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Minneapolis-St. Paul Transit Service Reliability Demonstration

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April 1984

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16. Abstract

This report summarizes the results of UMTA's first transit service reliability demonstration. The demonstration was implemented by the Metropolitan Transit Commission on a high-frequency branched bus route--Route 5 in Minneapolis. The aim of the demonstration was to test the hypothesis that a combination of rescheduling and dynamic strategies could improve reliability without significant increases in cost or other negative effects on operation.

The project involved application of a holding point strategy, preceded by schedule changes needed to fine-tune the route. The holding policy was based on improving schedule adherence, although it also incorporated efforts to moderate large headway gaps.

The results of the project indicate that reliability was improved by on-street supervision at a control point combined with application of specific holding policies. Furthermore, indications are that supervision alone was more important than the holding policy in improving reliability and that the benefits were sustained beyond the period of application. This implies that drivers have greater ability to control unreliability than they typically acknowledge, and that further study of driver behavior would be worthwhile. The resulting improvements in reliability should allow operators to reduce fleet size by more than enough to justify the costs of the supervisor. The cost-effectiveness could be even greater if several routes can be monitored at a single control point or strategies can be applied on an occasional basis.

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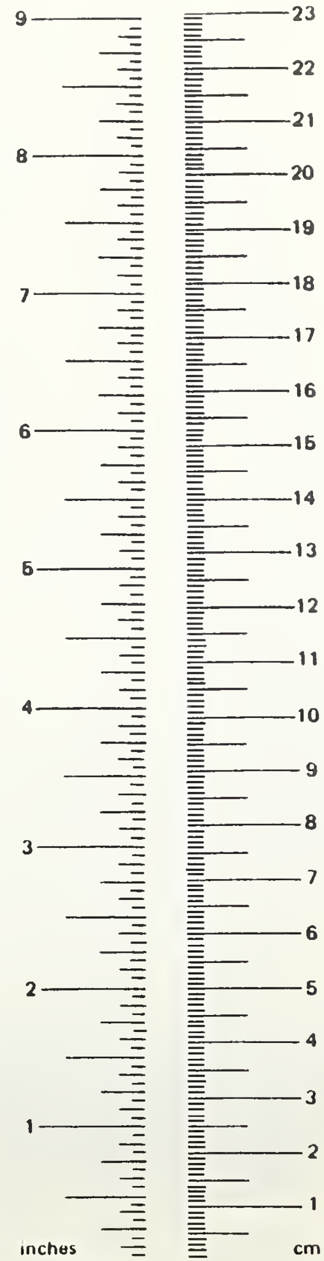
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
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cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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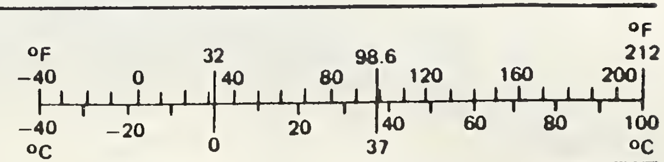
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report summarizes the results of UMTA's first transit service reliability demonstration. The report was prepared by Multisystems, The Consulting Division, Multiplications, Inc. under contract to the Department of Transportation, Transportation Systems Center, Cambridge MA.

The demonstration was implemented on Route 5 in Minneapolis by the Metropolitan Transit Commission. The purpose of the demonstration was to test the theory that a combination of rescheduling and dynamic strategies could improve reliability without significant rises in cost or other negative effects on operation.

The author wishes to thank the following individuals for their efforts over the course of the project:

Robert Waksman	Evaluation Manager, Transportation Systems Center
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Dick Loeffler	Senior Transit Supervisor, Metropolitan Transit Commission
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Bernard Blood — Former Chief, Service Assessment Division, Transportation Systems Center

Carla Heaton — Former Chief, Service Assessment Division and Contract Technical Monitor, Transportation Systems Center

The author also thanks the many others who assisted at various stages of the project.

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CHAPTER 1: INTRODUCTION

1.1 Background

In the past, little technical research in the U.S. has been devoted to a critical aspect of transit operation -- transit service reliability. In theory, transit service reliability is best defined as the invariability of transit level of service characteristics such as travel time, wait time and comfort. Thus, a service with long but invariable travel times (e.g., ranging from 16 to 17 minutes) may be viewed as more reliable than one whose travel times are shorter on average but are very variable (e.g., ranging from 10 to 20 minutes).

Transit travelers typically fall into two groups which view the variability of transit travel times, and thus reliability, in different ways. The first group is composed of the travelers who use transit without consulting the schedule and view variability of service characteristics with respect to their own day to day experience. For these travelers, measures of variability about mean performance are appropriate for characterizing reliability. The second group is composed of the travelers who consult schedules. For these passengers, it is more appropriate to define reliability as the extent to which actual service conforms to or deviates from published scheduled times. Thus, in practice, measures of schedule deviation rather than variability about the average performance are often used. The relative proportions of the two groups depend on the frequency of service and how frequently the traveler uses the service. Where service is very frequent, there is little advantage to consulting schedules, and in some instances schedules are not even distributed to passengers. Frequent users are also less likely than occasional users to consult schedules. Given the mix of travelers on most services, measures of both variability and deviation from schedules are useful in characterizing the service's reliability.

In actual practice, planners and operators often omit measures of both variability and schedule deviation and simply use average measures of performance to monitor service quality. Most demand models have also ignored reliability, despite the fact that numerous studies have documented the importance of transit service reliability in travel behavior decision-making. In order to consider these often ignored aspects of service in planning and evaluation, UMTA undertook a study of transit service reliability.

UMTA initiated its examination of reliability issues in 1976 through the Service and Methods Demonstration (SMD) program[1]. The initial study concluded that:

- For a variety of trip purposes and modes, travelers consider reliability to be one of the most important service attributes, even more important than average travel time and cost, according to some studies. Nevertheless, there has been relatively little work directed at understanding the effects of reliability on mode choice and departure time decisions.

- Operators are more concerned about predictability of bus arrival time at terminals than at intermediate points, despite the importance of the latter for passengers. This is probably due to the drivers' concern with layover time at the terminal and the operator's desire not to delay the next trip, as well as difficulty in monitoring intermediate points. Budget and resource constraints also often severely restrict the operator's ability to improve the situation.

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[1] Abkowitz, et al., Transit Service Reliability, Transportation Systems Center, Report No. UMTA-MA-06-0049-78-1, December 1978.

- Although it is hypothesized that the operator can reduce costs of operation and/or increase revenues by enhancing service reliability, scheduling and other operational considerations may restrict the level of benefits actually achieved. For example, reduced variability in travel time should, in theory, allow layover time to be reduced and schedules to be tightened. However, if the travel time savings are not of sufficient magnitude to save a bus or increase service frequency, there would be no tangible cost savings.

