peak fare discounts until after Phase 1 (Mass Transportation Commission et al., 1964). The results imply peak and off-peak service elasticities of +0.3 and +0.7, respectively.

Traveler Response Time Lag

The effects of service frequency and fare changes require time to fully develop. Existing and prospective transit riders need time to assess the ramifications of a change and sometimes to terminate old travel arrangements and make the different arrangements required by shifting to a new mode.

In the case of the 1960s Massachusetts experiments, some frequency improvements elicited ridership increases that stabilized within the first month. This was particularly true of the bus service experiments oriented to urban, off-peak travel. Other frequency improvements elicited a response that grew throughout the course of the 9 to 12 month experiments. For example, a suburban route into Boston exhibited a 27 percent ridership increase over the prior year in the fourth quarter compared to 18 percent in the first, while a suburban route into Worcester showed a 16 percent increase in the third quarter compared to none in the first (Mass Transportation Commission et al., 1964). Commuter railroad service frequency improvements attracted steadily increasing ridership over 16 to 18 month periods (Mass Transportation Commission et al., 1964; Southeastern Pennsylvania Transportation Authority, 1971; Tri-State, 1966).

An analysis of bus transit in Portland, Oregon, found that for service-level changes in suburban areas, the range of ridership development times was from 1 to 5 months. In the urban area, the service-level change response time range was 8 to 10 months. In contrast, fare change effects typically stabilized in about 3 months (Kyte, Stoner and Cryer, 1988). While the suburban versus urban differentiation appears to be reversed comparing Massachusetts and Portland, Oregon, it may nevertheless be concluded that ridership response to frequency and schedule changes often stabilizes at least somewhat faster than response to new transit routes. The two or up to three years that it takes to reach equilibrium with new routes is discussed in the "Related Information and Impacts" — "Service Development and Time Lag" subsection of Chapter 6, "Demand Responsive/ADA," and the corresponding "Traveler Response Time Lag" subsections of Chapter 10, "Bus Routing and Coverage," and urban rail Chapters 7 and 8.

VMT, Energy and Environment

Modeled rather than observed traveler response is the only available basis for evaluation of the impacts of transit service frequency changes acting alone on vehicle miles of travel (VMT), energy consumption and pollutant emissions. A hypothetical example of changes in vehicle headways for a corridor with 4 bus stops per mile and 1,000 person trips per hour indicates the potential VMT reduction benefits and air quality impacts that might accrue at the corridor level. Table 9-12 shows the results of the analysis, which suggest that in the context of early 1980s emissions controls, transit frequency improvements would reduce carbon monoxide (CO) and hydrocarbon (HC) emissions, but increase nitrous oxide (NO) emissions (Cambridge Systematics, 1992). Changes in emissions control technology and increased use of low or no emissions autos and/or buses may markedly alter the emissions and trade-offs shown.

Table 9-12 Hypothetical Corridor Bus Frequency Impacts on VMT and Emissions

Transit Headway	Bus	Emissions (kg/hr) from Buses			Automobile		Emissions (kg/hr) from Automobile			Emissions (kg/hr) from All Vehicles		
(minutes)	VMT	CO	HC	NO	VMT	Trips	CO	HC	NO	CO	HC	NO
30	24	1.23	0.18	0.70	2,360	708	193	18.6	6.63	194	18.8	7.33
15	48	2.46	0.37	1.40	2,160	649	177	17.1	6.06	179	17.5	7.48
5	144	7.39	1.11	4.20	2,070	622	170	16.4	5.83	177	17.5	10.0

Source: Joel Horowitz, *Air Quality Analysis*, The MIT Press, 1982, as cited in Cambridge Systematics (1992).

An earlier study indicates that within certain travel markets, increased transit fuel consumption may largely or completely offset the automobile energy saved by attracting trips to transit with frequency increases. To illustrate with an example from the most disadvantageous end of the spectrum, the impact of decreasing Chicago rail rapid transit wait time by 20 percent was estimated to be a 1.8 percent ridership gain accompanied by a net increase in urban transportation energy use equivalent to 0.5 percent of areawide automotive fuel consumption (Pratt and Shapiro, 1976). More comprehensive examination of bus frequency increases in combination with increases in service coverage have indicated that net energy savings are attainable in a number of travel markets, but not in others (see "Related Information and Impacts" — "Energy and Environmental Relationships" in Chapter 10, "Bus Routing and Coverage").

Notably, the net energy savings resulting from combining improved frequency with decreased fare is in most cases greater than the sum of the individual actions. This same synergistic effect is also evident when improved transit service is combined with auto use disincentives. In both cases the complementary actions assist in filling the additional transit vehicles required by virtue of the frequency improvement strategy, thereby increasing both transit and total energy efficiency (Pratt and Shapiro, 1976). (See also "Related Information and Impacts" — "Impacts on VMT, Energy and Environment" in Chapter 12, "Transit Pricing and Fares".)

Costs and Revenues

Transit service frequency increases will attract transit trips and thereby increase gross farebox revenue, but will seldom lead to a decreased net cost of transit operation. In any case, the net cost of a carefully designed service frequency increase may be found acceptable to the operating agency involved when examined in the context of mobility and other objectives. For example, see the new- and established-service farebox recovery ratio standards used by New Jersey Transit, described in Chapter 10, "Bus Routing and Coverage" under "Related Information and Impacts" — "Costs and Feasibility." Note that schedule regularization to provide greater public convenience and easy recollection of departure times may involve not much more than the start-up costs of rescheduling, which necessarily include resolution of any interlining issues and route redesign requirements.