- Environmental factors (such as traffic volume, demand levels, traffic signals, etc.) and factors inherent in fixed route bus operations contribute to service unreliability. An inherent factor causing unreliability is the instability of the headway distribution (i.e., a slight disturbance causes buses to drift toward bunches.) Studies have examined the contributions to variability of various factors, but findings regarding relative importance have been inconclusive to date.

- Techniques for improving reliability fall into three basic categories: priority, control and operational. Priority strategies enable transit vehicles to avoid delays to which other traffic is subjected. Control strategies correct problems en route and prevent further deterioration in reliability. Operational strategies involve changes in fixed schedules or operating procedures that reduce the potential for delays and service disruptions. Among the potentially most useful strategies (experimented with in various European cities) are control point holding strategies, which can be applied with a number of operating rules.

A major conclusion of the SMD reliability study was that additional research was needed, and demonstrations were suggested to test the effectiveness of promising strategies. In response, UMTA began a site selection procedure aimed at identifying transit properties operating routes with severe reliability problems and interested in (and capable of) participating in a demonstration project. The types of reliability problems of interest were bunching of buses, propagation of delays, inconsistent headways (on the trunk portions of routes with branches), and inability to maintain on-time performance. Minneapolis-St. Paul was finally selected as the site for a demonstration, due to its high rating on six evaluation criteria: (1) suitable demonstration routes; (2) adequate radio communication system; (3) weather and environmental factors; (4) evidence of management interest; (5) quality of technical staff and personnel resources; and (6) absence of labor, budgeting, institutional or other factors that would inhibit demonstration purposes.

The demonstration undertaken in Minneapolis-St. Paul was the first UMTA SMD project to focus directly on the issue of service reliability. UMTA provided a grant to the Metropolitan Transit Commission(MTC) of $239,630 to cover the costs of data collection, strategy implementation and administration. The Transportation Systems Center provided technical assistance to the MTC and contracted with Multisystems (the consulting division of Multiplications, Inc.) to serve as the demonstration's evaluator. All three organizations cooperated in the areas of strategy specification, data collection, and analysis. To provide data collection and data preparation services, the MTC contracted with Mid-Continent Surveys.

1.2 Project Description

Objectives and Approach

The overall aim of the Minneapolis-St. Paul project was to test the hypothesis (based on European experience with various reliability strategies) that:

> A combination of rescheduling and real-time techniques may be used by U.S. transit providers to improve passenger perceived level of service and system performance from the operator's perspective without great cost increases or harmful effects to the operation of the service.

Most reliability strategies aim to prevent, mitigate or correct delays and overcrowding. They often attempt to even out loads on consecutive buses so that individual buses do not experience exceptionally long dwell times at stops. Some strategies aim at maintaining even headways since these insure the shortest average wait time to randomly arriving passengers;

even headways do not necessarily provide minimum average wait time if demand is peaked (non-uniform), if service is infrequent, or if passengers cannot use any bus on the route due to differing terminals. In these latter cases, a schedule may be designed which is specifically tailored to meet the non-uniform demand and it is then important to insure that this schedule is maintained.

The various reliability strategies designed to meet these aims can be divided into fixed strategies and those which respond dynamically (or in real-time) to reliability problems. Fixed strategies involve scheduling or policy changes which do not require intervention of supervisors and thus are not typically as costly as dynamic strategies. The effectiveness of these latter dynamic strategies in meeting the above objectives is dependent on the prior development of a schedule which is not only accurate but also aims at similar objectives.

Dynamic strategies are appropriate for correcting disruptions that have already occurred or preventing propagation and worsening of problems. These more costly methods should not be used to deal with problems preventable through improved scheduling, such as predictable lateness and overcrowding. Furthermore, efforts should be undertaken to use scheduling means to avoid chronic variability.

While this demonstration primarily involved the application of dynamic, real-time strategies (in particular, control point holding techniques), scheduling changes were first investigated in order to improve reliability to the greatest extent possible with low-cost (i.e., fixed) methods. Scheduling strategies considered included:

- introducing more express service to minimize the effects of dwell time
- shortening the route so as to reduce the cumulative effects of delays
- modifying layover times to increase the ability to recover from delays and reduce late departures on the succeeding trip

- reallocating buses among branches to even out loads and thereby reduce headway instability

- modifying scheduled arrival times to better reflect average run times

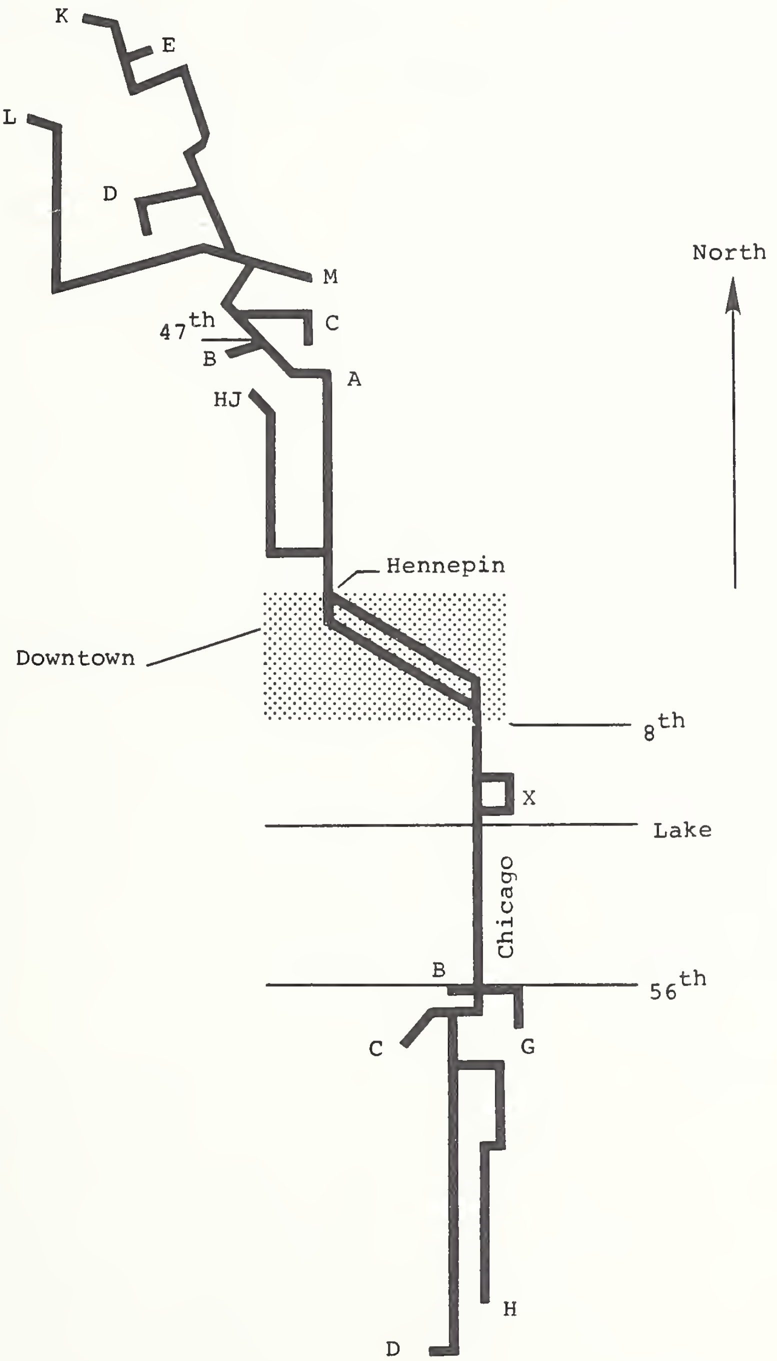
- changing routine operating procedures that may impact reliability, such as dwell time policies at stops, call in procedures, early departures and use of layover times.