Service frequency reductions are, on the other hand, a means to lower costs and increase net revenue, albeit at the expense of service quality and reduced patronage. Deficit reduction needs have forced this action, often taken together with fare increases, where economic circumstances required (Washington Metropolitan Area Transit Authority 1995; Allen, 1991). It is possible to reach a point of diminishing returns, however, when service quality drops below a certain point (Pratt and Bevis, 1971).

The marginal cost of off-peak service may be significantly less than the average systemwide full operating cost. Peak ridership demands determine the number of vehicles and heavily influence the number of drivers needed to provide service. Off-peak costs are thus closer to being determined by direct vehicle operating costs alone, particularly where full time drivers are not actually driving full shifts.

To quantify the lesser cost of off-peak service it is necessary to develop a cost model that differentiates between peak and off-peak costs. This was done for the Twin Cities of Minneapolis-St. Paul based on 1984 cost and ridership data. The result for the public carrier was the formula:

CST = \$1.065 x VM + \$20.255 x BVH + \$30.799 x PVH + \$19,941 x PV

where:

CST = system or route cost
VM = vehicle miles for route or system
BVH = base vehicle hours for route or system
PVH = peak vehicle hours for route or system
PV = peak vehicles in route or system

and the cost of each peak vehicle is expressed as annual cost which does not include capital costs (Regional Transit Board, 1987).

Note that "base vehicle hours" in this formulation refers to the hours accrued by the base fleet throughout the peak and off-peak, and "peak vehicle hours" refers to only the added increment in the peak over and above the base vehicle hours. "Peak vehicles," however, refers to the total count of vehicles in service during the peak, whether they are operating base or peak vehicle hours. Since the cost of each peak vehicle is expressed as annual cost, either the formula must be used to calculate annual costs, or the peak vehicle cost ($19,941 in the case of this 1984 calibration) must be divided by an appropriate cost annualization factor.

By applying a series of assumptions, such as an initial 2:1 ratio of peak to base service, an annualization factor for cost of 300, an average speed of 12 miles per hour including layovers, and 5 and 10 hour peak and off-peak weekday operating periods, respectively, it is possible to calculate that the weekday cost of a 50 percent increase in off-peak service would be just 40 percent of the cost of a 50 percent increase in peak service involving the same number of vehicle hours and miles. Results would vary according to the application, but off-peak service increases to frequencies less than or equal to the peak frequency will always be shown to be less expensive on a per hour/mile basis. If capital costs were to be included, they would make no addition to off-peak service costs.

A 1968 evaluation of suburban Long Island bus operating costs estimated that to cover the cost of adding off-peak bus service to a peak-only operation would require a ridership of only 6 percent over the peak period ridership (Pignataro, Falcocchio and Roess, 1970). Comparison of off-peak with peak-hour only service exaggerates normal conditions, and few operations today cover all costs as in the 1960s, but it is clearly inappropriate to use a flat, all day, per mile or per hour cost in assessing the viability of off-peak service improvements.

An examination of the commuter railroad cost impact of a 40 percent increase in car miles spread over both the peak and off-peak revealed the following operating cost increases (Mass Transportation Commission et al., 1964):

fuel	+40%
train crew labor	+32
car repair	+28
non-operating labor	+11

These relationships suggest that the incremental cost of the added service must have been substantially less per train mile than the service previously in place. It may be concluded that while transit ridership rarely increases as much as the percentage increase in service required to engender it, neither do the operating costs, at least if the service increase is primarily in the off-peak or counter to the predominant peak hours flow.

ADDITIONAL RESOURCES

The U.S. federal research *Patronage Impacts of Changes in Transit Fares and Services*, UMTA/USDOT Report Number RR135-1 (Mayworm, Lago and McEnroe, 1980) provides additional case study material and in-depth analyses specifically focused on transit frequency levels. A report of the International Collaborative Study of the Factors Affecting Public Transport Patronage, *The Demand for Public Transport*, published by the Transport and Road Research Laboratory (Webster and Bly, 1980), includes extensive compilation of transit service elasticities in developed countries, along with related evaluations and interpretations. Although no updates of these works are known to be available, a periodically updated "Transportation Elasticities" compendium with references and resources for more information is maintained on the www.vtpi.org website (Victoria Transport Policy Institute, 2003).

Several recent reports contain brief summaries of 1990s transit service change actions and outcomes. One with several examples of frequency and other transit scheduling changes is *TCRP Research Results Digest 29* (Stanley, 1998).

CASE STUDIES

Mass Transportation Demonstration Projects in Massachusetts

Situation. From 1962 to 1964, the Mass Transportation Commission of the Commonwealth of Massachusetts performed a variety of mass transit service improvement and fare reduction experiments. Although old, the information produced remains by far the most comprehensive quasi-experimental data set on individual transit route frequency change impacts available. The projects fall into three groups: the "MTA Experiments," involving the Metropolitan Transit Authority and centered on Boston; the "Bus Company Experiments," involving bus operators throughout the state other than MTA; and the "Rail Experiments," involving the commuter railroads serving Boston.

Analysis. Passenger and farebox gross revenue tallies were maintained throughout the experiments and compared with available data for prior year equivalent months. The patrons were sampled and interviewed to obtain information on rider characteristics and travel habits.

MTA Experiments

Actions/Results. The MTA experiments were all conducted within Boston and its inner suburbs. Off-peak service frequency was increased to match peak period frequency in 2 of the MTA experiments. On a 1 mile downtown bus route connecting Boston's North and South Stations, the off-peak headway was changed from 25 min. to 5 min. Results: 6 month revenue up 71 percent, with an average of 1,441 new riders per day; post experiment off-peak headway set at 8 min. On a suburban feeder to rapid transit bus route, off-peak frequency was improved from 10 to 5 min. Results: 5 month revenues up only 3 percent. Among the new bus lines tried were 2 circumferential services, 3 and 5 miles from downtown Boston respectively. Each passed through 7 rail transit stations and 7 to 8 dense residential and retail communities. Frequency was 10 min. peak and 15 min. base. Results: 697 average daily additional passengers gained for the 3 mile radius corridor, 3,347 for the 5-mile corridor; 2 and 27 percent increases in corridor revenues, respectively; revenues 5 and 20 percent of costs.

More... Of the riders newly attracted to MTA by increased bus frequency between North and South Stations, approximately 2 out of 3 had previously walked and 96 percent of the prior walkers were making train connections. On the inner circumferential bus route 94 percent of the riders interviewed had previously used another MTA service; of the remainder 66 percent had traveled by auto, 25 percent had walked, and 8 percent were making new trips. On the outer circumferential bus route 13 percent formerly traveled by auto, 44 percent by bus, and 43 percent via a combination of radial MTA rail lines.

Bus Company Experiments

Actions/Results. Several experiments were conducted outside the Boston MTA service area. These mostly involved increasing service frequency provided on established local service bus routes. Operator bankruptcy disrupted some of the experiments after the first 3 months. In six of the frequency enhancement demonstrations, 30 to 60 percent of the added service was retained afterward. Table 9-13 summarizes the frequency enhancements and the results.

Table 9-13 Massachusetts Bus Headway Changes and Ridership/Revenue Results

Route	Service Area Population	New Headway	Results (and Comments)	Average Weekday Total Inbound Passengers
Milford to Downtown Boston	22,000 (Suburban area only)	1 hour all day (78% service increase)	12 month revenue up 22% (18% first 3 months; 27% in the last 3 months)	232
Uxbridge to Worcester (pop. 187,000)	28,000 (Suburban area only)	Similar to above	9 month revenue up 5% (none in first 3 months, 16% in the last 3 months)	111
Amesbury-Newburyport	25,000	Half-hourly in the peak; hourly in the base (67% service increase)	8 month revenue up 19% (route through depressed industrial areas)	85
Adams-Williamstown	40,000	Better than hourly frequency (100% service increase)	3 month ridership up 48%	over 300
Pittsfield	74,000 (SMSA)	Service increased to 8 round trips (16% service increase)	3 month ridership up 87% (3 mile long radial route)	113
Pittsfield	74,000 (SMSA)	Service increased to 15 round trips (50% service increase)	3 month ridership up 30% (3 mile long radial route)	293
Fitchburg-Leominster	72,000 (SMSA)	1:40 PM to 6:00 PM bus trips doubled to give 10 min. headway all day; minor route extension	8 month revenue up 8% (high density service area; fare increase from 20¢ to 25¢ in 9th month)	1,561 (12 month average)
Fall River	124,000 (SMSA)	Service increase of 20%	Halted but did not reverse ridership decline (high unemployment and disruptive construction)	n/a

Notes: SMSA stands for 1960 U.S. Census Standard Metropolitan Statistical Area.

Most new routes attempted were unsuccessful, including service into light density suburbs of Fitchburg, short in-city routes to new developments, an industrial service, and 2 commuter railroad feeder routes. The services attempted varied from 5 bus trips a day to half-hourly frequency. The average bus trip carried less than 2 passengers. An expressway service into Boston attracted 61 inbound passengers; a modest success. A rapid transit feeder service, operating through dense suburbs on a 30 minute headway, attracted 193 inbound riders at a 10¢ fare, 183 at a subsequent 15¢ fare, and was retained in full after the demonstration.

More... The prior travel modes for new bus riders on the Milford, Uxbridge, Fitchburg, Adams, and Pittsfield demonstrations ranged from 18 to 68 percent "own car," 11 to 29 percent carpool, 0 to 7 percent taxi, 0 to 54 percent walk, and 0 to 11 percent train. Some 51 percent of all bus riders, old and new, said the bus service was a contributing factor in staying on their present job.

Rail Experiments

Actions. Experiments were conducted on the 3 systems then responsible for commuter rail operations in the greater Boston area. These were: The Boston & Maine Railroad (B&M), the New Haven Railroad (NH) and the New York Central Railroad.