Many of these possible approaches were considered and some were eliminated as infeasible or not likely to be appropriate given the nature of the reliability problems detailed on Route 5. The approach taken was a fine-tuning of the schedule in preparation for the application of dynamic strategies. A holding point strategy was viewed as having the most potential and various holding policies were considered. A selected holding policy was then tested and refined for application in the experiment.

Setting

The test route, Route 5 in Minneapolis, was identified by MTC as one having significant reliability problems. This 24 mile long route connects middle class suburban communities to the north and south of the downtown. The route traverses the downtown area, the major medical centers of the city, and several Minneapolis residential areas, including a large minority community. Although most of the 26,000 trips carried on the route each day are directed to the CBD, and several bus trips short-turn in the CBD, some through traffic also takes place. Significant transfers occur to and from Route 5, particularly with crosstown routes (to St. Paul) at Lake Street, south of the CBD.

The route structure includes a number of branches on both the north and south ends, some of which offer service every half hour or even less frequently. Since most buses traverse the 10-mile trunk portion, peak headways on this portion are about 5 minutes. The branching structure made this route a rather complex one to analyze with regard to reliability impacts. Figure 1 shows the route's branching structure, which



Note: Letters indicate north and south terminals.

FIGURE 1. MTC Route 5

has been relatively stable for quite some time; the trunk portion has remained fixed for approximately 50 years. At the outset of the demonstration, the scheduling department at MTC indicated interest in making some changes to Route 5 and expressed the desire to reevaluate the current branching structure as part of the reliability demonstration.

CHAPTER 2: PRE-IMPLEMENTATION PLANNING AND DESIGN

2.1 Preliminary Evaluation of Reliability

Pre-implementation data collection efforts were conducted in the spring of 1979 and the winter and spring of 1980 in order to evaluate the nature of existing reliability problems of Route 5 and to serve as a basis for strategy design. MTC and its data collection contractor, Mid-Continent Surveys, compiled an extensive set of timings, load counts and passenger surveys, which were analyzed by Multisystems and TSC. The data indicated that Route 5 did not exhibit the degree of reliability problems originally expected. For example, passenger surveys showed that only about 1 in 10 riders were dissatisfied with service reliability. These results were rather surprising, since one survey was conducted in winter, when passengers waiting for late buses would have had to stand outside in bitter cold.

Despite the high perceived level of reliability, time check data revealed that there were several locations and time periods which exhibited both considerable average lateness and variability about the schedule, particularly in the p.m. period. Furthermore, running times were rather variable in several locations and headways often differed from the schedule values. Thus, the demonstration proceeded to investigate ways to improve performance with the understanding that it might be difficult in this case to use passenger perceptions as an evaluation measure.

2.2 Schedule Changes

Given the nature of the problems identified, the first step in the demonstration was to optimize the schedule to form a basis for implementing the dynamic strategies. Since the reliability problems identified did not suggest the need for major changes in the schedule, only fine-tuning was believed to be required before proceeding with the dynamic strategies. It should be noted that on other transit routes, one might discover more serious reliability problems requiring other types of scheduling strategies. Specific suggestions for several schedule changes were made by TSC based on analysis of the collected data, and in November 1980, MTC implemented several changes based on a synthesis of TSC suggestions and MTC's own ideas. These included modifications to scheduled running-times and, to a lesser extent, headways. In general, 1 to 4 minutes of running time were added at certain time periods to selected route segments where running times were previously 10 to 15 minutes.

Before the implementation of dynamic strategies, the effects of the schedule changes were evaluated to determine whether they in fact helped improve reliability. However, given the small extent and nature of scheduling changes implemented and the degree to which such changes depend on the pre-existing schedule, the evaluation cannot address the general potential of scheduling strategies. Furthermore, even within this demonstration, it is not possible to make relative comparisons between the effects of the scheduling and dynamic strategies.

The impact analysis of the scheduling strategies examined the effects on schedule adherence (or lateness), loading and headways; it also included comparisons of before and after values of several key measures, such as measures of the average, shape and spread of the distributions of arrival time, schedule adherence, loading and travel time. Generally, the shape measures included the incidence of observations falling outside a range or "reliability window" (e.g., the percentage of trips arriving more than one minute early or more than two minutes late, the percentage of buses with loads greater than the vehicle's seated capacity, etc). The spread measures included standard deviations and other variability measures (e.g., variability about the mean arrival time, variability about the scheduled arrival time, etc). (Section 3.2 provides a detailed description of the measures.) The values of these measures were compared using statistical tests to determine if a change of a specified magnitude was detected at a 95% confidence level. The critical magnitudes of the changes were selected to be important to operators and passengers.

In the assessment, several measures showed important changes, most of these occurring during the p.m. peak period. The schedule changes reduced lateness and the variability of arrival times at the majority of the observation locations in the p.m. period[1] and at some locations in the a.m. period. (As an example of the magnitude of the improvement, note that the average lateness at locations where lateness was reduced was 4.2 minutes in the before case and only 1.2 minutes in the after case, clearly a noticeable improvement.) The "reliability window" measures (that is, those measures of the incidence of service worse than a specified threshold), which are most similar to the types of measures used by MTC's scheduling department, were noticeably affected only during the p.m. period.

In general, the schedule changes were designed to fine-tune running times and improve adherence to the schedule rather than to even out headways or loads, and the data showed that loading was unaffected by the changes. Nevertheless, there may be potential for improvement in loading variability through additional schedule changes. Note that the MTC had established the existing uneven headway distribution (which tends to increase average wait times under uniform demand circumstances) to achieve even loading of buses in the face of non-uniform

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[1] Measures of variability of arrival time (about its mean and about the scheduled arrival time) showed reductions of 25 to 50%.

demands. The substantial degree of variability of loads within hourly time segments (often 10-20 persons per bus) suggests this goal had not really been achieved and that further fine-tuning of the schedule might have been worthwhile.

The schedule changes also affected headway variability; these impacts were distributed throughout the route. Interestingly, in more than half of the cases of improvement in variability of actual headways, the variability of scheduled headways <u>at that point</u> had not been changed. This result suggests that the schedule changes at <u>other</u> locations or times resulted in improved schedule adherence which in turn impacted the actual headway distribution at the given time and location. This supports the theory that service deterioration down the route can be reduced by schedule improvements upstream.

The measures of extremely long headways did not exhibit the improvements found in the headway variability (standard deviation) measures. This is not due to a lack of extreme headways needing correction; before the schedule changes went into effect there were considerable percentages of actual headways greater than 10 minutes, which is indicative of bunching problems. While it may be hard to understand why one measure would show improvement while a related measure would not, there are actually several reasons why this could have occurred. First, large reductions in the number of buses slightly off-schedule could have reduced standard deviation, while inability to affect very late buses through schedule revisions could have constrained improvement in the incidence of long headways. Second, the "importance criteria" we selected for the extreme headway measures may have been stricter than the criteria selected for the headway variability measures; more experience in working with reliability measures will help to determine what the importance criteria should be. Finally, the headway measures themselves may still need to be refined; we examined actual and schedule headways independently, and therefore the measures we used did not fully capture the goal of the scheduling changes which was to improve adherence to scheduled headways.

In summary, it appears that on-time performance improved slightly and that variability of bus arrival times was reduced as a result of the schedule changes made. If one assumes that passengers arrive at bus stops randomly (without regard for the schedule), the effect of these improvements on average wait time would be a reduction of about one-half minute or about 12%. Of course, many passengers on Route 5 plan their arrival at the bus stop by consulting the schedule. Their wait time savings cannot be calculated without more information about their arrival planning, but they should be able to plan their arrivals better since the variability of bus arrival time and schedule adherence was reduced. Since the potential benefits of further schedule changes were not obvious, it was decided to proceed with the experiment of real-time, dynamic strategies.

2.3 Dynamic Strategies Considered

At the outset of the demonstration, the real-time control strategies to be tested were left open to investigation. The spectrum of such strategies which were candidates for consideration included:

- Instructing drivers to increase or decrease running speed and dwell times to the best of their ability, in order to maintain uniform or scheduled headways and/or adherence to schedules.
- Skipping stops in order to close a large headway gap or to compensate for a large deviation from schedule.
- Operating closed door to reduce dwell time and close gaps. This is most useful when buses are already bunched since, otherwise, it is neither easy nor desirable to turn away passengers.
- Instructing the lightly loaded second bus in a bunch to pass the first bus (which is overcrowded and falling further behind schedule).
- Short turning buses operating in a platoon to close a gap ahead (on the return trip).
- Injecting reserve buses to fill gaps.
- Holding buses at control points to maintain either uniform or scheduled headways.

The analysis of before data, route-specific considerations and a review of extant MTC practices suggested that holding strategies might be both the most effective experiment to implement and the most innovative for the MTC. Holding strategies, of course, address only one type of on-street reliability problem, that of maintaining headway and/or schedule adherence in the face of random variations in travel and bus stop dwell times. Their selection for this experiment should not be taken to imply that they are superior to other approaches or that they address all reliability problems on this route.

The belief that holding strategies would prove to be the most interesting stems from several observations:

1. Reliability deteriorates markedly in the route's mid-section (downtown) where a holding strategy would logically be applied.

2. Route 5 is rather long and has a major turnover of passengers at its midpoint. Thus, holding buses at terminals or at the midpoint could potentially benefit a large number of boarding passengers while delaying those few passengers onboard only minimally.

3. MTC's mobile supervisors already employ a number of other corrective strategies to break bunches once they have formed. Thus, a before/after comparison of such strategies might not be a meaningful test.

4. More extensive use of other strategies would have required a much heavier telecommunications load and a change in call-in procedures which MTC viewed as infeasible.

Since holding strategies involving on-street personnel are quite costly to operate, they were not likely to be continued by the MTC after the demonstration. However, the experiment was undertaken with the understanding that other, less costly methods for implementing holding strategies might be worth investigating if the experiment indicated that holding strategies produce substantial benefits.

2.4 Selection of a Holding Point Strategy

Holding strategies generally fall into two major groupings: those aimed at restoring schedule adherence and those directed at controlling or equalizing headways. The former group simply involves enforcement of the schedule by the supervisor (i.e., preventing early departures). The latter group includes a variety of policies. For example, one may delay the bus until the scheduled headway is achieved or one may try to equalize headways before and after the bus in question. Some policies aiming to equalize headways require complete information on the whereabouts of following buses, while others rely on the assumption that the following bus will arrive at the average headway.

Holding strategies can easily deal with early buses, but by definition they cannot <u>directly</u> affect late buses. However, it is believed that early buses contribute to lateness of succeeding buses by increasing the number of passengers to be carried by the succeeding bus. Thus, holding early buses to schedule should result in some improvement in lateness along the route. Since hold-to-headway strategies are focused on headway maintenance, lateness of a given bus with respect to the <u>schedule</u> is not of concern. However, pure hold-to-headway strategies implemented without knowledge about the arrival time of succeeding buses can tend to propagate lateness through the day and result in a longer average headway than desired.

The selection of an appropriate holding strategy should be based on the goals of the strategy. Where service is infrequent, the goal should be to improve adherence to the schedule; where service is very frequent, headways should be the focus so as to keep loads balanced and wait times short. Where headways are scheduled to be uniform (as on many high frequency bus routes), the holding policy may aim at balancing out the headways before and after each bus. In this case, the exact policy may depend on the availability of information about the whereabouts of succeeding buses.

A <u>hold-to-schedule</u> strategy was selected for Route 5 for several reasons:

- The uneven scheduled headways on Route 5 were presumably designed to address non-uniform demand patterns. This means that adherence to the schedule is important to keep buses from overcrowding and keep wait times at a minimum. A hold-to-headway strategy could be counter-productive under these circumstances, even if buses are held to the scheduled uneven headways. Propagation of delays could result in substantial deviation from the scheduled departure times which would sabotage the original intent to match the peaked and non-uniform demand pattern.

- Infrequent service on several branches requires that passengers plan their arrivals according to the schedule; thus schedule adherence rather than headway maintenance is crucial for these passengers.

Detailed analysis conducted at TSC, including simulation of the route's operation, indicated the potential of holding strategies for improving reliability on Route 5. The results indicated that holding p.m. peak buses to schedule at their point of entry into the CBD could potentially reduce deviation from schedule at a minimum of inconvenience to inbound passengers.[1]

2.5 Fine-Tuning the Strategy

In order to fine-tune the proposed strategy, one-day trial experiments were conducted in both the a.m. and p.m. peak periods. In each case, it was found that simple hold-to-schedule policies would not adequately address the route's reliability problems and therefore needed to be augmented or modified. The a.m. and p.m. experimental designs which were developed are discussed briefly below.