The B&M experiment consisted of 3 phases: Phase 1 incorporated an overall 77 percent increase in service (including weekends) and a 28 percent decrease in fares. The weekday service expansion was 92 percent (peak service 82 percent and off-peak 96 percent); the fare decrease varied from 12 to 72 percent. Phase 2 involved retention of Phase 1 service improvements, coupled with virtual elimination of the fare reductions, except for adjustments to provide an off-peak fare discount. In Phase 3 service levels were adjusted while the fare structure remained the same. The NH experiment consisted of 2 phases: In Phase 1, the total overall average service level was increased by 42 percent and fares were reduced by an average of 10 percent. In Phase 2, part of the NH operation was returned to pre-experiment service levels, and fares were raised to approximately pre-experiment levels except for provision of off-peak fare incentives. New York Central Railroad operation was used as an experimental control; no significant changes were made to service or fares, nor was there any special advertising of the service.

Results. Ridership increases on the B&M were immediate; ridership in January 1963 was up 30 percent (5,500 more weekday riders) over December. Overall patronage gains on the B&M averaged 27, 37.5 and 44 percent over pre-experiment levels for Phases 1, 2, and 3 respectively. The NH experienced ridership increases of 10 and 11.5 percent for Phases 1 and 2, respectively. Riding on the New York Central continued downward during 1963. The average decline was 5.9 percent, similar to pre-experiment trends on the other 2 railroads. On 2 individual lines of the B&M which received only fare reductions, the total Phase 1 ridership increased by only about 3 percent. Similar results were observed on individual NH lines. Moreover, the Phase 2 B&M and NH patronage increases occurred despite fare increases. It was therefore concluded that service level improvements were more effective than fare reductions for increasing ridership. Nevertheless, the fare reductions were perceived: Of new train riders surveyed, 22 percent cited lower fares as the principal reason they used trains more often, while 14 percent cited the increase in train service and 6 percent noted both. Additional revenues earned during Phase 1 covered the loss inherent in the fare reduction but not the costs of added service; new revenues earned during the final phases were sufficient to cover the full incremental cost of the experiment, but not much of the overall operating deficit.

More... The 35 percent B&M Phase 3 increase over a pre-experiment passenger count reflected a 21 percent peak period increase and a 79 percent off-peak increase. (All off-peak data includes reverse commutation during the peak.) The NH percentage increases were similarly large in the off-peak relative to the peak. Riders using commuter trains more often previously traveled 63.6 percent in their own car, 16.9 percent as a carpool member, and 19.5 percent via bus. Of all inbound riders, 41.0 percent drove and parked their own car at the station, 27.7 percent walked to the station, 1.8 percent took a bus, and 2.2 percent took a taxi. While 83 percent of inbound NH commuters walked to their destination, 55 percent of B&M commuters used subway or bus (40 percent walked) because of the station location.

Source: Mass Transportation Commission, MA, McKinsey & Co., Systems Analysis and Research Corp., and Joseph Napolitan & Assoc., "Mass Transportation in Massachusetts." U. S. Housing and Home Finance Agency, Washington, DC (July 1964).

Frequency and Service Hours Enhancements in Santa Clarita, California

Situation. Santa Clarita, California, is an outlying suburb in the foothills north of the San Fernando Valley. Except for a pedestrian spine and rib system in the central community of Valencia, the development is transit unfriendly, with walled communities, dry river barriers, and no sidewalks in industrial areas. Metrolink commuter rail service to Los Angeles was initiated in October 1992, and the station serves as a common point for most routes. In 1992, Santa Clarita Transit local bus coverage was provided on hourly headways, Monday through Saturday, and peak period express service was offered to downtown Los Angeles. Combined headways were 30 minutes on certain local bus trunk route segments. Buses were and are routed primarily via arterials without frequent deviations into neighborhood streets. Junior and Senior High School student transportation is provided by regular routes and fixed-route deviations. There are 9 local routes including a Metrolink feeder, 4 through-routed, plus additional branches and deviations. Destinations served include a Six Flags theme park. The Santa Clarita Transit local service area has a 1998 population, including locales outside of the incorporated city, of approximately 150,000. Commuter express service in and out of the area is provided on 7 lines as of 1998. Ridership is 82 percent local, 5 percent dial-a-ride, and 13 percent commuter; and 20 percent senior, 37 percent adult, and 43 percent youth.

Actions. The growth between 1992 and 1998 in Santa Clarita Transit local route vehicle revenue hours and miles operated is documented in Table 9-14. While there have been route adjustments and certain extensions, most of the local route service growth has been in expanded service hours and increased frequencies. Saturday service hours were expanded by three hours in 1992. Weekday service hours were expanded by two hours in 1992, and again in 1995 on three routes. Sunday service was introduced on about two-thirds of the local routes in 1996. In the FY 1995-96 through FY 1997-98 period, 30 minute headways all-day were introduced on 4 routes, including two on weekends, and peak service was increased to approximately 15 minute headways on two routes (and most of a third on the basis of combined headways). Transfer policies were modified in 1992 to provide a 90-minute pass, fares were raised 33 percent in 1993, and youth passes were increased from $10 a month to $15 in 1996. New express commuter bus services to and from the area were added in 1994 and 1995.

Analysis. This evaluation documents the ridership growth and calculates year by year and 5-year overall log arc service elasticities for the local service. Demographic growth, modest within the city limits, and the effect of fare changes were both ignored in the elasticity calculations, as was any effect of the 1994 Northridge earthquake.