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[1] Debra F. Loo, Evaluation of Schedule-Based Holding For Transit Vehicles: A Case Study of Bus Route 5 in Minneapolis, Minnesota, (Staff Study), Transportation Systems Center, May 1981.

The A.M. Peak Period Experiment

The a.m. experiment was designed to improve the reliability of buses along the northbound trunk route for morning inbound travelers. Of particular importance is the Lake Street area, due to transfers from crosstown service which operates from St. Paul. The 47th Street intersection, 17 blocks upstream from Lake Street and 9 blocks beyond the 56th Street trunk terminus, was selected as the optimal holding point by the MTC (see Figure 2).

Observations during the trial experiment indicated that few buses arrived early at 47th Street; therefore, there was little opportunity to enact the holding policy. (It had been hoped that the earlier scheduling changes would have sufficiently alleviated the consistent lateness previously detected on the route.) Furthermore, it was noted that problems downstream were typically created by buses which arrived late at 47th Street causing the following bus to be lightly boarded and to run "hot" (get ahead of schedule) downstream. As a result, the strategy was modified to deal with this typical headway problem without shifting to a more complex headway-based policy which would be disruptive to the schedule. The modified policy was to hold buses to schedule except in cases where the preceding bus was late; in such cases the following bus would be held 1 minute behind schedule. It was hoped that this policy would moderate the headway variation caused by the late bus and the resulting impact on loading, without significantly departing from the schedule. Thus, the modified policy aimed at 1) reducing variability of arrivals and loads and improving schedule adherence at Lake Street, and 2) moderating the effects of headway disturbances. In a sense, it represents a hybrid between a schedule-based and a headway-based holding policy.

The P.M. Peak Period Experiment

The p.m. experiment was designed to ensure that bus departures from the CBD to the south adhere to the schedule. A

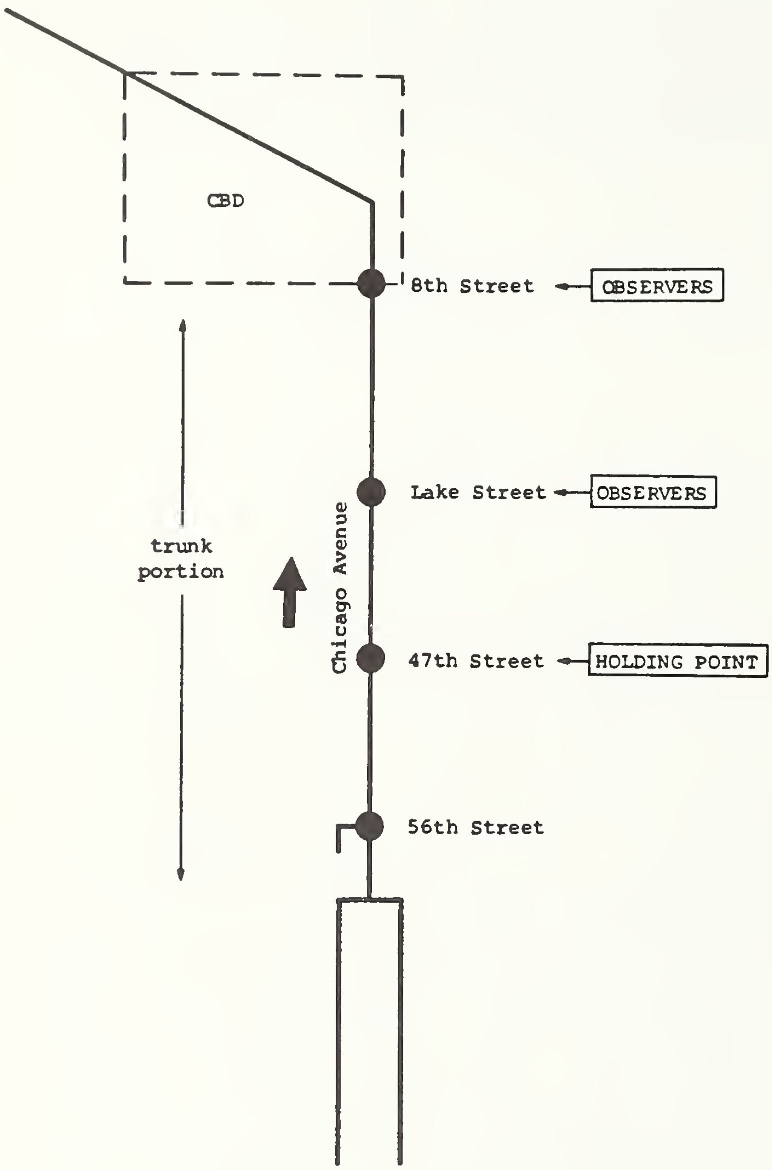

FIGURE 2. A.M. EXPERIMENT (NORTHBOUND ONLY)

holding point was selected just north of the CBD and the initial policy was much the same as that applied in the morning. A test of the policy revealed that there was considerable lateness at the holding point which prevented the holding policy from being enacted. The problem was even greater than experienced in the a.m. experiment. As a result, several modifications were made to the holding policy to adjust for these inaccuracies in the schedule; normally such schedule changes should take place before implementing any holding strategy.

In order to compensate for the fact that buses were consistently late at the holding point, an unofficial schedule change was implemented. It was decided to hold buses to a new scheduled departure time one minute behind the old schedule. Drivers were instructed to maintain the new "schedule" and evaluation of the arrival time at succeeding points was carried out taking this enforced delay into account.

As a result of discussions with MTC staff and the observations of the one-day trial (of the hold-to-schedule strategy), another modification was built into the revised holding policy. Since it was believed that long line buses often suffered from excessive loads (which caused delays), it was decided to reduce the headway between short-line and succeeding long line buses. This was accomplished by making the unofficial schedule change discussed above different for short and long line buses: short line buses were held until two minutes behind schedule while long line buses were held until one minute behind schedule. Thus the P.M. strategy aimed at insuring on-time departures from the CBD (compared to the revised schedule) and reducing unusually high loads on long line buses by adjusting the scheduled headways.

Unfortunately, the results of this strategy were inconclusive; since improvements were detected at some locations and times but negative effects (or no change) were detected at others, it is unclear whether benefits resulted from the holding policy. Perhaps the modifications made to the simple hold-to-schedule policy were responsible for the inconclusive results. The "unofficial" schedule changes, to correct for consistent lateness and to reduce the headway between the short line and succeeding long-line buses, may have introduced additional variation and confused some drivers. Had the strategy been nearly identical to the a.m. strategy one might be forced to conclude that the holding policy is not always effective (or possibly not effective under the p.m. circumstances). However, since the a.m. and p.m. strategies were so different, we believe the a.m. conclusions can stand on their own. Therefore, the following chapter addresses the a.m. experiment only, which was a more straightforward application of a holding policy and more clearly indicates that holding to schedule can yield reliability improvements.

CHAPTER 3: IMPLEMENTATION AND IMPACTS

3.1 Implementation of the Experiment

The a.m. experiment, conducted during February and early March of 1982 between the hours of 6:30 and 9:00 a.m., consisted of three stages. The first stage was a 2-week period of no action during which "before" data was collected by observers at three locations: the holding point (47th Street) and two down-route locations (Lake Street and 8th Street). This was followed by a second 2-week period in which holding strategies were applied by a supervisor at 47th Street and data was collected by on-street observers. Finally, a third 2-week period involved data collection without applying any holding strategy to determine if there were any residual effects. (During this last 2 weeks, a p.m. period experiment was conducted.)

The supervisor at the holding point was provided with an extra bus and driver to use if a major service disruption occurred and it was necessary to inject a bus. (This need did not arise.) Drivers were advised of the experiment and told to report to the supervisor at the holding point and to follow the supervisor's instructions. Drivers were cooperative and the experiment proceeded without any problem.

3.2 Evaluating the Impacts of the Experiment

Measures

The analysis of the impacts of the holding point strategy experiment utilized measures of the average, variability and percent of extreme values for lateness, load and headway characteristics (see Table 1). The selection of measures was based on the recommendations of the earlier UMTA study which specified that measures of spread (variability) and skewness (extreme values) were necessary to fully characterize reliability. In some cases, the measures are rather complex due to a desire to capture the viewpoint of the daily traveler or exclude the effects of the schedule. Due to the fact that there are no data available with which to compare the estimated values, the measures are more difficult to interpret than more typically used measures.

For lateness, measures included the average deviation from the schedule (Measure #1 in Table 1), obviously a key measure for travelers who consult schedules, and a measure of extreme deviation (including both lateness and earliness; Measure #2). This latter measure was the percent of buses which fell outside a reliability "window". Two different windows were used. In the first case, the window was specified as from 1 minute early to 2 minutes late and, in the second case, from 2 minutes early to 5 minutes late. These measures, which address the circumstances most onerous to passengers and operators, are most similar to the on-time performance measures used by MTC and many other transit authorities. (It may be desirable to separate early from late departures, especially where service frequencies are low; this was not done here in conformance with MTC procedure.) Finally, two measures of arrival variability were used. The first is a measure of schedule adherence and was expressed as a "root-mean square" of schedule deviation(#3). The second is a measure of absolute arrival variability, that is, the variation of arrival time about the mean for each bus(#4). This measure, which isolates system variability effects from those related to scheduling most closely approximates the experience of the traveler who rides the same bus frequently and does not consult the schedule.

Similar types of measures were used for load and headway effects. For load, three measures of load variation were used in addition to average load(#5), which in itself is not a measure of reliability but is information required for making

TABLE 1. MEASURES OF RELIABILITY USED IN THE EVALUATION

Impact	Measure	Criteria
LATENESS:		
1.	Average deviation from schedule	1 minute
2.	Percent of very late or early buses - Outside the reliability "windows," from 1 minute early to 3 minutes late and from 2 minutes early to 5 minutes late.	5%,10%
3.	"Root-mean-square" of schedule adherence	½ minute
4.	"Root-mean-square" of arrival variability (with respect to bus average arrival)	½ minute
LOADING:		
5.	Average load (not in itself a measure of reliability).	5 pass.
6.	Percent of very overcrowded buses (reached capacity and crush load)	5%, 10%
7.	Standard deviation of load	5 pass.
8.	"Root-mean-square of load" - (with respect to the daily average load)	5 pass.
HEADWAYS (ACTUAL AND SCHEDULED):		
9.	Average headway	1 minute
10.	Percent of very large gaps	5%, 10%
11.	Standard deviation of headway	½ minute

comparisons. A measure of overcrowded buses(#6) was utilized to capture the incidence of such problems. Both percent of buses at seated and 125% of seated capacity were identified, taking into account the added capacity of articulated buses in each case. A simple "standard deviation" measure(#7) was used to characterize the variability of loads on a series of consecutive buses. A second measure was designed to remove the normal day-to-day load variation from the measure by examining variation with respect to average load for the given day during the time period of interest. This measure took the form of a "root-mean square of load" (#8).

Headway measures included average headway(#9), the percent of very large gaps (specified as both 7 and 10 minutes; #10) and the standard deviation of headway(#11). Note that the standard deviation is directly related to the wait time passengers experience, which for randomly arriving passengers can be easily calculated. Since the route does not have uniform scheduled headways, the above measures were calculated for both actual and scheduled headway distributions in order to contrast actual headway variation with that already "built-in" to the schedule. Nevertheless, the headway effects remain somewhat difficult to interpret due to the non-uniform nature of the schedule. Finally, at the holding point, measures of dwell time, similar in specification to those of headway, were also calculated.

At the outset of the analysis, minimum changes (criteria) between before and after observations of a measure were specified which would be considered "important" to detect. Statistical tests were applied to determine whether changes of this magnitude had occurred. If the requirements of statistical tests were not met, it was concluded that there was insufficient evidence of an "important" change.

Impacts

Dwell time data at 47th Street (the holding point) indicate that only about 20% of the buses were actually held. The average dwell time for those buses was about 0.5 minutes and fewer than 4% were held to one minute behind schedule. While this indicates that the strategy was minimally disruptive, it also suggests that either very few buses arrived at the holding point early during the test period or, possibly, that the strategy may not have been completely adhered to by the supervisors. In fact, as will be described further on, the most likely explanation is that the drivers exerted a substantial influence on reliability because they were under surveillance.

In any case, a comparison of measures before and during the experiment reveals that there were reductions in several measures which meet our criteria for importance and statistical significance (see Table 2). The measures of arrival variability and schedule adherence (lateness) variability were reduced by more than 40% at all three locations where an observer was stationed. (In the case of the holding point, departure time was used rather than arrival time for constructing these measures in order to capture the effect of the holding strategy.) The reduction at the holding point was on the order of what had been expected based on TSC's simulation of holding to average arrival time.[1]

The measures of extreme lateness, the percent of buses outside the 2 minutes early/5 minutes late window, were reduced at the holding point from 10% to less than 2%. As one proceeds down-route, the improvement in lateness diminishes more sharply than the improvement in the arrival variability and schedule adherence measures. This is most likely due to the fact that the strategy completely eliminates any early departures from the holding point but not from downstream locations.