Results. Table 9-14 provides ridership data along with bus hours and bus miles service elasticities for Santa Clarita Transit local service. The magnitudes of the one-year elasticities are suspect because there is no statistical smoothing of short-term anomalies, but it is notable that all are over +0.50. The majority of the 1-year elasticity values, and the 5-year overall service elasticities as calculated on both bus hours and bus miles, are all in the elastic range: over +1.0. Ridership thus increased more than service. The bus miles 5-year overall service elasticity of +1.14 is probably the result of most significance. The bus hours elasticity calculations were influenced by an increase in average operating speed from 16 mph in FY 1992-93 to 19 mph in 1997-98. Passengers per hour performance rose from 16 in 1992-93 to 21 in 1997-98, peaking at 23 passengers per hour the previous year. Passengers per mile performance, while increasing slightly overall, has stayed close to 1.0 per local bus mile.

Table 9-14 Santa Clarita, CA Local Fixed Route Performance and Log Arc Service Elasticities

Local Fixed Routes-Year	City Population	Annual Rev. Bus Hours	Annual Rev. Bus Miles	Annual Bus Rides	Bus Hours Elasticity	Bus Miles Elasticity
FY 1992-93	123,400	48,778	787,807	769,137	—	—
1993-94	124,000	53,391	1,018,021	915,869	+1.93	+0.68
1994-95	124,300	60,028	1,163,607	1,107,587	+1.62	+1.42
1995-96	124,800	62,750	1,179,140	1,366,537	+4.74	+15.84
1996-97	n/a	66,947	1,389,082	1,527,253	+1.72	+0.68
1997-98	n/a	81,216	1,569,891	1,693,173	+0.53	+0.84
5 Fiscal Years	+2% (4 yrs.[a])	+66%	+99%	+120%	+1.55	+1.14

Note: [a] Calendar years 1992 (122,949 pop.) through 1996 (125,153 pop.).

More... Santa Clarita Transit suburbs to suburbs and reverse commute express bus service introduction and results are presented in Chapter 4, "Busways, BRT and Express Bus."

Sources: Kilcoyne, R., Telephone interview. Santa Clarita Transit. (July 6, 1998a). • Kilcoyne, R., *Timeline of Service Changes Santa Clarita Transit 1992-1998*, unpublished [1998b]. • City of Santa Clarita Transit Division, *Fact Sheet*. Santa Clarita, CA [1997]. • Santa Clarita Transit, *Local Ridership [and service measures]*. Tabulations, Santa Clarita, CA (1993-1998). • Assembly of population data, calculations of elasticities, and interpretations are by the Handbook authors.

Mt. Pleasant Bus Route Service Reduction in Toronto — Panel Survey

Situation. Service was reduced on the Mt. Pleasant Road trolleybus (Route 74) in Toronto, Canada, in October 1987. An experimental panel survey procedure was used to determine travel characteristics and transit service elasticities of demand exhibited by the riders.

Actions. The following changes were made to this route's schedule:

- Peak-period headways were widened from 10 to 15 minutes (50 percent increase).
- Early-evening (7-9 PM) headways were widened from 15 to 30 minutes (100 percent increase).
- Midday (15 minutes) and late evening (20 minute) headways were not changed.

Analysis. The survey panel members were recruited by interviewers at bus stops to record their travel before and after the change. A 75 percent response rate was obtained, providing 57 sets of trip records, each covering two weeks prior to the service reduction and two weeks during the fourth and fifth weeks after the service reduction. The surveys provided before and after 14-day trip totals and weekly trip rates by mode for the Mt. Pleasant route rider panel, as well as Mt. Pleasant route and total bus transit before and after mode shares. Elasticities were computed on the basis of headway using the mid-point arc elasticity formulation.

Results. Average weekly rides on the Mt. Pleasant bus dropped from 7.5 to 6.2 trips per respondent. The loss in ridership was mostly a loss to competing routes. The Mt. Pleasant route's share of all travel by the panelists declined from 70.5 to 61.7 percent. The percentage of trips that panelists made on any transit route dropped only slightly; from 82.7 to 81.3 percent. The observed shift was thus mostly a "route shift"as contrasted to a "mode shift."

Table 9-15 displays the elasticity estimates for the Mt. Pleasant route, total transit usage, and total trips for the panelists. Since the elasticities are computed on the basis of headways, rather than a service quantity measure, the elasticities tend to be negative.

Table 9-15 Headway Elasticities for Mt. Pleasant Trolleybus Route Panelists, Toronto

		Headway Elasticities		
Trip Purpose	**Time Period**	**Mt. Pleasant**	**Total Transit**	**Total Trips**
Work and School trips[a]	All Periods	-0.40	-0.06	0.00
Non-work and non-school trips[b]	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

Notes: [a] Given that a majority of work/school trips occur during the morning and afternoon peak periods, it was assumed that the relevant headway for computing work/school trip elasticities is the peak-period headway.

[b] It was assumed that the relevant headway for computing non-work/non-school trip elasticities is the early evening headway. Early evening was judged the relevant time period for workers and students because the majority are away from home earlier. It was also judged the relevant period for non-workers and non-students, given that most round trips by panelists in this group either began or ended during the early evening period.

More... The relatively few non-workers and non-students in the panel, mostly senior citizens, exhibited responses that differed from the majority. They did not engage in shifts of bus route choice, but reported taking fewer trips. Non-worker and non-student trips reported dropped by 14 percent. This group appeared to be truly "captive" to transit.