The strategy also brought about reductions in the variability (i.e, standard deviation) of headways, but these reductions were relatively small and diminish substantially as one proceeds down-route. While the standard deviation of actual headway was reduced by 31% (from 3.8 to 2.6 minutes) at the holding point, it should be noted that some portion of the

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[1] Loo, op. cit. p. 48

TABLE 2. RESULTS OF THE A.M. EXPERIMENT

Measure		Before	During	Percent Reduction	Follow-up
Percent of Buses More than 2 Min. Early or 5 Min. Late (#2)	47th	10.2	1.6	85	2.1
	Lake	14.3	3.8	73	7.4
	8th	17.4	10.0	43	15.4
Root-Mean Square of Schedule Adherence (#3) (in minutes)	47th	3.6	1.7	54	2.0
	Lake	3.3	1.9	42	2.1
	8th	4.5	2.6	41	3.1
Root-Mean-Square of Arrival Variability (#4) (in minutes)	47th	2.3	1.0	56	1.2
	Lake	2.6	1.5	43	1.7
	8th	3.4	1.8	47	2.4
Standard Deviation of Actual Headway (#11) (in minutes)	47th	3.8	2.6	31	3.4
	Lake	4.0	2.9	27	3.2
	8th	4.1	3.6	13	3.7
Standard Deviation of Scheduled Headway (#11) (in minutes)	47th	2.6	2.3	12	2.2
	Lake	2.1	1.9	10	1.9
	8th	1.9	1.9	0	1.9

standard deviation is built into the schedule (since headways are not scheduled to be uniform) and therefore would not be removed even if all buses adhered to the schedule absolutely. (Note that the "built-in" standard deviation was measured at 2.3 to 2.6 minutes.) Moreover, since the standard deviation measure is aggregate in nature, this large reduction achieved in actual variability, which resulted in a standard deviation on the order of the "scheduled" level, does not mean that the service was subsequently adhering to scheduled headways.

While various other measures (including load variability, percent of large loads and percent of long headways) showed reductions, they did not meet the criteria for importance or significance. The fact that variability of loads did not show improvement indicates that a substantial anticipated benefit of improved reliability never occurred (i.e., increased productivity and passenger comfort through more efficient distribution of loads). While some unevenness in load is inevitable at some points along the route, due to the combination of long and short branches, evidence from the p.m. period, when long-line and short-line buses were investigated separately, suggests that the largest portion of the variability was among buses of similar length branches, and therefore that some of the problem may be due to schedules which do not reflect current demand.

The importance of reduced headway variability to the randomly arriving trunk passenger is illustrated by calculating the expected average wait time (for any Route 5 bus). The average wait at the Lake Street bus stop during the a.m. period is estimated as 4.2 minutes in the "before" case and 3.6 minutes in the "during" case. Thus, average wait time theoretically improved by about 14% due to the 47% reduction in headway variability.[1] However, because of the short headways on the trunk, the absolute value of this improvement is obviously quite small.

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[1] The average wait time for passengers who arrived without regard to the schedule is in theory a function of average headway and headway variability.

This small improvement could have a substantial effect on the transit operator, however, if the route is operating considerably under capacity. The operator then could reduce fleet size by increasing scheduled (average) headways so that the average wait time was the same as before the improvement. In the example above at Lake Street, average headway could theoretically be increased from 5.6 to 7.3 minutes, which could result in a 20% reduction[1] in fleet (or 10 buses). This assumes that average wait time for randomly arriving passengers is the only level of service variable of interest. In reality, however, many passengers (particulary on longer headway branches) plan their arrivals. Presumably, for these riders, the longer headway would be offset by shorter waits due to improved ability to plan arrivals. Other level of service factors must also be considered. For example, given the observed loading characteristics on Route 5, reducing the scheduled headway would be likely to cause crowding at some locations and times of day. A further constraint on headways for this particular route results from its branching characteristics, which would limit flexibility in adjusting the schedule. Thus, only a portion of the estimated fleet size reduction benefit could be realized by the operator.

Nevertheless, if just one bus could be eliminated (a rather conservative assumption since it is only 10% of the theoretically possible savings and a mere 2% of the fleet operating during the peak) a savings of $80,000 per year might result -- more than enough to justify the annual cost of a peak period supervisor ($50,000). Since this route did not exhibit a high degree of unreliability and since supervisors might be able to monitor more than one route at some control points, one would expect higher cost-effectiveness in some other applications. Based on these results, the stationing of on-street supervisors at control points seems to be an idea worthy of further study.

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[1] This percent reduction is a rough approximation based on only the shorter trunk trips; applying the percentage to the entire route's fleet, as many as ten buses could be saved.

A very interesting finding of the experiment which could make holding strategies look even more cost-effective was the fact that immediately after removal of the strategy, most of its benefits were sustained. One explanation for this might be that the presence of the supervisor and the implementation of control raised driver awareness and concern about on-time performance. The implication is that perhaps these strategies need not be applied on a continuous basis in order to improve service levels, and stationing on-street supervisors at control points on a rotating basis would be nearly as effective at a much lower cost. This is especially true if the benefits of a supervisor could be spread over several routes in this manner. The results of the experiment suggest, at least, that applying these strategies on a part-time basis would be cost-effective.

While the general conclusion of the experiment is that reductions in several measures of reliability can be achieved by the stationing of supervisors on the street to control bus departures, this does not say whether the effect is due to the holding strategy or simply the presence of on-street supervisors and checkers. The premise of the experiment was that drivers alone cannot control for random variation effects brought about by traffic and passenger demand and require the intervention of the supervisor to implement a holding policy. However, it may be that simple surveillance of bus operations could induce drivers to take action to correct for delays due to exogenous influence and to restrain their tendency to run "hot" (so as to maximize their layover time). This latter hypothesis is supported by the fact that during the strategy application the vast majority of buses were not held, and that the removal of the supervisor did not cause service to deteriorate markedly.

To examine this phenomenon further, the arrival times at the holding point before and during the experiment were compared; the arrival times at the holding point showed nearly as much improvement as the departure times. One can infer from this that drivers were able to improve service reliability on their own, and that the incentive or motivation to do so is the important issue. The fact that supervisors were on-the-street and were expected at certain locations seems to have been more important than the specific corrective actions they took.

This does not diminish the importance of the finding that reliability was still improved after the supervisor was removed. One can assume that drivers realized the supervisor was no longer monitoring performance after several days had passed without a supervisor at the holding point. (While checkers remained on the street, they were at concealed locations whenever possible as in the "before" data collection period.) Thus, even though the holding strategy may not have had a hold-over effect, supervision itself appears to impact service beyond the period in which it is administered. Unfortunately, even this conclusion is tempered by a possible complication: since the p.m. experiment was in place on the same days as the follow-up observations of the a.m. experiment, the presence of a supervisor during the p.m. could have had an influence on the drivers a.m. behavior.

CHAPTER 4: CONCLUSIONS AND IMPLICATIONS

4.1 Conclusions

Although there are a variety of dynamic strategies that can be applied to improve transit service reliability, this experiment focused on holding strategies which are easy to implement and do not propagate lateness. During the a.m. period, a modified schedule-based strategy, which also adjusted for headway gaps, was used.

The results of the experiment suggest that a substantial portion of variability in time-related service characteristics can be eliminated by stationing supervisors at key control points. Large relative improvements were detected both at the control point and, more importantly, at key loading points downstream. Variability of headways and arrival times were reduced to nearly half their previous levels and a substantial amount of the remaining variability appears to be due to the nature of the schedule rather than random effects. The most noticeable improvements were the reductions in the percent of very late (or early) buses and in the percent of long headways. However, because the reliability problems experienced on Route 5 were rather modest, the absolute values of the detected improvements were small. Furthermore, the effects of the strategies on the variability of vehicle passenger loads were minimal.

The detected headway variability improvements translate into improvements of just under one minute in average wait time for randomly arriving passengers; they also reduce wait time for other passengers who plan their arrivals at the bus stop to coordinate better with bus arrivals. While the wait time improvement may seem small, it could result in substantial reductions in required fleet size if the operator chose to reschedule the route to maintain perceived service quality (i.e., average wait time) at previous levels. The degree to which this can be achieved depends on the current loading levels and passenger perceptions. However, if just one bus is saved (only 10% of the theoretical potential savings), estimates indicate that the supervisor's time would be well worth the benefits. Locating control points where several radial routes intersect could further improve cost-effectiveness.

Another important conclusion of the demonstration, supported by the fact that improvements in several measures were sustained over the short-term, is that the benefits of supervisor control/holding strategies may extend beyond the duration of the strategy's application. (Note, however, that there is a chance that the presence of a supervisor on the route in the p.m. peak period may have influenced the drivers and thus affected this finding.) If this conclusion is valid, perhaps supervisors may be rotated through several points in a transit system to maximize the benefits of the strategy.

A result of this demonstration which is potentially very significant was that the presence of the supervisor at the control point likely did more to improve driver adherence to schedule than the holding action the supervisor enacted. This indicates that drivers may have more control over schedule adherence than they acknowledge. Note that the use of on-street supervisors, which was more prevalent several decades ago, declined as their usefulness and effectiveness were questioned. MTC makes very little use of stationary on-street supervisors (although it does use mobile supervisors). While this demonstration did not test all methods of supervision, it did indicate that supervisors can have a substantial impact on reliability and can justify their cost on this basis. A subject of interest related to the results of this project is whether surveillance by radio or AVM would yield results similar to human supervision. These possibilities should be examined in further experimentation.

It is evident that drivers have ability to control a substantial degree of unreliability in transit operation, and that supervisor presence, possibly enhanced by particular holding strategies, can bring this capability into action, and appears to be cost effective. However, before any specific course of action can be recommended, further investigation of the effects of supervision, alternative holding strategies and alternative methods for encouraging drivers to excercise their control capabilities is required.

The potential impact of supervisory presence also has important implications for any future data collection efforts. Data collected "openly" is likely to show reliability characteristics which are better than those experienced by passengers and could mislead operators into believing that service is reliable when it is not. The most promising way around this dilemma is to introduce some type of automated data collection, such as AVM or APC's.

The experience gained with the measurement of transit service reliability (and the data collection necessary to estimate the measures accurately) is among the most significant benefits of this project. Specifically, the project included several new measures of reliability which were designed to: 1) capture the viewpoints of both frequent passengers and passengers who consult schedules, and 2) include both the "spread" and "shape" of the distribution of service and characteristics. The costs of data collection and analysis needed for application of either scheduling or dynamic strategies should not be underestimated. The sample sizes necessary for estimation of variability effects are large and editing of data must be done carefully to avoid inclusion or exclusion of erroneous data, without distorting the measures.

The experience gained in this project should help in the design and implementation of future reliability demonstrations.

4.2 Transferability

Several complicating factors make it difficult to determine whether the conclusions of this demonstration are transferable to other possible applications. Assuming that the presence of a holding point in the p.m. period (at a different location on Route 5) did not influence drivers during the a.m. period, it seems safe to suggest that the conclusion that the strategies will have an effect extending beyond their application period is transferable to other sites. Unfortunately, the opening assumption may be tenuous.

The effects of the scheduling changes themselves are very specific to this application. On a route with more severe reliability problems, problems of a different nature, or a different route structure, it is possible that more substantial impacts might have been detected.

The fact that the supervisor's presence had a greater impact than the holding strategy itself is of questionable transferabilty. The degree of reliability problems on Route 5, the effectiveness of scheduling changes, and of course the pre-implementation use of only mobile supervisors may have impacted the results of the demonstration.

4.3 Future Research

This demonstration was the first UMTA has sponsored to investigate issues of transit service reliability. The demonstration applied new measures of reliability in keeping with the recommendations of the earlier theoretical study, and it identfied some potential for particular courses of action, namely on-street supervision and holding point control strategies. It is appropriate that the Service and Management Demonstration Program follow up on these findings and continue to study ways to improve transit productivity and level of service through similar management techniques. Further experimentation with both techniques and measurements should prove useful to transit operators who have to "do more with less" in a period of budget constraints.

This demonstration's program of tasks was somewhat complicated by the rather complex structure of Route 5. It should also be noted that the route did not exhibit severe reliability problems, despite the fact that it was a high priority problem route for the MTC. It is recommended that routes with simpler structures and schedules that are experiencing severe reliability problems be selected for succeeding demonstrations. A more straightforward evaluation of both scheduling and dynamic strategies would then shed light on the relative potential of these measures before further study of complex (yet rather typical) routes like Route 5. It should be remembered, however, that a single demonstration is unlikely to yield conclusive results on the potential of scheduling strategies due to their route and site specific nature.

Several unexpected findings resulted from this study. While the focus was on strategy definition and implementation, issues related to personnel (both drivers and supervisors), came to the surface, and it appears that the potential effectiveness of the driver may have been underestimated in the past. Perhaps, the most useful research would be to investigate how drivers can be motivated to use their abilities better to correct reliability problems.

Questions to be answered in further research include the following:

Holding Strategies:

- Can supervisors be more effective by implementing particular holding point strategies?
- Which strategies are appropriate to which types of routes?

- Does the benefit of implementing holding strategies and/or disciplinary supervision really extend beyond the period of administration? If so, how long?

Supervisor Deployment:

- How does the effectiveness of mobile supervisors compare with that of supervisors stationed at a holding point?

- Can a supervisor effectively monitor and implement strategies on more than one route?

Driver Motivation and Control:

- What are the driver reactions to on-street supervision and holding strategies?

- Is the employee "production circle" concept (where employees contribute to management policies and set their own goals) applicable to transit operation? Could it encourage drivers to use their own control capability more effectively?

- How can on-time drivers be rewarded to encourage better performance (e.g., higher pick priority or vacation bonuses)?

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