Source: Miller, E. J. and Crowley, D. F., "Panel Survey Approach to Measuring Transit Route Service Elasticity of Demand." *Transportation Research Record 1209* (1989).

Fare and Frequency Changes in Metropolitan Dallas

Situation. Dallas Area Rapid Transit (DART) reduced bus fares and expanded bus service following DART's formation in 1983. Base cash fare was reduced from $.70 to $.50 at the outset of 1984. Nine major service expansions in city and suburbs doubled peak bus requirements by late 1986. Ridership increased to almost 50 percent above pre-DART levels. However, low cost recovery forced a degree of retrenchment in late 1986 and 1987, a time of decreasing gasoline prices and corresponding recession in the oil-dependent local economy.

Actions. The period of case study analysis included the final mid-1985 to mid-1986 service expansions, with increases in urban bus (DTS) and suburban express bus (TCT I) revenue miles. In addition, suburban local bus (TCT II) service was initiated (18 crosstown/feeder routes) and expanded (28 more routes). The case study also included and focused on the mid-1986 to mid-1987 retrenchment period, during which urban bus revenue miles were reduced 13 percent, and suburban local bus revenue miles were reduced 33 percent in total. During this retrenchment period, suburban express revenue miles were actually increased by 6 percent. Systemwide revenue miles nonetheless were down 16 percent overall. Retrenchment period service adjustments focused primarily on changes in frequency and hours of service, but some consolidation was involved. Also during this period, fares were increased for all services. First, base cash fares were increased from $.50 to $.75, zone fares likewise went up 50 percent or nearly so, and special fares were also adjusted upward. A month later, pass and commuter card prices were increased by 35 percent. The lesser increase relative to cash fares upped the savings of pass use compared to cash by 10 percent.

Analysis. Data on boarding passengers were collected for some nine fare categories with DART's registering fareboxes. Analysis of this farebox data along with sales for pre-paid fare media allowed development of ridership profiles over time for up to 12 payment options for each of DART's three contract service providers: DTS (urban bus), TCT I (suburban express bus), and TCT II (suburban local bus). Ridership was adjusted for holidays and seasonality. A regression model was developed for each operation to isolate the effects of fare and service changes between mid-1985 and mid-1987 and to segregate these effects from those of cheaper auto travel and the local recession, reflected in the model by gasoline prices. This allowed computation of fare and service elasticities intended to be independent of effects of the economy and gas prices.

Results. By late 1987, ridership was approximately 16.5 percent lower than 1986 levels while revenues had increased by 20 percent. DART forecasts had estimated a 9.2 percent ridership decline and a revenue gain of 30 percent. Reluctant to engender further ridership loss, DART canceled a planned second round fare increase. Shifts in fare payment methods accounted for 10 percent of the revenue shortfall. Use of passes and commuter cards rose from 27 to 32 percent of fare payments, and the proportion of riders transferring increased by about 3 percent. Ridership loss accounted for 90 percent of the revenue shortfall. Table 9-16 gives the mid-1986 and 1987 average weekday boardings for each service provider, the corresponding loss in ridership resulting from the fare and service changes and external factors, and elasticities calculated for the full 1985-1987 two year period (except for TCT II as noted).

Table 9-16 Results of DART Fare Increases and Service Changes

	Avg. Weekday Boardings		Weekday Boardings Loss		1985-1987 Arc Elasticities	
DART Operation	**Mid-1986**	**Mid-1987**	**Number**	**Percent**	**Fare**	**Service**
Urban (DTS)	167,000	134,000	33,000	-20%	-0.35	+0.32
Suburban Express (TCT I)	10,200	9,550	650	-6%	-0.26	+0.38
Suburban Local (TCT II) (see note)	11,000 (October)	7,900	3,100	-28%	-0.25	+0.36

Note: The elasticities given for the suburban local bus (TCT II) service are only for the August 1986 through July 1987 12-month period.

More... DTS, the provider of local, express, and crosstown bus service mainly in the city of Dallas, had already been experiencing declining ridership earlier in 1986, presumably in response to the local economy. DTS serves the majority of low income and transit dependent areas in the city. The suburban operations serve more affluent areas and seemed to be little affected by gas prices and economic conditions. They suffered less from the fare increase, but were more sensitive to service levels. The elasticities given in Table 9-16 for the suburban local bus (TCT II) service are only for the August 1986 through July 1987 12-month period. Analysis of the months from September 1985 through 1986 suggested that the response to service changes may initially have exhibited an elasticity on the order of +1.04. This period involved expansion of service coverage more than frequency changes.

Source: Allen, J. B., "Revenue and Ridership Impacts of DART Service and Fare Adjustments." Unpublished, APTA Western Education and Training Conference '91, Austin, TX (1991).

REFERENCES

Abkowitz, M., et al., *Transit Service Reliability*. Transportation Systems [Volpe] Center and Multisystems, Inc., Cambridge, MA (December 1978).

Allen, J. B., *Revenue and Ridership Impacts of DART Service and Fare Adjustments*. Unpublished, APTA Western Education and Training Conference '91, Austin, TX (1991).

Barton-Aschman Associates, Inc., "Estimation, Calibration, and Validation of the Houston Mode Choice Model. Technical Report." Prepared for Metropolitan Transit Authority of Harris County, Houston, TX (September, 1993).

Cambridge Systematics, Inc., "Transportation Control Measure Information Documents." U.S. Environmental Protection Agency, Washington, DC (March, 1992).

Catoe, J. B., Jr., Telephone interviews, Santa Monica Municipal Bus Lines. (September 28 and October 13, 1998).

Charles River Associates Inc., "Building Transit Ridership: An Exploration of Transit's Market Share and the Public Policies That Influence It." *TCRP Report 27*, Transportation Research Board, Washington, DC (1997).

City of Santa Clarita Transit Division, *Fact Sheet*. Santa Clarita, CA [1997].

Dueker, K. J. and Stoner, J., "Examination of Improved Transit Service." *Highway Research Record 419* (1972).

Dueker, K. J. and Stoner, J., *Mass Transit Technical Study: Iowa City Final Report*. Urban Mass Transit Administration, U.S. Department of Transportation, Washington, DC (1971).

Elmore-Yalch, R., "A Handbook: Integrating Market Research into Transit Management." *TCRP Report 37* (1998).

Ferguson, E., "Temporal Effects of Incidents on Transit Ridership in Orange County, California." *Transportation Research Record 1297* (1991).

Finn, P., "VRE, Facing '99 Shortfall, Is Urged to Think Smaller." *The Washington Post*, Washington, DC (Dec. 6, 1997).

Furniss, R. E., *Evolution and Operations of the Reston Virginia Commuter Bus Service.* CACI, Inc., Los Angeles, CA (1977).

Golob, T. F., et al., *An Analysis of Consumer Preferences for a Public Transportation System.* General Motors Research Laboratory Report No. GMR-1037, Warren, MI (1970).

Goodman, K. M., Green, M. A., and Beesley, M. E., *The San Diego Transit Corporation: The Impacts of Fare and Service Changes on Ridership and Deficits*. The Urban Institute, Working Paper 5066-5-1, Washington, DC (May, 1977).

Henderson, G., Kwong, P., and Atkins, H., "Regularity Indices for Evaluating Transit Performance." *Transportation Research Record 1297* (1991).

Hocking, R. J., "Effectiveness of Downtown Transit Centers." *ITE Journal* (Sept. 1990).

Holland, D. K., *A Review of Reports Relating to the Effects of Fare and Service Changes in Metropolitan Public Transportation Systems.* Center for Urban Programs, St. Louis University. St. Louis, MO (June 1974).

Hufstedler, G., Dallas Area Rapid Transit, telephone interviews and e-mail to the authors with accompanying undated presentation materials, tabulations and graphs (February 6-9, 2004).

Jolliffe, J. K. and Hutchinson, T. P., "A Behavioral Explanation of the Association Between Bus and Passenger Arrivals at a Bus Stop." *Transportation Science.* Volume 9, Number 3. (November 1975).

Kilcoyne, R., Telephone interview. Santa Clarita Transit. (July 6, 1998a).

Kilcoyne, R., *Timeline of Service Changes Santa Clarita Transit 1992-1998*, unpublished [1998b].

Kim, K.-H., *Technical Specifications for the March 1998 Travel Demand Model*. Metro Transportation Department, Portland, OR (March, 1998).

Kurth, D., Chang, C., and Costinett, P., "Enhancements to Circulator-Distributor Models for Chicago Central Area Based on Recently Collected Survey Data." *Transportation Research Record 1443* (1994).

Kyte, M., Stanley, K., and Gleason, E., *Planning, Implementation, and Evaluation of a Timed-Transfer System in Portland, Oregon's Suburban Westside*. 1982 Annual Meeting of the Transportation Research Board, Washington, DC (1982).

Kyte, M., Stoner, J., and Cryer, J., "A Time-Series Analysis of Public Transit Ridership in Portland, Oregon, 1971-1982." *Transportation Research -A*, Vol. 22A, No. 5 (1988).

Lago, A., Mayworm, P., and McEnroe, J., "Ridership Response to Changes in Transit Services." *Transportation Research Record 818* (1981).

London Transport, "London Transport Buses" — "Bus Service Planning." http://www.londontransport.co.uk/ltbuses/b_fact04.html, London, UK (Webpage revised June, 1998).

London Transport Planning Department, *London Transport Traffic Trends 1971-1990*. Research Report R273 (February, 1993).

Lunden, P., "Shorter Waits for the Bus." *Norwegian Trial Scheme for Public Transport* (May 3, 1993).

Mass Transportation Commission, MA, McKinsey & Co., Systems Analysis and Research Corp., and Joseph Napolitan & Assoc., "Mass Transportation in Massachusetts." U.S. Housing and Home Finance Agency, Washington, DC (July 1964).

Mayworm, P., Lago, A., and McEnroe, J., *Patronage Impacts of Changes in Transit Fares and Services.* Ecosometrics, Inc. Bethesda, MD. Sponsored by Urban Mass Transportation Administration, U.S. Department of Transportation (Sept. 3, 1980).

Miller, E. J. and Crowley, D. F., "Panel Survey Approach to Measuring Transit Route Service Elasticity of Demand." *Transportation Research Record 1209* (1989).

Michael Baker Corporation, Crain & Associates, LKC Consulting Services, and Howard/Stein-Hudson, "The Potential of Public Transit as a Transportation Control Measure: Case Studies and Innovations, Draft Document." Annapolis, MD (October, 1997).

Newman, D. A., Bebendorf, M., and McNally, J., *Timed Transfer: An Evaluation of Its Structure, Performance, and Cost.* Final Report. Urban Mass Transit Administration, U.S. Department of Transportation, Washington, DC (1983).

Paine, F. T., et al, *Consumer Conceived Attributes of Transportation.* University of Maryland, College Park, MD (1967).

Peat, Marwick, Mitchell and Company, "Assessment of the Impacts of the AC Transit Strike upon BART." Prepared for the Metropolitan Transportation Commission, Berkeley, CA (1975).

Parsons Brinckerhoff Quade and Douglas, Inc., "Calibration of the Mode Choice Models for the Minneapolis-St. Paul Region." Prepared for the Metropolitan Council (September 30, 1993).

Parsons Brinckerhoff Quade and Douglas, Inc., "Cleveland Regional Travel Demand Forecasting Model Documentation Report." Prepared for the Greater Cleveland Regional Transit Authority and the Northeast Ohio Areawide Coordinating Agency (December 1998).

Parsons Brinckerhoff Quade and Douglas, Inc., "Travel Demand Model Development Methodology Report." Northeast Illinois Regional Commuter Railroad Corporation (METRA) (June 30, 1999).

Parsons Brinckerhoff, Richard H. Pratt, Consultant, Inc., and RJM Engineering, Inc., "Long Range Model Methodology." Virginia Railway Express Commuter Rail Patronage Forecasts Technical Memorandum (October, 1994).

Pignataro, L. J., Falcocchio, J. C., and Roess, R. P., "Selected Bus Demonstration Projects." *Transportation Engineering Journal*, Volume 96, No. TE3 (August 1970).

Pratt, R. H. and Bevis, H. W., *An Initial Chicago North Suburban Transit Improvement Program 1971-1975 -Vol. I: Report and Exhibits -Vol. II: Technical Supplement.* Urban Mass Transit Administration, U.S. Department of Transportation, Washington, DC (1971).

Pratt, R. H., Pedersen, N. J., and Mather, J. J., *Traveler Response to Transportation System Changes - A Handbook for Transportation Planners* [first edition]. Federal Highway Administration, U.S. Department of Transportation (February, 1977).

Pratt, R. H., and Shapiro, P. S., *The Potential for Transit as An Energy Saving Option.* R.H. Pratt Associates, Inc., Kensington, MD, (March, 1976).

Public Technologies, Inc., "Tri-Met Line 5 Ridership." Vancouver, WA SMD (Service and Methods Demonstration) Brief #4, Urban Mass Transportation Administration, Washington, DC (September, 1980).

Quarmby, D. A., "Choice of Travel Mode for the Journey to Work — Some Findings." *Journal of Transport Economics and Policy*, Vol. 1, No. 3 (1967).

Regional Transit Board, *Transit Service Needs Assessment*. St. Paul, MN (March, 1987).

Rosenbloom, S., "Transit Markets of the Future: The Challenge of Change." *TCRP Report 28,* Transportation Research Board, Washington, DC (1998).

SG Associates, Inc. and Transportation Behavior Consultants, "Marketing Routes and Schedules Study for Charlottesville, Virginia Final Report." Annandale, VA (December, 1982).

Santa Clarita Transit, "Local Ridership [and service measures]." Tabulations, Santa Clarita, CA (1993-1998).

Schultz, G. W., *Modeling Approach*. Memorandum to Seattle Metro Files (March 5, 1991).

Shunk, G. A. and Bouchard, R. J., "An Application of Marginal Utility to Travel Mode Choice." *Highway Research Record 322* (1970).

Southeastern Pennsylvania Transportation Authority, "Sepact III: Final Report — Operation Reading." Sponsored by U.S. Department of Transportation , Washington, DC (June 1971).

Stangeby, I., "The Dream: A Seat on a Bus that is Never Late!" *Norwegian Trial Scheme for Public Transport* (May 3, 1993).

Stanley, R., "Continuing Examination of Successful Transit Ridership Initiatives." *TCRP Research Results Digest 29.* Transportation Research Board, Washington, DC (August 1998).

Tebb, R. G. P., *Passenger Resistance to a Rural Bus - Bus Interchange.* Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Special Report Number 269 (1977).

Tri-State Transportation Commission, "Suburban Service Adjustment Experiment." U.S. Housing and Home Finance Agency, Washington, DC (February 1966).

U.S. Environmental Protection Agency, "COMMUTER Model Coefficients." Washington, DC (October, 2000).

Victoria Transport Policy Institute, "Transportation Elasticities — How Prices and Other Factors Affect Travel Behavior." *TDM Encyclopedia*. http://www.vtpi.org/tdm/tdm11.htm (Webpages updated December 17, 2003).

Washington Metropolitan Area Transit Authority, "Impact of the District of Columbia Fare and Service Changes on Ridership and Revenues. " Unpublished [1995].

Webster, F. V., and Bly, P. H., *The Demand for Public Transport.* Transport and Road Research Laboratory, Crowthorne, Berkshire, England (1980).

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ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation