Human Factors for Transitway Safety Improvement

Final Report for Phase II

Prepared for:

Intelligent Transportation Systems' Institute
Center for Transportation Studies
University of Minnesota

Prepared by:

Stephen Scallen, Ph.D.
Interim Director, Human Factors Research Laboratory

and

Stirling Stackhouse, Ph.D.
Independent Consultant

November 1998

ACKNOWLEDGMENT

This human factors study was conducted as part of the Transitway Safety Improvement Program. The program was guided by a committee formed by the Department of Safety and Health at the University of Minnesota. The Transitway Safety Improvement Committee was chaired by Paul Tschida, the Assistant Vice President for Safety and Health Management.

This human factors study was sponsored by the Intelligent Transportation Systems' Institute at the University of Minnesota's Center for Transportation Studies. Mr. Lowell Benson served as the Program Manager. The authors want to acknowledge the contributions of many undergraduate students who participated in the project as data collectors.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

This sheet deliberately left blank

EXECUTIVE SUMMARY

This report details human factors evaluations of a 3.1 mile dedicated bus route (buses and emergency vehicles) connecting Minneapolis and St. Paul campuses of the University of Minnesota. The dedicated route (Transitway) contains eight intersections. Two intersections are controlled by signal lights activated by the approach of a bus and six intersections are controlled by STOP signs. The motivation for the study was the unexpected increase in the number of accidents when the route was transferred from city streets to the Transitway in March, 1992. This human factors initiative was conducted as part of the Transitway Safety Project at the University of Minnesota.

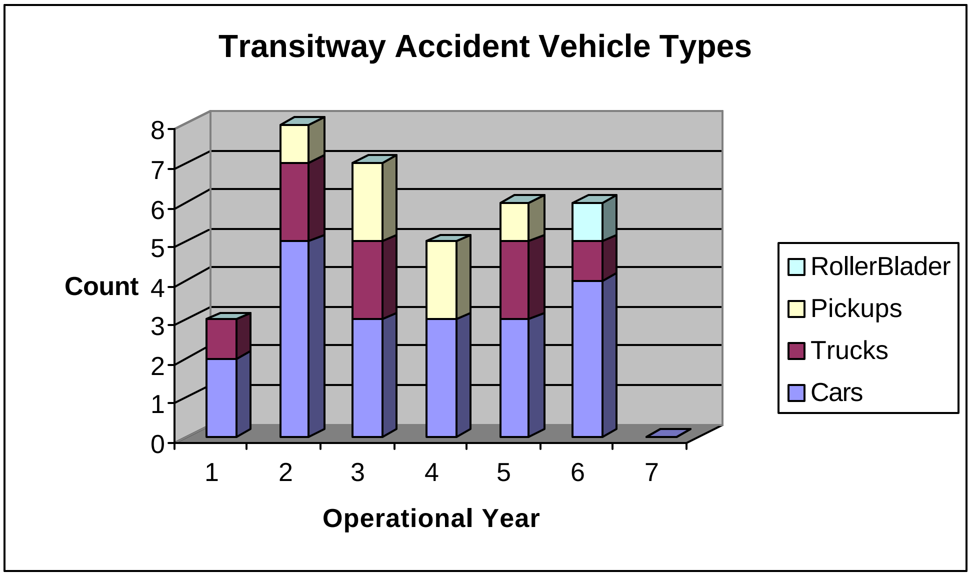
Research was conducted in two phases. In Phase I, the Human Factors Research Laboratory (HFRL) at the University of Minnesota evaluated bus driver behavior, sight distances at intersections, and behavior of the driving public at each of the eight intersections. Complete results can be located in the Phase I final report. In short, Phase I evaluations concluded: bus drivers were operating vehicles within established guidelines; only 5 of the 32 triangular sight distances met minimum guidelines; and two percent of drivers run STOP sights with about 50% use a rolling rather than a full stop.

Subsequent to the Phase I study completion, numerous improvements were implemented in the Transitway. Major changes consisted of adding warning lights at STOP signs and fiber optic highlighting at STOP signs. At certain intersections, loop sensors detected the approach of a vehicle and activated warning lights or messages. In addition, small strobe lights were attached to the tops of buses; a bicycle path was added alongside the western end of the Transitway; landscaping was changed at some intersections and these changes either increased or decreased the sight distances; and NO TURN and other non-electronic warning signs were added.

The present report details Phase II research, a 1998 evaluation of the effectiveness of the safety improvements implemented in the Transitway, using the same measures as those used in Phase I, with the exception that bus driver evaluations were dropped from Phase II research. The following is a summary of Phase II conclusions and recommendations.

The overall accident rate prior to Transitway improvements was 0.44 accidents per month. This rate didn’t change until electronic devices were activated in January 1998. These data should be interpreted with care as accidents are rare events. These statistics merely *imply* that the Transitway is as dangerous a roadway as the average Minnesota roadway.

A single cause for the Transitway accidents which have occurred over the first five years was not identified. However, data suggests that certain factors acting in combination may have contributed to Transitway accidents. Overall data indicated only a slight improvement in driver behavior with an overall five percent increase in the frequency of complete stops. Transitway improvements had little or no impact on the frequency of STOP sign running, with an overall rate of about two percent steady across the two phases of research. Three intersections demonstrated behavioral improvements, two demonstrated behavior detriments and data for one intersection did not support a definitive conclusion. Behavioral effects did not seem to be specific to warning devices, although the fiber optic lighted stop sign demonstrated some potential. A single intersection demonstrated a dramatic rise in red light violations, with anecdotal reports supporting the conclusion that specific safety efforts should be directed at this intersection. There have been no 1998 accidents as shown in year 7 of the following chart.



Analyses of the triangular sight distances indicated that some sight distances at intersections have been improved over the Phase I measurements. However, other sight distances have been decreased by the installation of cabinets for the electronic control equipment. At several intersections, vegetation continues to obstruct stop line sight lines. Short triangular sight distances suggest that average approach speeds should be reduced (for non stopping drivers). Calculations of required average speeds to enable a complete stop at a STOP sign indicated that only one intersection would support a speed greater than 10 mph.

Data collected in Phase II also suggested that the increase in the number of signs at intersections has contributed to visual clutter, too many messages which were too close together in space and time. Signal light timing continues to appear to be sub-optimal at two intersections. Bus drivers were regularly observed slowing and even stopping at intersections.

Discussion of Phase II results suggested that Transitway safety improvements were overly focused on enhancing the utilitarian value of STOP signs. There was no data suggesting that the ordinary STOP signs were obscured either visually or in meaning to drivers approaching the Transitway. Accident reports did not suggest that alcohol contributed to a reduction in drivers' understanding of the meaning of STOP signs or that visual obscurity contributed to accidents. Most evidence suggests that drivers see and comprehend the STOP signs.

Recommendations did not specifically address the problem of risk-taking behavior or scofflaws, other than to suggest a more frequent and conspicuous police presence at Transitway intersections. Other recommendations were:

- Improve sight distances by eliminating the sight line obstacles whenever this is possible. Where not possible, employ warnings such as BLIND DRIVEWAY.
- Implement and enforce lower speed limits on streets approaching Transitway intersections.
- Be especially diligent and thorough about snow and ice removal at the approaches to the Transitway intersections
- Adjust the timing parameters of the bus-actuated system for switching traffic lights to permit buses to drive at a constant speed when approaching and passing through the intersections.
- Considering the development and use of "new wave" messages designed to have high impact (NEVER HIT A SCHOOL BUS. THE BUS WILL HIT BACK) Messages could address the factors cited above as potentially accident causing. Such messages should be on programmable electronic media and changed frequently to maintain their impact.

(This page intentionally left blank)

INTRODUCTION

The University of Minnesota's Transitway connects the Minneapolis and St. Paul campuses with a 3.1 mile roadway restricted to buses and an adjacent path for bicycles. The Transitway's intersections, whether controlled by signal lights or stop signs, always give the right of way to the buses and bicycles on the Transitway. Buses run about every five minutes in both directions from 7:00 a.m. to 4:30 p.m. and then every 30 minutes until 9:30 p.m. The bus traffic volume during the day on the Transitway is thus 228 buses per day during the day and 54 buses during the evening. A Metro Transit bus line also uses the transitway. The streets intersecting the Transitway with the highest volumes have about 900 vehicles per day.

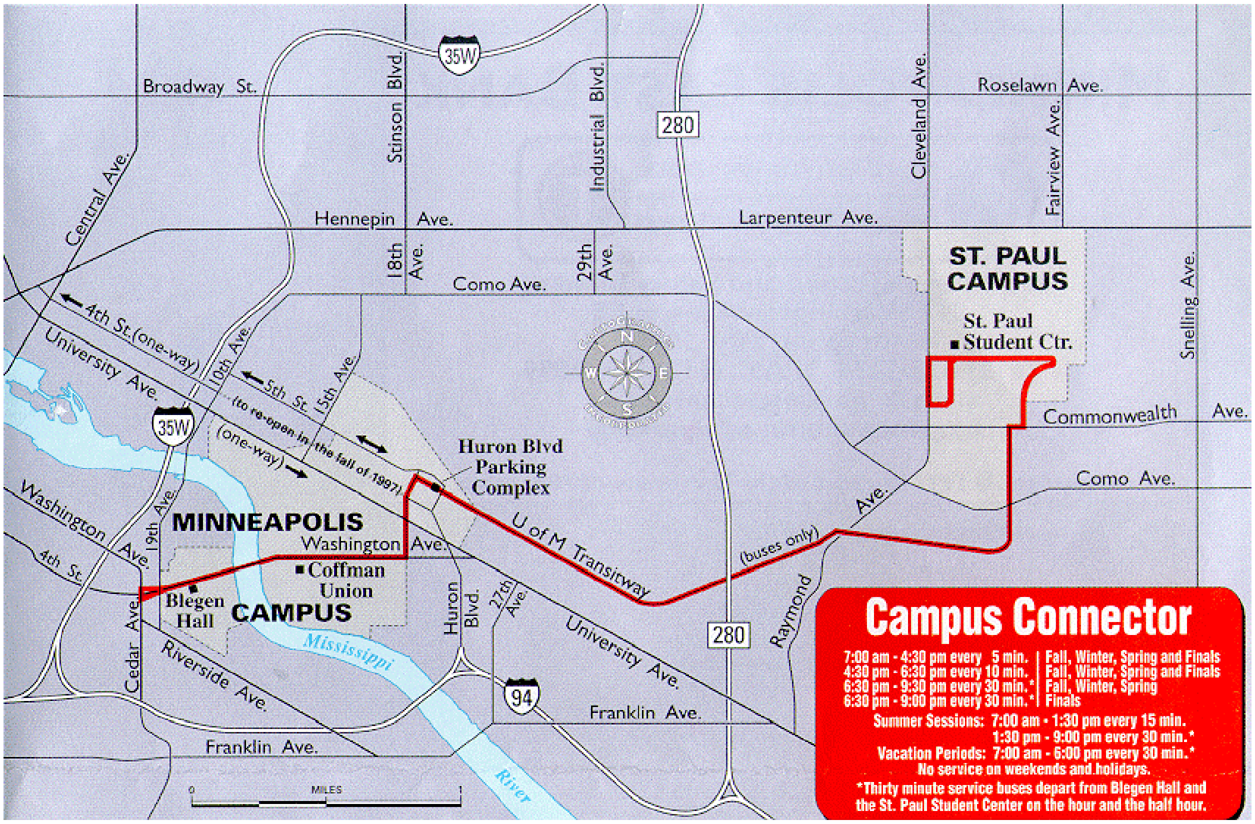


Figure 1. The University of Minnesota's Transitway Bus Route.

Project Motivation

In the year before Transitway operation began, the buses transferring students between the Minneapolis and St. Paul campuses operated on city streets. There was one minor accident in the last year of operation on the city streets. In the first five years of Transitway operation there had been on average nearly one accident for each two months of operation, a six-fold increase in accident rate. It is important to identify the reason or reasons for this apparent change in accident rate since the Transitway was expected to reduce accident frequency. Until we understand why Transitway accidents occur, it will be difficult to implement cost effective solutions for reducing the number of accidents.

A Phase I human factors study (1) was performed to identify potential causes of accidents at eight Transitway intersections. Data were collected on bus operators' driving behavior, on motorists' behavior at Transitway intersections then on triangular sight distances at the intersections. Triangular sight distances are usually determined when ascertaining the warrant for stop signs at railroad crossings. The study included the sight distance analysis because of the functional similarity. Accident frequencies were calculated based on the number of cars crossing each intersection per year. Data were related to the immediate causes of reported accidents.

Phase I analysis of data (for vehicles crossing the Transitway, not the Transitway buses) suggested that the following were potentially contributory to intersection accidents:

- Two percent of the drivers ran the stop signs and about 50% of the drivers used a rolling rather than a full stop.
- About 20% of drivers did not look both ways before crossing the Transitway.
- Winter weather brought slippery roads and reduced visibility conditions.
- The timing for bus actuated traffic lights might not be optimal.
- Only five of the 32 triangular sight distances met minimum guidelines.

The data supports the idea that each of the above factors may have contributed to Transitway accidents. Interpretation of the data suggests that combinations of these factors are more likely to have contributed to accidents than any factor operating alone. The causes of accidents are complex and combinations of factors causing accidents need not be the same for all accidents.

While we had no suggestions for eliminating the risk-taking behavior of scofflaws, we recommended a more frequent and conspicuous police presence at Transitway Intersections. Other Phase I recommendations were:

- Improve lighting at the intersections to improve visibility. We cannot prevent snow or fog but we may be able to reduce their impact on drivers' ability to detect on-coming buses.
- Improve sight distances by eliminating the sight line obstacles whenever this is possible. If this is not possible, then information signs could be used to warn drivers of the short sight distances. For example, one such frequently seen sign in cities is BLIND DRIVEWAY.
- Be especially diligent and thorough about snow and ice removal at the approaches to the Transitway.
- Adjust the timing parameters of the bus actuated system for switching traffic lights to permit buses to drive at a constant speed when approaching and passing through the intersections.
- Consider the effect on accident reduction of reducing bus speed. We showed the clear relationship between bus speed and sight distance (1). This could be especially important in the vicinity of intersections where sight distances cannot be improved.
- We recommended considering the development and use of 'new wave' messages on signing for the streets intersecting the Transitway. The signing could be done on portable or permanent electronic signs. Messages would address the factors cited above as potentially accident-causing. The messages would be designed to have high impact. For example, NEVER HIT A SCHOOL BUS. THE BUS WILL HIT BACK.

Potential Accident Causes

Several potential causes for Transitway accidents, either singly or in combination, seem possible:

- *There is no real increase over the pre-Transitway accident rate. Our observations on relative accident frequency are the result of sampling error and chance fluctuations.*

There is no valid way to make statistical comparisons between the pre- and post-Transitway accidents. Clearly, city streets and the Transitway differ in ways which suggest that direct statistical comparisons based solely on number of accidents would have no meaning. The amount of traffic interacting with the buses is much greater on city streets than on the Transitway and this cannot be used to explain the difference in numbers of accidents. The best we can do in trying to decide whether there has been a real increase in accidents, is to make the common sense observation that the Transitway, which was meant to reduce travel time between campuses, has instead resulted in a six-fold increase in accidents. While we may not be able to demonstrate statistical significance, we can state our surprise and seek for the reasons which may account for this unexpected and unwanted outcome.

- *Bus drivers are careless or deliberately engage in risk taking driving behavior.*

We included this potential reason for the increase in accidents based on the following observations.

On May 5, 1995 one of the authors of this report took a round trip Transitway ride starting at the Huron Boulevard Parking Lot boarding at about 11:20 am and leaving the bus at the main bus stop on Bufford St. near the St. Paul Campus Student Center. While waiting about ten minutes for a return bus, two seemingly significant events were observed.

Improper Parking. Just east of the bus stop shelter, on the sidewalk at curbside on the north side of Bufford St., is a fire hydrant. Opposite the fire hydrant, a station wagon was parked with the driver behind the wheel. An incoming bus going west on Bufford St. parked closely alongside the station wagon with the bus's front door just in front of the station wagon's front bumper and the bus's rear door just behind the station wagon's rear bumper. The first passenger pushed the front bus door open to leave the bus. At this instant, the station wagon accelerated just missing the disembarking passenger. This was very close (less than one second) to producing a serious injury.

Left Turn at Intersection. Another bus departed and with its loud horn blowing continuously. It was the bus going west on Bufford St. and approaching the T-intersection with Cleveland Ave. The light was red as the bus approached. However, the bus driver initiated and completed the left turn onto Cleveland while running the red light. This was not even close to a yellow light dilemma. The bus was going slowly and the driver had plenty of time to stop for the red traffic signal. Fortunately, both north- and south-bound traffic on Cleveland Ave. stopped to let the bus driver make the left turn on their green light. This was not a close-call.

A potential reason for running the red light is the additional observation that if northbound traffic on Cleveland Ave. stops close to the Bufford intersection, it is difficult for the bus driver to make the left turn onto Cleveland Ave. without hitting the encroaching car. Space for making the turn is limited.

- *Bus drivers have become relaxed and overly confident due to the apparent protection afforded by the right-of-way for Transitway buses.*

This possible, but incorrect contributory explanation, was explored by collecting data as described in the Methods Section of this report.

- *Drivers of vehicles crossing the Transitway are scofflaws and this driving behavior at the Transitway intersections may sometimes result in accidents.*

The results from collecting data on this issue are described in the Results Section.

- *Poor geometry at the Transitway intersections contributes to accidents.*

The intersections on the Transitway are nearly orthogonal and level. However, short sight distances, as described below, could be contributory.

- *The traffic control signs and signals for the intersecting streets are in some way inadequate.*

We can not directly provide data bearing on this issue. However, based on other comparisons we can draw tentative conclusions on the effectiveness of the signs and signals.

- *Unauthorized vehicles on the Transitway are a cause of accidents.*

We have some data on this issue but found that it could only be a weak contributor, if it contributes at all, to Transitway accidents.

- *Other subtle, less identifiable factors are causing the accidents.*

The only way to be sure that the above statement is not true, is to be able to account for all or almost all of the observed accidents by means other than those just listed.

Literature Review and Analysis

In this review we noted that there was little literature on roadways analogous to the University of Minnesota's Transitway. There were, however, numerous transit authorities either considering or developing busway-like operations. Brief descriptions of some of these projects are identified below.

- Pittsburgh. Pennsylvania has developed two dedicated busways and is now planning a third. The Sought Busway was opened in 1977 and operates as a 6.4 km (4 mile), two-lane, two-direction, limited-access roadway. The counter-flow lanes help speed buses from the South Busway and other routes south of the Monongahela River through downtown Pittsburgh. The East Busway (later renamed the Martin Luther King East Busway) is a 6.8 mile, two-lane bus roadway built on exclusive right-of-way, connects Downtown Pittsburgh with densely populated neighborhoods in the City's East End, Borough of Wilkinsburg, and other east suburban communities. On the East busway routes operate exclusively on the busway except in the downtown area. On the South busway buses and LRT share the right of way. In 1993, a 2.5 mile East Busway extension was being planned. Pittsburgh was also considering a 19-mile Airport Busway (1993). Additional information on the Pittsburgh busways can be located in (7) (8) (9) and (10). Safety statistics for the Pittsburgh busways were not available to the authors. However, at least two major accidents have been documented. Early in the South Busway operation there was a serious accident involving a bus (7). In 1996, Two commuter buses on the East Busway collided head-on on a snow-covered highway, killing one of the drivers and injuring at least 52 people, several seriously (11).

- Auckland, New Zealand. The North Shore Busway is a combination of busway and high priority vehicle lane designed to improve the efficiency of passenger transport through the Northern Corridor. Construction of the busway is expected to commence in 1998. New Zealand has also initiated a 'Buses First' program that aims to make bus travel more reliable by reducing the travel time of buses and taking buses out of traffic congestion. 'Bus Priorities' comprise a package of bus lanes, signal pre-emption (where buses can set lights to green), super-low-floor buses, improved information, and more frequent bus services.
- Brisbane, Australia. The proposed Inner Northern Busway will be the second stage of the South East Queensland Busway Network which, when complete, will encompass at least 75 kilometers of dedicated busways and around 65 stations. The Council and Queensland Transport have commissioned an Impact Assessment Study and Feasibility Study of the Busway project.
- South Dade, Florida. The Florida Department of Transportation (FDOT) constructed a 8.2 mile roadway just for Metrobus routes. Express buses on the exclusive lanes shuttle passengers from Dadeland South Metrorail station to Cutler Ridge Mall and South Dade Government Center. Both full-size buses and minibuses operate on the Busway and in adjacent neighborhoods, entering the exclusive lanes at major intersections.

- Other major cities. Other major US cities that are believed to be operating or developing exclusive busways or barrier-separated high occupancy vehicle (HOV) facilities include: Portland, OR; Houston, TX; Los Angeles, CA; and Virginia. Those cities operating buffer-separated and non-separated HOV facilities include: Seattle, WA; Los Angeles, CA; Marin Co., CA; and Miami, FL. Descriptions of these facilities were unavailable to the authors.

Accident and safety information for busways was difficult to obtain for a variety of reasons. In some cases, collision and accident information was unavailable or was not formally reported. In most cases, agencies did not specifically report busway information or incorporated information into categories such as HOV accident rates. Information in this form may not relate to the present project because HOV facilities often share right-way-privileges. HOV facilities vary in design as well. They may be barrier-separated, buffer-separated, or non-separated facilities. Nevertheless, a report prepared for the Federal Transit Administration (US DOT) addressed HOV and adjacent facility accidents rates (12). For barrier-separated facilities (four cases), number of accidents per million vehicle miles were lower (range 0.4-1.0) for HOV lanes than for adjacent mixed flow lanes (range 1.1-2.4). For buffer-separated and non-separated facilities (five cases), number of accidents per million vehicle miles were generally higher for HOV lanes (range 1.9-3.2) than for adjacent mixed flow lanes (range 1.3-3.6).

A case study of HOV project experiences indicated that the implementation and operation of HOV lanes have not caused a noticeable increase in accidents, nor have the facilities degraded safety. However, the authors noted that complete information on accidents was not available for many areas due to different reporting procedures by local and state enforcement agencies, incomplete accident records, and difficulties in determining the cause of a specific accident. Citing studies conducted in Minneapolis, Los Angeles/Orange County, and Santa Clara County the authors concluded that HOV facilities were operated safety and have not adversely impacted the safety of the freeway general-purpose lanes (13). Similar conclusions were presented by (14) who stated that the limited information made available seems to indicate that accident rates for the HOV lanes are generally either lower, or the same, as those reported ton the general-traffic lanes.

A report evaluating the public interest of HOV facilities concluded that HOV lane construction is in many ways creating rather than solving traffic problems. Trends toward allowing general purpose traffic on HOV lanes in non-peak periods is increasing accident and enforcement problems. The authors suggest that bus-only lanes have lower accident rates than general purpose lanes, whereas HOV lanes have higher accident rates than general purpose lanes (15).

In summary, available literature indicates that busways and, to a lesser extent HOV lanes, have accident rates comparable to general purpose areas. Additional literature, including literature related to railroad-highway grade crossings, since this is, to an extent, analogous to the Transitway intersecting streets situation is located in Appendix A.

Human Factors Project Objective

The objective of this project is to collect and analyze data related to human factors aspects of Transitway safety. This information can be used to identify aspects of the Transitway which contribute to accidents at Transitway intersections. Knowing the source of safety problems may help to suggest further solutions which may increase Transitway safety.

Following the completion of the Phase I Human Factors study, various changes were made at the Transitway intersections (see 'Methods'). When these implementations were completed, the Phase II Human Factors study was begun. The purpose of Phase II was to look for differences ascribable to the new implementations at the intersections.

Report Organization

We collected independent sets of observations which related to one or more of the potential accident causes listed above. For each of these sets, we presented a description of the method used. Once all the methods were discussed, the results were shown. In the Discussion and Conclusion and Recommendations sections all results were discussed together rather than an independent discussion for each set of observations. We have emphasized comparisons between the Phase I and Phase II findings, relating these comparisons to the new implementations at the intersections and the accident data.

METHODS

New Transitway Features

This section presents the changes in the Transitway that were made during the Program. These changes are summarized here and are more extensively documented by Sohrweide and Benson (5). This summary is taken from the information in (5).

- Efforts were made to improve stop line sight distances at intersections (details are presented in a subsequent section, 'Sight Distances') (Summer 1995).
- A bicycle path was added, paralleling the western portion, displaced a few feet from the road.
- Small strobe lights were installed on the top of buses (Summer 1997).
- Signing and warning devices were installed at intersections (see below) (Fall 1997).

STOP Signs and Warning Devices

The following presents the changes made at each of the intersections included in this study which do not have traffic control signals (Energy Park Drive and Como Avenue have signals). The traffic control lights switch to green for buses and red for cross traffic when an approaching bus is detected. Stop signs and warning signs at the other intersections are located on both the right and left sides of the intersecting streets.

At the 23rd Avenue and Westgate Drive intersections, continuously flashing, red warning lights were mounted above the standard STOP signs.

Figure 2. View of the STOP sign and red warning light at 23rd Ave. SE and Transitway.

Figure 3. View of the STOP sign and red warning light at Westgate and Transitway.

At 25th Avenue, red warning lights were mounted above the STOP sign these lights flashed when detector loops sensed an approaching bus or an approaching bicycle. A couple of seconds after the bus passed the intersection the lights stopped flashing.

Figure 4. View of the STOP sign and red warning lights at 25th Ave. SE and Transitway.

At 29th Avenue, a fiber optic STOP sign (white border and letters outlined with fiber optic illumination) was installed which was activated by detector loops.

Figure 5. View of the STOP sign at 29th Ave. SE and Transitway.

At 30th Avenue, a blank-out (BUSES/BIKES DO NOT STOP) illuminated warning sign was installed which was activated by Autoscope™ video detection.

Figure 6. View of the STOP sign and illuminated sign at 30th Ave. SE and Transitway.

At Malcolm Avenue, a blank-out fiber optic warning sign, activated by Autoscope™, was installed.

Figure 7. View of the STOP sign and fiber optic warning sign at Malcolm and Transitway.

Both the detector loops and the Autoscope™ provided 10 seconds of warning for buses approaching at 30 mph and seven seconds of warning for buses approaching at 40 mph.

NO TURNS Signs

White signs with black lettering stating NO TURNS were installed at some of the intersections in 1996. From the drivers point of view these signs are on the far side of the Transitway. The Minnesota's Manual on Uniform Traffic Control Devices (4) is ambiguous relative to placement of NO TURNS signs. This sign placement suggests that once the driver has crossed the Transitway, no turns should be made. However, the actual intention is to tell the driver not to turn onto the Transitway.

Intersection Observations

Students were trained in data collection techniques using materials and procedures developed in Phase I of this study. To ensure data collection consistency among observers and across Phases, additional training was developed. All collectors were interviewed by the first author (instructor) for suitability. Collectors and the instructor then reviewed the data collection sheets and instructions for recording observations were provided. Collectors then reviewed a video tape film of a transitway bus ride, recorded from the perspective of the bus driver. Intersections were noted by the instructor. Collectors then reviewed a video tape recorded from a recommended observation position at some target intersections. The video tape depicted numerous auto-intersection encounters. The instructor reviewed relevant aspects of driver behavior and environmental variables as the tape played. Eventually, collectors were required to record their observations using the data collection sheet. The sheet was reviewed for accuracy by the instructor. Upon completion of these training procedures, collectors entered the field to engage in data collection. Other instructions and constraints for the data collection operation are outlined below:

- Data were only collected during daylight hours
- Data were only collected Monday through Friday.
- Data was not collected during snow or rain or while pavement conditions were adversely effected by snow or rain

- When a line of traffic occurred, only the first vehicle was used for data collection purposes.
- Motorcycles were not considered for data collection purposes.
- For 'Type of Vehicle' evaluation, 'car' was operationally defined as a four-wheel automobile or minivan used for personal transportation. 'Light truck' was defined as a pick-up truck, or panel truck (van) used for personal transportation. 'Commercial truck' was defined as a truck, van, or any cargo-carrying vehicle used for business purposes (usually displayed a business logo or identifier). 'Semi-truck' was defined as an 18-wheel cargo-carrying vehicle.
- For 'Type of Stop' evaluation, 'complete' was operationally defined as the total absence of forward vehicle movement. 'Yield' was defined as a minimum forward movement, characterized by initial deceleration but observable continuous forward movement. 'Ran it' was operationally defined as an extension of 'yield' where the rolling speed and forward movement was excessive enough to move the vehicle into the intersection before any other driver behavior could be completed (e.g., look both ways).
- For 'Did Motorist Look Both Ways' evaluation, 'yes' was operationally defined as noticable head turn to both the left and right. 'No' was defined as the absence of a noticable head turn to either the left or the right. 'Unable to See' was recorded for any vehicle observation where the observer could not view the drivers head position or was less than 100% confident in a 'yes' or 'no' observation.
- For 'How many Buses Were in Sight?' evaluation, a bus was considered 'in sight' when it could be seen by a motorist while stopped at the intersection stop line.
- For 'Was There an Incident' evaluation, 'incident' was operationally defined as any crash involving vehicles, pedestrians, bicyclists, or in-line skaters occurring at an intersection or as a direct result of actions taken while at an intersection.

Sight Distances

If all drivers crossing the Transitway always stopped at the stop signs and red traffic signals, we would not need to consider sight distance. Unfortunately for safety, this is not the case. Measurements and calculations were collected during Phase I to aid in interpreting the safety impact of these sight distances. The calculations are based on a study by Easa (2) which was in turn based on Federal Highway Administration's and American Association of State Highway And Transportation Official's guidelines. Figure 8 depicts the conventional sight line triangle.

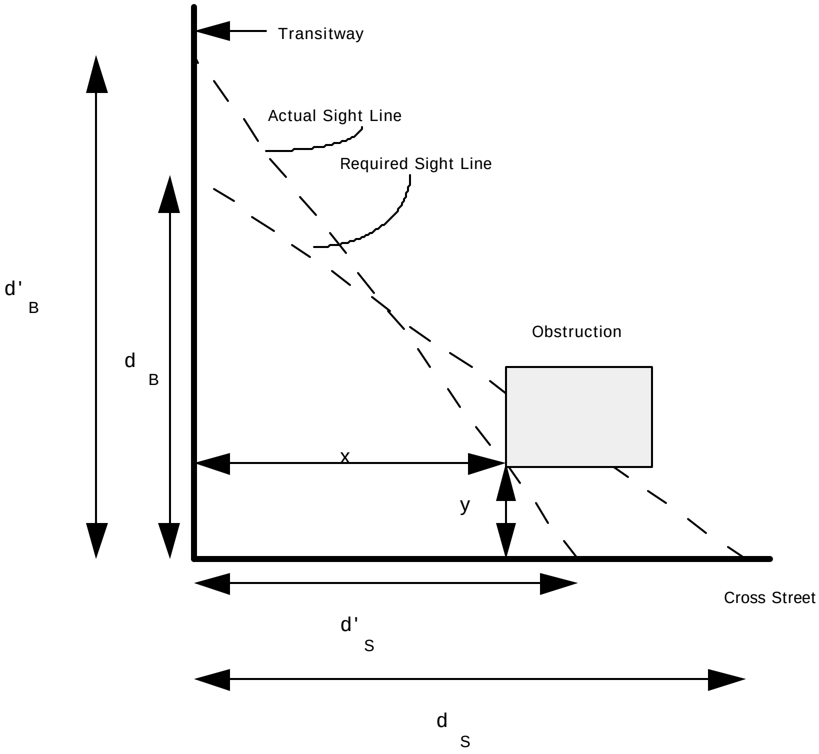


Figure 8. Sight line triangle.

To address the sight distance leg (in feet) along the avenue Equation 1 was employed (Phase I).

$$d_S = 1.47\ Vv\ t + (Vv/30\ f) + D + De \qquad [1]$$

To address the sight distance leg along the Transitway we used Equation 2.

$$d_B = Vv[1.47Vv\ t + (Vv/30f) + 2D + L + W] \qquad [2]$$

where,

D_S = sight distance along the avenue

D_B = sight distance along the Transitway

Vv = velocity of the approaching vehicle (in mph)

Vb = velocity of the Transitway bus

t = perception/reaction time (2.5 seconds)

f = coefficient of friction (f= 0.429 - (0.0023 Vv)

D = distance from the stop line to the near edge of the bus (10 ft)

De = distance from the driver to the front of the vehicle (8 ft)

L = length of vehicle 20 feet, W = width of Transitway lanes (40 feet)

In the Results Section of the Phase I report actual, measured sight distances were compared with the required sight distances calculated from Equations 1 and 2. There are three cases of potential interest: 1) The case in which a car is stopped at the crossing and we wish to know the distance down the Transitway required to detect an oncoming bus; 2) The case in which a vehicle is approaching the Transitway and the driver fully intends to stop or nearly stop; and 3) The case in which a driver either deliberately or inattentively will run the stop sign or red traffic signal. The first two cases are not of interest here, since it is unlikely that accidents will be caused when drivers observe the signs and signals controlling Transitway crossing. For the third case, however, when drivers fail to stop at the stop sign or red traffic light, these drivers would need to see down the Transitway in both directions to avoid hitting a bus or being hit by one.

In Phase I we compared the measured and calculated sight distances with the recommended sight distances. Between Phase I and Phase II, some changes were made to the Transitway surroundings which affected sight distances. Brush, bushes and trees were trimmed or removed and certain areas were designated NO PARKING. These changes were intended to improve (increase) sight distances and often succeeded. Other changes were made such as the installation of electronic control cabinets for the intended improvement of signing at the Transitway intersections. These cabinets had the undesirable effect of serving as obstructions which decreased sight distances at the Transitway intersections. The reason for considering these changes in sight distances relates to the consideration of sight distance effects in Phase II. If we assume that sight distance improvement such as trimming or removing bushes and weeds and sight distance reductions due to the placement of electronic equipment cabinets represent the best that can be done for sight distance improvements, then we should consider methods which might be used to encourage drivers to cope with short sight distances. The obvious suggestion to the motorist is to request a speed reduction on the approach to the Transitway intersection. This is something that can be undertaken beyond the prior efforts to improve sight distances. In Phase II we have expressed sight distance findings as the speed ranges necessary for safely approaching the intersection given the location of the obstructions to the sight line. To determine these speeds, we have used actual measurement values of x and y values as defined in Figure 1. Equation [3] shows the relationship for the x and y variables using the definitions of variables shown above:

$$\frac{x}{d'_H} = \frac{d'_r - y}{d'_r} \qquad [3]$$

We have adopted a convention for labeling directions. In what follows, the Transitway runs east and west and the crossing avenues north and south even though this is not strictly correct for all intersections.

Figure 9 shows the required vehicle *average* speed for bus speeds of 20 mph and 40 mph

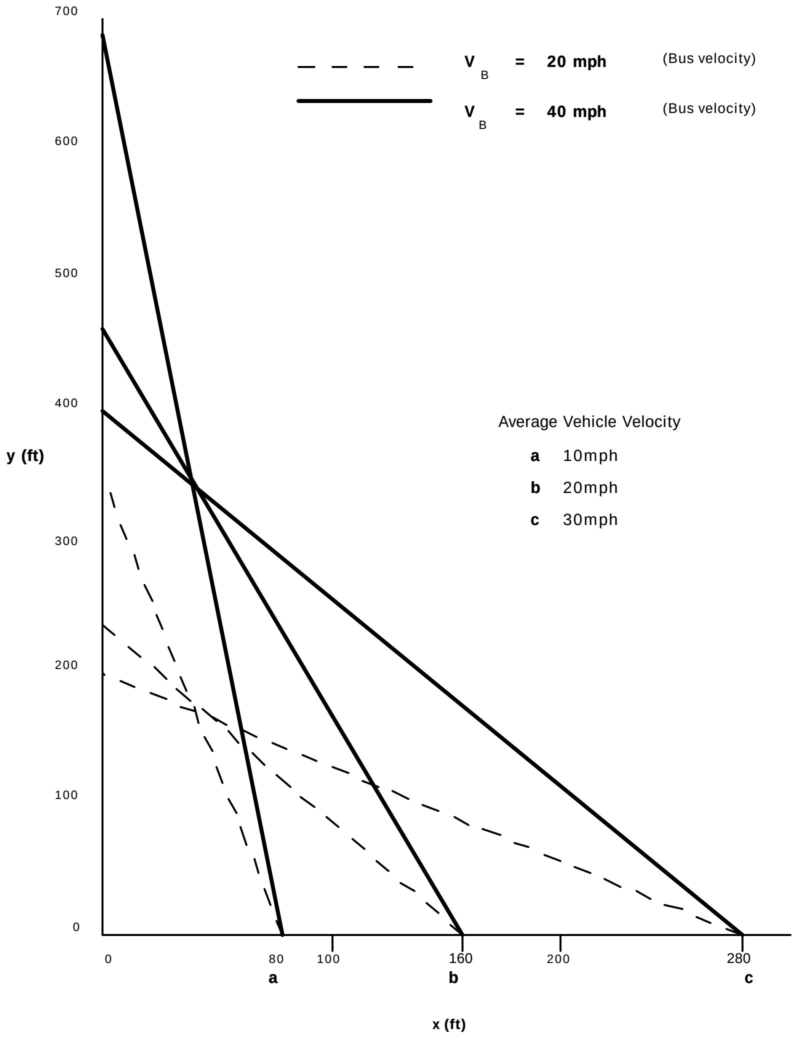


Figure 9. Required vehicle average speeds for Transitway bus speeds of 20 mph and 40 mph.

The values of x and y, as defined in Figure 9, are presented in the results section. At each intersection there are four x, y pairs of distances. These values for x and y are defined in Figure 10.

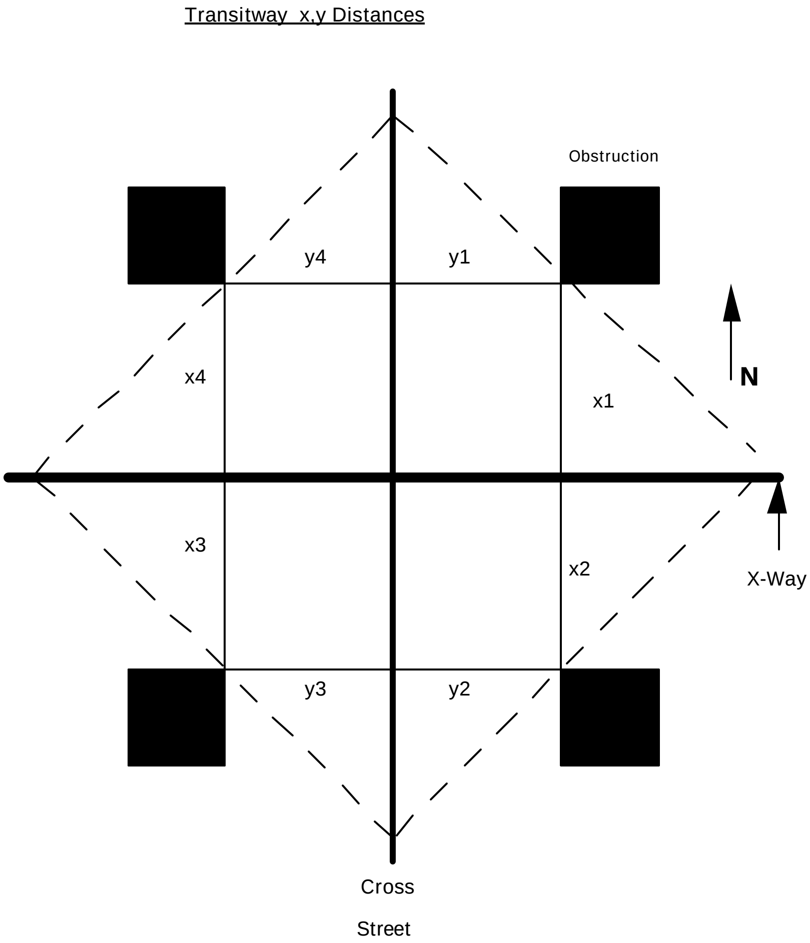


Figure 10. Definition of the x, y distances for cross street-Transitway intersections.

The vehicle speeds, with respect to x and y shown in Figure 2, hold for vehicle average speeds of less than 33 mph and this is the case for Transitway intersections.

RESULTS

(BEFORE AND AFTER TRANSITWAY CHANGES)

Intersection Observations

Data collection sheets were collected and tabulated by the first author. Only complete observations were included in the analysis (e.g., if 'type of vehicle' was not filled in, the entire observation was disregarded). Observations for motorcycles were also disregarded (3 observations). In total, 2601 independent observations were included in the analysis. Number of Observations by intersection are reported in Table 1.

Table 1. Number of Observations by Intersection.

Intersections	Phase I Observations	Phase II Observations	
23rd	210	278	
25th	563	563	
29th	205	203	
30th	391	377	
Malcolm	240	285	
Westgate	281	324	
Energy Park Dr.	265	284	
Como Ave.	265	287	
	2420	2601	5021

Data for motorists' behavior at 23rd, 25th, 29th, 30th, Malcolm, Westgate, Energy Park Dr., and Como Ave. are summarized in Tables 2-9, respectively. Overall data (all intersections combined) are summarized in Table 10. In all tables, Phase I data are also displayed to facilitate comparison with new Phase II data.

Table 2. Motorists' Behavior at 23rd Ave. SE and Transitway.

All data is frequency with percentage of total in brackets ( )

Total Number of Crossing Vehicles

*Phase I	**Phase II
210	278

Direction of Crossing Vehicle

	Phase I	Phase II
Northbound	95(45)	102(37)
Southbound	115(55)	176(63)

Type of Crossing Vehicle

	Car		**Lt. Truck**		**Co. Truck**		**Semi-Truck**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	145(69)	173(62)	41(20)	68(24)	23(11)	29(10)	1(00)	8(03)
Northbound	67(69)	68(67)	19(20)	23(23)	11(11)	9(08)	0(00)	2(02)
Southbound	78(69)	105(60)	22(19)	45(26)	12(11)	20(11)	1(01)	6(03)

Type of Stop for Crossing Vehicle

	Complete		**Rolling**		**Ran It**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	105(50)	68(25)	102(49)	204(73)	3(01)	6(02)
Northbound	42(42)	25(24)	56(57)	74(72)	1(01)	3(03)
Southbound	63(57)	43(24)	46(41)	130(74)	2(02)	3(02)

Did the Motorist in the Crossing Vehicle Look Both Ways?

	Yes		**No**		**Observer Did Not See**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	180(86)	254(91)	23(11)	15(05)	7(03)	9(03)
Northbound	80(84)	89(87)	8(08)	4(04)	7(07)	9(09)
Southbound	100(87)	165(94)	15(13)	11(06)	0(00)	0(00)

No. of Buses Within Sight for the Crossing Driver

	Zero		**One**		**>One**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	170(81)	177(64)	32(16)	94(34)	8(03)	7(03)
Northbound	74(78)	69(68)	18(19)	28(27)	3(03)	5(05)
Southbound	96(83)	108(61)	14(12)	66(37)	5(04)	2(01)

*Phase I conducted in 1996

**Phase II conducted in 1998

Table 3. Motorists' Behavior at 25th Ave. SE and Transitway.

All data is frequency with percentage of total in brackets ( )

Total Number of Crossing Vehicles

Phase I	Phase II
563	563

Direction of Crossing Vehicle

	Phase I	Phase II
Northbound	278(49)	279(50)
Southbound	285(51)	284(50)

Type of Crossing Vehicle

	Car		**Lt. Truck**		**Co. Truck**		**Semi-Truck**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	265(47)	267(47)	200(36)	118(21)	69(12)	66(12)	29(05)	112(20)
Northbound	124(44)	131(47)	106(38)	60(22)	40(14)	37(13)	10(04)	51(18)
Southbound	141(50)	136(48)	94(33)	58(20)	29(10)	29(10)	19(07)	61(21)

Type of Stop for Crossing Vehicle

	Complete		**Rolling**		**Ran It**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	273(48)	285(51)	280(50)	269(48)	10(02)	9(02)
Northbound	149(50)	145(52)	133(48)	131(47)	4(01)	3(01)
Southbound	133(47)	140(49)	147(52)	138(49)	6(02)	6(02)

Did the Motorist in the Crossing Vehicle Look Both Ways?

	Yes		**No**		**Observer Did Not See**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	500(89)	440(78)	18(03)	5(01)	45(08)	118(21)
Northbound	257(96)	226(81)	7(03)	4(01)	5(02)	49(18)
Southbound	243(83)	214(75)	11(04)	1(00)	40(14)	69(24)

No. of Buses Within Sight for the Crossing Driver

	Zero		**One**		**>One**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	486(86)	450(80)	62(12)	107(19)	14(02)	6(01)
Northbound	242(88)	225(81)	26(09)	49(18)	8(03)	5(02)
Southbound	244(85)	225(79)	37(13)	58(20)	6(02)	1(00)

*Phase I conducted in 1996
**Phase II conducted in 1998

Table 4. Motorists' Behavior at 29th Ave. SE and Transitway.

All data is frequency with percentage of total in brackets ( )

Total Number of Crossing Vehicles

*Phase I	**Phase II
205	203

Direction of Crossing Vehicle

	Phase I	Phase II
Northbound	104(51)	107(53)
Southbound	101(49)	96(47)

Type of Crossing Vehicle

	Car		Lt. Truck		Co. Truck		Semi-Truck	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	81(39)	92(45)	59(29)	75(37)	40(20)	18(09)	25(12)	18(09)
Northbound	37(36)	42(39)	30(29)	41(38)	26(25)	13(12)	10(10)	11(10)
Southbound	44(43)	50(52)	29(28)	34(35)	14(14)	5(05)	15(15)	7(07)

Type of Stop for Crossing Vehicle

	Complete		Rolling		Ran It	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	124(60)	158(78)	75(37)	43(21)	6(03)	2(01)
Northbound	72(66)	84(79)	32(29)	23(21)	5(05)	0(00)
Southbound	52(54)	74(77)	43(45)	20(21)	1(01)	2(02)

Did the Motorist in the Crossing Vehicle Look Both Ways?

	Yes		No		Observer Did Not See	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	189(92)	190(94)	8(03)	2(01)	8(04)	11(05)
Northbound	93(89)	97(91)	5(05)	1(00)	6(06)	9(08)
Southbound	96(95)	93(97)	3(03)	1(01)	2(02)	2(02)

No. of Buses Within Sight for the Crossing Driver

	Zero		One		>One	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	178(87)	166(82)	26(12)	34(17)	1(00)	3(01)
Northbound	96(92)	89(83)	7(07)	16(15)	1(01)	2(02)
Southbound	82(81)	77(80)	19(19)	18(19)	0(00)	1(01)

*Phase I conducted in 1996
**Phase II conducted in 1998

Table 5. Motorists' Behavior at 30th Ave. SE and Transitway.

All data is frequency with percentage of total in brackets ( )

Total Number of Crossing Vehicles

*Phase I	**Phase II
391	377

Direction of Crossing Vehicle

	Phase I	Phase II
Northbound	204(52)	178(47)
Southbound	187(48)	199(53)

Type of Crossing Vehicle

	Car		**Lt. Truck**		**Co. Truck**		**Semi-Truck**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	178(46)	202(54)	161(41)	113(30)	39(10)	28(08)	13(03)	34(09)
Northbound	93(46)	103(27)	84(41)	49(28)	18(09)	14(10)	8(04)	12(07)
Southbound	85(45)	99(26)	77(41)	64(32)	21(11)	14(07)	5(03)	22(11)

Type of Stop for Crossing Vehicle

	Complete		**Rolling**		**Ran It**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	214(55)	282(75)	166(42)	94(25)	11(03)	1(00)
Northbound	114(56)	142(80)	83(41)	35(20)	6(03)	1(01)
Southbound	100(53)	140(70)	83(44)	59(30)	5(03)	0(00)

Did the Motorist in the Crossing Vehicle Look Both Ways?

	Yes		**No**		**Observer Did Not See**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	358(92)	335(89)	11(03)	2(01)	22(01)	40(11)
Northbound	179(87)	162(91)	7(03)	1(01)	20(10)	15(08)
Southbound	179(97)	173(87)	4(02)	1(01)	2(01)	25(13)

No. of Buses Within Sight for the Crossing Driver

	Zero		**One**		**>One**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	333(85)	315(84)	49(12)	58(15)	9(03)	4(01)
Northbound	167(83)	157(88)	31(15)	19(11)	3(01)	2(01)
Southbound	166(87)	158(79)	18(09)	39(20)	6(03)	2(01)

*Phase I conducted in 1996
**Phase II conducted in 1998

Table 6. Motorists' Behavior at Malcolm SE and Transitway.

All data is frequency with percentage of total in brackets

	*Phase I	**Phase II
Total Number of Crossing Vehicles	240	285

Direction of Crossing Vehicle	Phase I	Phase II
Northbound	116(48)	151(53)
Southbound	124(52)	134(47)

Type of Crossing Vehicle

	Car		Lt Truck		Co Truck		Semi-Truck	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	99(41)	102(36)	54(23)	61(21)	22(09)	39(14)	65(27)	83(29)
Northbound	58(48)	56(37)	23(19)	30(20)	10(08)	18(12)	30(25)	47(31)
Southbound	41(34	46(34)	31(26)	31(23)	12(10)	21(16)	35(29)	36(27)

Type of Stop for Crossing Vehicle

	Complete		Rolling		Ran It	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	114(48)	107(38)	121(50)	171(60)	6(03)	7(03)
Northbound	62(53)	59(39)	52(44)	88(58)	3(03)	4(03)
Southbound	51(41)	48(36)	69(56)	83(61)	3(02)	3(02)

Did the Motorist in the Crossing Vehicle Look Both Ways

	Yes		No		Observer Did Not See	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	211(88)	216(76)	12(05)	2(01)	17(07)	67(24)
Northbound	102(85)	106(70)	5(04)	0(00)	13(11)	45(30)
Southbound	109(91)	110(82)	7(06)	2(01)	4(03)	22(16)

No. of Buses Within Sight for the Crossing Driver

	Zero		One		>One	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	217(91)	240(84)	20(08)	43(15)	3(01)	2(01)
Northbound	102(89)	125(83)	12(11)	25(17)	0(00)	1(01)
Southbound	115(91)	115(86)	8(06)	18(13)	3(02)	1(01)

*Phase I conducted in 1996
**Phase II conducted in 1998

Table 7. Motorists' Behavior at Westgate and Transitway.

All data is frequency with percentage of total in brackets ( )

Total Number of Crossing Vehicles

*Phase I	**Phase II
281	324

Direction of Crossing Vehicle

	Phase I	Phase II
Northbound	119(42)	103(32)
Southbound	162(58)	221(68)

Type of Crossing Vehicle

	Car		**Lt. Truck**		**Co. Truck**		**Semi-Truck**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	140(50)	158(49)	76(27)	93(29)	25(09)	33(10)	40(14)	40(12)
Northbound	61(52)	40(39)	28(24)	29(28)	10(08)	18(17)	19(12)	16(15)
Southbound	79(48)	118(53)	48(29)	64(29)	15(09)	15(07)	21(13)	24(11)

Type of Stop for Crossing Vehicle

	Complete		**Rolling**		**Ran It**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	116(41)	223(69)	155(55)	95(30)	10(04)	6(02)
Northbound	53(45)	65(63)	62(53)	35(34)	3(03)	3(03)
Southbound	63(39)	158(71)	93(57)	60(27)	7(04)	3(01)

Did the Motorist in the Crossing Vehicle Look Both Ways?

	Yes		**No**		**Observer Did Not See**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	251(89)	270(83)	8(02)	0(00)	22(08)	54(17)
Northbound	113(95)	88(85)	4(03)	0(00)	2(02)	15(14)
Southbound	138(85)	182(82)	4(02)	0(00)	20(12)	39(18)

No. of Buses Within Sight for the Crossing Driver

	Zero		**One**		**>One**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	242(86)	273(84)	31(11)	45(14)	8(02)	6(02)
Northbound	106(91)	83(81)	9(08)	17(17)	2(02)	2(02)
Southbound	136(83)	189(85)	22(13)	28(13)	6(04)	4(02)

*Phase I conducted in 1996
**Phase II conducted in 1998

Table 8. Motorists' Behavior at Energy Park Dr. and Transitway.

All data is frequency with percentage of total in brackets ( )

	*Phase I	**Phase II
Total Number of Observations	265	284

Direction of Crossing Vehicle

	Phase I	Phase II
Northbound	117(44)	150(53)
Southbound	148(56)	134(47)

Type of Crossing Vehicle

	Car		**Lt Truck**		**Co Truck**		**Semi-Truck**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	180(68)	171(60)	55(21)	68(24)	22(08)	23(08)	8(03)	22(08)
Northbound	87(74)	93(62)	24(20)	34(23)	5(04)	12(08)	2(02)	11(07)
Southbound	93(63)	78(58)	31(21)	34(25)	17(12)	11(08)	6(04)	11(08)

Type of Stop for Crossing Vehicle

	Complete		**Rolling**		**Ran It**		**Green**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	36(14)	56(20)	5(02)	0(00)	1(01)	14(06)	223(84)	214(75)
Northbound	19(16)	25(17)	1(01)	0(00)	1(01)	7(05)	98(82)	118(79)
Southbound	17(12)	31(23)	4(03)	0(00)	0(00)	7(05)	125(86)	96(72)

Did the Motorist in the Crossing Vehicle Look Both Ways?

	Yes		**No**		**Observer Did Not See**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	41(15)	51(18)	221(83)	186(65)	3(01)	47(17)
Northbound	16(14)	21(14)	101(86)	98(65)	1(01)	31(21)
Southbound	25(17)	30(22)	120(82)	88(66)	2(01)	16(06)

No. of Buses Within Sight for the Crossing Driver

	Zero		**One**		**>One**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Total	228(86)	206(73)	36(13)	72(25)	1(00)	6(02)
Northbound	100(85)	113(75)	17(14)	34(23)	1(01)	3(01)
Southbound	128(87)	93(62)	19(13)	38(25)	0(00)	3(02)

*Phase I conducted in 1996
**Phase II conducted in 1998

Table 9. Motorists' Behavior at Como Ave. and Transitway.

All data is frequency with percentage of total in brackets ( )

	*Phase I	**Phase II
Total Number of Observations	265	287

Direction of Crossing Vehicle		Phase I	Phase II
	Northbound	127(48)	142(49)
	Southbound	138(52)	145(51)

Type of Crossing Vehicle		**Car**		**Lt Truck**		**Co Truck**		**Semi-Truck**	
		Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	Total	147(55)	195(68)	77(29)	74(26)	34(13)	11(04)	7(03)	7(02)
	Northbound	78(62)	102(72)	29(23)	37(26)	16(13)	2(01)	3(02)	1(01)
	Southbound	69(50)	93(64)	48(35)	37(26)	18(13)	9(06)	4(03)	6(04)

Type of Stop for Crossing Vehicle		**Complete**		**Rolling**		**Ran It**		**Green**	
		Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	Total	48(18)	80(28)	0(00)	1(00)	1(00)	3(01)	216(81)	203(71)
	Northbound	25(20)	42(30)	0(00)	0(00)	0(00)	2(01)	101(80)	98(69)
	Southbound	23(17)	38(26)	0(00)	1(01)	1(01)	1(01)	115(83)	105(72)

Did the Motorist in the Crossing Vehicle Look Both Ways?		**Yes**		**No**		**Observer Did Not See**	
		Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	Total	57(22)	61(21)	199(75)	211(74)	9(03)	15(05)
	Northbound	29(22)	37(26)	100(78)	97(68)	0(00)	8(06)
	Southbound	28(21)	24(17)	99(73)	114(79)	9(07)	7(05)

No. of Buses Within Sight for the Crossing Driver		**Zero**		**One**		**>One**	
		Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	Total	204(77)	204(71)	49(18)	77(27)	12(05)	6(02)
	Northbound	101(74)	97(68)	28(20)	41(29)	8(06)	4(03)
	Southbound	103(80)	107(74)	21(16)	36(25)	4(03)	2(01)

*Phase I conducted in 1996
**Phase II conducted in 1998

Table 10. Total Observations of Motorist Behavior at Transitway Intersections.

All Data is frequency with percentage of total in brackets ( )

	*Phase I	**Phase II
Total Number of Observations	2420	2601

Direction of Crossing Vehicle		Phase I	Phase II
	Northbound	1160(48)	1212(47)
	Southbound	1260(52)	1389(53)

Type of Crossing Vehicle	**Car**		**Lt. Truck**		**Co. Truck**		**Semi-Truck**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	1235(51)	1360(52)	723(30)	670(26)	274(11)	247(09)	188(08)	324(12)

Type of Stop for Crossing Vehicle	**Complete**		**Rolling**		**Ran It**		**Green**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	1029(43)	1259(48)	904(37)	877(34)	48(02)	48(02)	439(18)	417(16)

Did the Motorist in the Crossing Vehicle Look Both Ways?	**Yes**		**No**		**Observer Did Not See**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	1787(74)	1817(70)	500(21)	423(16)	133(05)	361(14)

No. of Buses Within Sight of the Crossing Driver	**Zero**		**One**		**>One**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	2058(85)	2031(78)	306(13)	530(20)	56(03)	40(02)

Was There an Incident?	**Yes**		**No**	
	Phase I	Phase II	Phase I	Phase II
	0(00)	0(00)	2420(10)	2601(10)

Type of Other People at the Intersection	**Bicyclist**		**Pedestrian**		**Police**		**Other**	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
	265(11)	92(04)	134(06)	65(02)	11(00)	6(<1))	16(01)	9(<1)

*Phase I conducted in 1996
**Phase II conducted in 1998

Sight Distances

Table 11 shows the measured values of the x, y distances for each of Transitway intersections evaluated for Phase II. The definitions for the x and y values are found in Figure 10.

Table 11. Required Average Speeds to Enable a Stop at The Stop Sign.

	23dAve	**25thAv**	**29thAv**	**30thAv**	**Malcm**	**Wgate**	**EPark**	**Como**
y1	81	55	8	40	76	37	82	35
x1	25	21	54	27	19	56	26	6
Bus Vel=40mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph
Bus Vel=20mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph
y2	28	0	40	43	21	60	34	31
x2	91	33	45	18	19	36	42	6
Bus Vel=40mph	**<20mph**	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph
Bus Vel=20mph	**<20mph**	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph
y3	21	9	10	8	28	19	26	24
x3	103	20	23	24	30	33	61	26
Bus Vel=40mph	**<20mph**	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph
Bus Vel=20mph	**<20mph**	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph
y4	27	68	41	9	27	13	31	0
x4	45	20	18	47	59	27	27	33
Bus Vel=40mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph
Bus Vel=20mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph	<10mph

Note that only at the Transitway intersection at 23rd Avenue did the average acceptable speed exceed 10mph and then for only two of the four cases (x,y pairs). In Phase I we found that 27 of the 32 sight distances failed to meet state and federal requirements.

Accident Data

Table 12 shows the accident history for the eight Transitway intersections considered in this project. The data for each intersection are divided into two parts. The first part are those accidents which occurred prior to the changes in Transitway signing. The second part are those accidents which occurred after the changes. The new signing was introduced during the summer and fall of 1996.

Table 12. Transitway Accident History (April 1992 - May 1998).

Intersection	**4/92-9/96(54 months)**	**10/96-5/98 (20 months)**
23 Avenue	1	1
25 Avenue	2	0
29th Avenue	2	0
30th Avenue	1	0
Malcolm Avenue	6	2
Westgate Drive	5	3
Energy Park Drive	3	2
Como Avenue	4	1
Totals	**24**	**9**

In addition to these accidents, there were two accidents recorded on Oak Street near the entrance to the Transitway. This intersection was not included in the study. The highest accident rates were achieved in the months of October through February, omitting December. December was a low accident month because of the break in classes following the end of the Fall term and Christmas vacation. Bus service was suspended or dramatically reduced.

DISCUSSION

Accident Rate

The overall accident rate prior to any improvements (described in the previous section) was 0.44 accidents per month. The overall accident rate following the improvement project start was 0.45 accidents per month. This data suggests that the improvements have not changed the accident rate on the Transitway. The electronic devices were only active for a quarter of this period. However, accident rate data should be interpreted with some caution. There have been millions of occasions of vehicles crossing the Transitway since it was opened. There have been only 35 accidents. That is, accidents are relatively rare events. We know that during the first two years of Transitway operation the accident rate on the Transitway was 30 times higher than the average for all Minnesota roads. However, this statistic does not speak to the effect of the Transitway improvements on the accident rate. This statistic merely implies that the Transitway is as dangerous a roadway compared as the average Minnesota roadway. Since accidents are rare, accident rates *per se* are not a satisfactory metric for measuring changes due to the Transitway's improvements.

In an attempt to assess the effects of the improvements to the Transitway we have relied on measured changes in the behavior of drivers crossing the Transitway and on other factors which reasonable people would agree affect (or in some cases would fail to affect) Transitway safety.

Comparison of Drivers' Behavior Before And After Transitway Improvements

The primary focus of the behavioral portion of this report was to determine the extent of safe and unsafe driver actions at intersections, and draw conclusions as to the effectiveness of intervening technology. Data for 'type of stop' (complete, rolling, run) and 'look both ways' (yes, no, unable to see) will comprise the basis for decisions as to safe motorist behavior. Hypothetically, the most desirable change would be an increase in complete stops and looking both ways with a corresponding decrease in rolling stops, runs, and not looking both ways. Table 13 was derived with information presented in Tables 2-10.

Table 13. Changes (in percentage) in 'Safe' Behaviors by Intersection.

		Motorist Stopping Behavior				Motorist Looking Behavior		
Street	Control Device	Complete Stop	Rolling Stop	*Ran	Green	Look Both Ways	Don't Look Both Ways	Observer Did Not See Motorist
23rd	Flasher	-25	+24	+1		+5	-6	0
25th	Flasher w/ loop	+3	-2	0		-11	-2	+13
29th	Fiber Optic Stop w/loop	+18	-16	-2		+2	-2	+1
30th	Blank out Warning	+20	-17	-3		-3	+6	+10
Malcolm	Blank-out Fiber Optic	-10	+10	0		-12	-4	+17
Westgate	Flasher	+28	-25	-2		-6	-2	+9
Energy Park	None	+6	-2	+5	-9	+3	-18	+16
Como	None	+10	0	+1	-10	-1	-1	+2
**Overall		+5	-3	0		-4	-5	+9

* numbers are based on extremely limited samples (low frequency of occurrence)

** numbers are not calculated from data in this table.

The following questions are deemed relevant to the evaluation of safety and/or are of interest to the Transitway Safety Project Team.

- *Overall, did driver behavior become safer after the introduction of intersection warning devices?*

Overall data (summarized across all intersections) indicated that there was only a limited shift toward safer motorist behavior at intersections. Complete stops increased 5% while rolling stops decreased by 3%. While there were mixed benefits for looking behaviors, results are difficult to interpret because of the increase in 'did not see' reports by data collectors. Generally, the higher number of 'unable to sees' reported in Phase II will make conclusions concerning looking behaviors extremely speculative. At three intersections there was an increase in drivers running the stop sign, at three intersections no change and at three intersections a decrease in stop sign running. Such data does not offer support for the efficacy of the improvements. Ultimately, intersection warning devices appeared to have no impact on the frequency of runs, with an overall rate of about 2% steady across testing phases.

- *Can any conclusions be drawn concerning individual intersections?*

Data in Table 13 indicates that the impact of intersection warning devices on motorist behavior can be beneficial, detrimental, or indeterminable (no impact, inconclusive evidence). The data for 29th, 30th, and Westgate demonstrated increases in complete stops accompanied by decreases in rolling stops and decreases in runs, exemplifying the beneficial impact of the devices. In particular, 29th also demonstrated conclusive and desirable shifts in looking behavior, where changes in 'did not see' not as much of a factor as some other intersections. In contrast, 23rd and Malcolm demonstrated detrimental effects for intersection warning devices, with decreases in complete stops, and increases in rolling stops. However, some conclusive looking benefits were demonstrated at 23rd with an increase in looking both ways. Finally, data at 25th did not support a conclusion. Changes in motorist behavior were small and looking behavior data was inconclusive.

- *Can changes in motorist behavior be linked to particular intersection warning devices?*

Conclusions concerning warning devices are difficult to draw because of the large number of changes implemented by the project team and the large differences in the physical layout among intersections. A controlled experiment would have required more than one installation at each intersection with repeated testing. This design, however, was impractical. Thus, the following conclusion should be viewed with some skepticism. Data from intersections with flashers (23rd, 25th, and Westgate) demonstrated contradictory effects or limited success. It appears that flashers may be effective at only some intersections because of some property of the intersection, and not some warning property specific to the device. More research is needed to determine why flashers work in some intersections and not at others. Contradictory results were also evident for intersections with blank-out signs (30th and Westgate), again supporting the conclusion that the blank-out device may be effective at only some intersections because of some property of the intersection, and not some warning property specific to the device. Finally, the Fiber Optic Stop Sign activated through detector loops (29th) may have proved effective, though a definitive conclusion is only warranted with further testing.

- *What is the potential for frequency of exposure to undermine the effectiveness of warning devices (habituation)?*

Data appears to support the conclusion that habituation is not a formidable problem. The intersections at 29th and 30th are not public thoroughfares and have very low frequencies. Vehicles travelling these routes are likely to be driven by employees of a small number of businesses adjacent to the intersection. Thus, it was highly likely that data collectors recorded the same vehicles coming and going from the same businesses. Had initial effects of warning devices worn off over repeated exposure, that data would not reflect the large differences reported. The same principle applies to Malcolm and Westgate, where the situation is much the same, though with a larger number of businesses.

- *Was there a 'global' response associated with the introduction of intersection warning devices?*

The global effect hypothesis predicts that the overall effect of implementing many changes would produce safer behavior across the entire system, regardless of warning device or location. Two pieces of data refute this hypothesis. First, data for driver behavior varied across intersections. It is unlikely that a global safety awareness would differentiate itself across intersections. Second, we would expect that driver behavior across *all* intersections would be safer, even at those intersections where no devices were installed (Energy Park Dr. and Como Ave.). These intersections were consistent across testing phases or demonstrated more unsafe behavior (5% increase in runs at Energy Park Dr.).

- *Were changes in motorist behavior due to differences in data collectors or collection phases?*

Overall data indicated that factors such as direction of travel and vehicle type were remarkably consistent across collection phases, indicating stability in the traffic patterns being observed. Individual intersections also demonstrated consistency in these factors with only a limited number of minor deviations. Taken together, these data indicated that collectors were observing similar traffic and recording data appropriately. Data for Energy Park Dr. and Como Ave., where the frequency of vehicles required the observer to select from a moving pool of possibilities, indicated a consistency among observers and phases. Data for direction and type of vehicle were consistent and minor differences for stopping behavior were easily accounted for by changes in green light exposure.

- *It is understandable how the new warning devices improved motorist behaviors; it is also understandable how the devices might have had no noticable effect on motorist behavior. But how could the devices have actually worsened motorist behavior?*

Human factors analyses of behavior often identifies unwanted or unintended changes in human behavior. Systems are designed to produce behavioral effect A; when humans interact with systems, behavioral effect B is observed. As an example, examine changes in stopping behavior at 23rd and at Malcolm. In both cases, stopping behavior went down (worsened) after the introduction the respective warning devices. The data collected in this project does not address *why* behavior changed, thus the following explanations are offered as hypotheses, based on the expertise of the authors and anecdotal evidence of the data collectors. Why did stopping behavior worsen at 23rd? The warning device installed at 23rd was a continuously flashing red light. The flashing light is designed to grasp driver attention, which it effectively does. In fact, it grasps motorist attention far before the motorist arrives at the intersection. The flashing light serves as a stimulus for the driver to begin the upcoming task – slowing and looking down the transitway for traffic. In effect, the flashing light cues the motorist to preview the intersection, a task made easy by the good sight lines present at 23rd. In the majority of instances where there is no transitway traffic, the motorist has already decided it is safe to move through the intersection prior to actually arriving at the intersection. Thus, the actual stopping behavior is compromised. Why did stopping behavior worsen at Malcolm? The warning device installed at Malcolm was a blank-out fiber optic sign activated by Autoscope™. Motorists using this intersection are repeatedly exposed to the device because the intersection is not a major thoroughfare and serves a limited number of business. After limited exposure, motorists quickly comprehend how the device works, activating only when traffic is present on the transitway. Importantly, motorists see the device work accurately. Soon, motorists begin to *rely* on the device to tell them if traffic is present. As motorist approach the intersection, they see the device is not activated, thus no traffic will be present in the intersection. Thus, motorist looking and stopping behavior is compromised at the intersection. The real danger in this case is that safety is completely dependent on the device working 100% accurately.

In the case of a malfunction or missed signal (perhaps an in-line skater) the driver is not sufficiently prepared to stop because they think there will be no traffic at the intersection.

- *Are there additional data that bears attention?*

The Phase II data set produced a number of individual data points worth additional mention.

- The overall 9% increase in the number of times observers could not see motorist looking behavior ('did not see') does not accurately reflect the tremendous variability across individual intersections.
- The number of bicyclists, pedestrians, police, and others (e.g., in-line skaters) recorded at the intersections was significantly reduced in Phase II as compared to Phase I.
- The number and percentage of 'runs' rose dramatically at Energy Park Drive.
- *Is there any anecdotal evidence addressing safety concerns on the transitway?*

In the opinion of the authors, The Energy Park Dr. intersection should represent a major safety concern, requiring swift and immediate action. This intersection is characterized by:

- poor and limited sight lines for motorists
- poor and limited sight lines for bus drivers
- limited preview due to elevation changes and roadway curvature
- high volume of traffic
- high vehicle speeds
- large number and percentage of red light running (5% in Phase II)

On numerous occasions, the authors and data collectors observed flagrant red light running on the part of Energy Park Dr. traffic. On numerous occasions, bus drivers had to reduce speed dramatically in order to avoid potential crashes, despite that fact that buses had the right of way (green light). As a safety strategy, bus drivers were frequently observed reducing speed when entering the intersection. Based on this evidence, the authors conclude that it is the conscientious and attentive action of bus drivers *alone* that has averted a major crash at the Energy Park Dr-transitway intersection.

Sight Distances

In the Phase I report for this project (1), one of our conclusions was that combinations of factors were most likely responsible for the accidents occurring at the Transitway intersections. Inadequate sight distances were one of these factors. Since the spring of 1996 some sight distances have been improved by trimming brush, bushes and trees and by adding some NO PARKING signs. However, other sight distances have been decreased by the installation of the cabinets for electronic control equipment for regulating the signs and detectors on the Transitway and vegetation at some intersections still serves to unduly restrict sight distances. We anticipate that some efforts will continue to prune the obstructing vegetation. However, it is unlikely that all on-street parking near the Transitway intersections will be forbidden. It is equally unlikely that the electronic controls cabinets will be moved to locations where they would not restrict sight lines. For these reasons we place a different emphasis, compared to the Phase I report, on the meaning of the sight distance data. The interpretation we discuss here relates to speed restrictions

It is obvious that if cars approached the Transitway at five mph, sight distances could be very short and safety could still be maintained as far as sight distances are concerned. Since sight distance improvements seem to have been concluded, another approach to improving safety with respect to sight distances is to reduce the speeds of either buses or cross street traffic or both. The data presented in Table 11 showed that at only the 23rd Avenue intersection could the average approach speed be more than 10 mph for bus speeds of either 20 mph or 40 mph. At all other intersections the average approach speeds must be less than 10 mph even for bus speeds as low as 20 mph. At 23rd Avenue the average approach speed could exceed 10 mph for only the northbound traffic with buses going either eastbound or westbound. It does not seem likely that bus average speeds will be controlled to less than 10 mph. The alternative is to greatly reduce the speeds of traffic approaching the Transitway. Realistically, it seems unlikely that cross street speeds could be sufficiently reduced to compensate for short sight distances without an extensive police presence or the legalization of the technology which records both speeds and license plate numbers with the owner of the vehicle responsible for the speeding violations. We can only surmise that short sight distances will continue to be a contributing factor in Transitway accidents.

Visual Clutter

In the Methods section of this report we mentioned the placement positions of the NO TURNS signs. In addition to this potential for confusing the motorist, at some intersections there are the conventional diamond shaped warning signs, black and white rectangular signs stating BUSES DO NOT STOP or BIKES AND BUSES DO NOT STOP with arrows pointing east and west, black and white rectangular signs with an arrow pointing straight up and the word ONLY. There are also STOP signs of varying degrees of elegance with and without lights or flashing lights and in addition most of these signs are in duplicate by being placed to both the left and the right of the driver. One potential result of visual clutter is that the most important message for safety is obscured by the presentation of too many messages which are too close together in space and time. Clearly, the most important message for safety at Transitway intersections is the STOP message. If a driver has stopped, looked up and down the Transitway for approaching traffic, and then turned left, albeit illegally, there is no dangerous consequence as long as this action is a relatively rare event. It is more dangerous to obscure the message STOP by adding visual clutter. Whether or not drivers encroach on the Transitway due to visual clutter is only a matter for speculation. We have no data which directly relates to this issue on the Transitway, although the deleterious effects of visual clutter, in many circumstances, are widely known. Perhaps a reduction in non-essential information would be prudent. For example the removal of the NO TURNS signs located on the wrong side of the Transitway would reduce clutter without reducing the supply of relevant information. The NO TURNS signs currently in use could be replaced by the standard sign showing a turn arrow with a red diagonal line through it. These signs could be placed well away from the intersections as long as no driveways would make these signs appear to deny turns into the driveway. Locating these signs well back from the Transitway would reduce the clutter at the Transitway without reducing the relevant information.

Signal Light Timing

The timing for the traffic signal lights could be improved at Como and Energy Park Drive. The bus driver should not be required to reduce speed to accommodate the traffic light's change to green for the bus and then to increase speed to pass through the intersection before the light changed back to red for the bus and green for the cross traffic. The bus drivers should be allowed to maintain a constant speed.

During data collection for Phase II we observed that on occasion, the signal lights failed to give the Transitway buses the right-of-way. The buses were required to stop and wait until the light changed. This is possibly due to system malfunction. If instead there is some schedule which states that on occasion the signal lights will not give buses the right-of-way, drivers should be carefully coached and then warned when this event is to occur. It would be even better not to switch back and forth between the two forms of control.

Bus-Mounted Strobe Lights

Small strobe lights were mounted on the top of the Transitway buses beginning in August 1997. These lights are not conspicuous during daylight hours. During the dark hours of operation, the normal lighting of the buses, including their headlights and interior lights make them adequately conspicuous. We should not sacrifice other safety features to accommodate the strobe lights.

(This page left intentionally blank)

CONCLUSIONS

In the Introduction to this report we discussed the motivations for performing the investigations reported here. We maintained that until we understand why Transitway accidents occur, it will be difficult to identify cost effective solutions which will reduce the number of accidents.

We have seen that most of the solutions implemented thus far have focused on enhancing the utilitarian value of stop signs. Our belief must be that ordinary stop signs are obscured either visually or in meaning to drivers approaching the Transitway. Is it reasonable to believe that sober drivers do not understand the meaning of the familiar stop sign? This is clearly a difficult position to maintain. In the accident reports for the Transitway there is nothing to suggest that intoxication has reduced drivers' understanding of the meaning of stop signs. We believe that we should accept the idea that drivers crossing the Transitway understand that stop signs mean that they should stop at the level of the stop sign.

Can we maintain that the stop signs on the avenues intersecting the Transitway are visually obscure? There is no evidence to suggest that this is the case. In fact, we have much evidence to show that drivers indeed see and comprehend the stop signs. The accident reports do not suggest that visual obscurity of stop signs was involved in accident causation.

If we accept that the stop signs at the avenues intersecting the Transitway were both visible and understandable before the embellishments to the stop signs were undertaken, how do we explain the reasoning which underlies the addition of flashing lights and fiber optic illuminations to the stop signs? That is, how do we explain how stop sign illuminations add to either understanding of stop signs' meaning or visibility in such a way as to reduce accidents? We have no data or speculation which would serve to answer this question. What we do have are data which shows that the accident rate per month didn't changed following the 1996/1997 changes to the Transitway sign system and the 1998 warning lights haven't been in place long enough to have an effect on the rate.

We were not able to identify a single cause for the Transitway accidents which have occurred over the last four years. The data has, however, allowed us to suggest that certain factors acting in combination, may have contributed to causing Transitway accidents.

Bus Driver Behavior

- In general bus drivers are operating their vehicles within established guidelines (Phase I)

Accident Rates

- The overall accident rate prior to any Transitway improvements was 0.44 accidents per month. The overall accident rate since the improvements beginning in 1996 until May of this study was 0.45 accidents per month. The electronic warning devices were only in operation for 5 of these months. These data should be interpreted with care as accidents are rare events. These statistics merely *imply* that the Transitway continues to be just as dangerous roadway as compared to the average Minnesota roadway.

Driver Behavior (Crossing Vehicles)

- Overall, data suggest only a slight shift toward safer driver behavior at intersections after transitway safety improvements were implemented. (5% increase in complete stops)
- Overall, transitway safety improvements had little or no impact on the frequency of runs, with an overall rate of about 2% steady across testing phases.
- About 20% of drivers do not look both ways before crossing the Transitway.
- Subsequent to transitway safety improvements, 3 intersections demonstrated behavioral improvements (29th, 30th, and Westgate), 2 demonstrated behavior detriments (23rd and Malcolm), and 1 intersection (25th) did not support a definite conclusion.
- Data from intersections with flashers demonstrated contradictory effects or limited success. Contradictory results ere also evident for intersections with blank-out signs. The Fiber Optic Stop Sign proved effective, though a definitive conclusion is only warranted with further testing.
- Data does *not* support the conclusion that habituation or frequent/repeated exposure degrades the effect of the warning devices in question.
- Data does *not* support the contention that the numerous improvements in transitway safety created a 'global' safety conscience on the behalf of transitway users.
- Conclusions regarding changes in driver looking behavior were somewhat compromised by an increased reporting of 'did not see' in Phase II.

- One intersection (Energy Park Drive) demonstrated a dramatic rise in red light violations in Phase II.

Sight Distances

- 27 of 32 triangular sight distances failed to meet state and federal requirements (Phase I). Short sight distances suggest that average approach speeds should be reduced (Phase II).
- Calculations of required average speeds to enable a complete stop at a stop sign indicated that only one intersection (23rd) would support a speed greater than 10mph. (Phase II)
- Since the spring of 1996 some sight distances at intersections have been improved. However other sight distances have been decreased by the installation of the cabinets for electronic control equipment for regulating the new warning signs.
- Vegetation continues to obstruct stop line sight lines at a few intersections intersections.

Other

- The addition of signs at intersections has contributed to visual clutter, too many messages which are too close together in space and time.
- To a layman, the design of the fiber optic stop sign appears to be inconsistent with the Minnesota Manual on Uniform Traffic Control Devices, in that the sign is not an octagon (section 2B-4). Mn/DOT was consulted and agreed that the square background behind the sign was proper, not unlike mounting a sign on the side of a building next to an alley. The sign meets the octagonal, reflector, and illumination requirements of the manual.
- The position of the NO TURN sign appears to be inconsistent with Minnesota Manual on Uniform Traffic Control Devices, in that the sign is not placed in advance of the condition to which it calls attention (section 2A-25).
- Signal light timing continues to appear sub-optimal. Bus drivers are regularly observed slowing and even stopping at intersections.
- Efforts at Transitway safety improvements have been overly focused on enhancing the utilitarian value of the stop sign.

- Anecdotal evidence, supported by observational data, suggests that the Energy Park Dr.-transitway intersection represents a significant safety concern.

(This page intentionally left blank)

RECOMMENDATIONS

The data we have collected are supportive of the idea that each of the above factors may have contributed to Transitway accidents. Interpretation of the data suggests that combinations of these factors are more likely to have contributed to accidents than any factor operating alone. The causes of accidents are complex and combinations of factors causing accidents need not be the same for all accidents.

While we have no suggestions for eliminating the risk-taking behavior of scofflaws, we recommend a more frequent and conspicuous police presence at Transitway Intersections. Other recommendations are:

- Improve sight distances by eliminating the sight line obstacles whenever this is possible. If it is not possible, then information signs could be used to warn drivers of the short sight distances. One such frequently seen sign is BLIND DRIVEWAY.
- Be especially diligent and thorough about snow and ice removal at the approaches to the Transitway.
- Adjust the timing parameters of the bus actuated system for switching traffic lights to permit buses to drive at a constant speed when approaching and passing through the intersections at Como and Energy Park Dr.
- Consider the effect on accident reduction of reducing both bus speed as well as cross street traffic speed. We have shown the clear relationship between bus speed and sight distance. This could be especially important in the vicinity of intersections where sight distances cannot be improved.
- Reduce visual clutter by removing non-essential information from intersections, make the sign set consistent from intersection to intersection.
- Identify and evaluate safety improvements not related to the utilitarian value of the stop signs.
- We recommend considering the development and use of “new wave” messages on signing for the streets intersecting the Transitway. The signing could be done on portable electronic signs.

Messages would address the factors cited above as potentially accident causing. The messages would be designed to have high impact for example NEVER HIT A SCHOOL BUS. THE BUS WILL HIT BACK.

- We recommend increased safety efforts specific to the Energy Park Dr. intersection. Efforts should be focused on increasing sight lines, reducing motorists' speed, adjusting light timing parameters, and reducing red light violations.

REFERENCES

1. Stackhouse, S.P. and Donna Tranchida. 1996. Human factors for Transitway safety improvement. Final Report to the Center for Transportation Studies.
2. Easa, S.M. (1993). Should vehicle 15-percentile speed be used in railroad grade crossing design? ITE Journal, August, p 37-46.
3. Lerner, N. (1990). Driver behavior at rail-highway crossings. Prepared by the Comsis Corporation.
4. Minnesota Department of Transportation (1991 MN MUTCD). Minnesota manual on uniform traffic control devices for streets and highways.
5. Sohrweide, Tom - P.E. and L.A. Benson. 1998. Transitway ITS Safety Applications. Pre-print of the 1998 ITE International Conference Proceedings. Toronto, Canada.
6. Weiss, M. Minnesota Department of Transportation's Signing Engineer. Personal communication, May,1998.
7. Wilkins, V. (1993). Pittsburgh plans busway expansion. Bus World, 15, 4-7.
8. Wilkins, V. (1983/84). Pittsburgh finds the busway can provide the ;functional advantages of a rapid transit line at much lower capital cost and bus routings are much more flexible. Bus World, 6, 9-13.
9. No author (1983). Pittsburgh's East Busway opens for service. Bus Ride, 19, 62-63.
10. Lyons, W., Shadle, P., Dysher, B., Jensen-Fisher, R., Ducca, F., and Salvucci, F. (1993). Review of the transportation planning process in the Pittsburgh metropolitan area. Final report produced for the Federal Transit Administration and the Federal Highway Administration by the Volpe National Transportation systems Center, Research and Special Programs Administration, and the US Department of Transportation (Report # RSPA/VNTSC-SS-TM392-04).
11. USA Today, January 12, 1996.

12. Cohen, H. and Reno, A. (1992). Characteristics of urban transportation systems. Final report prepared for the Federal Transit Administration, US Department of Transportation. (7th Edition, revised).

13. No author (1992). High occupancy vehicle project case studies: Historical trends and project experiences. Report prepared for the Federal Transit Authority by the Texas Transportation Institute. Washington, DC: US Department of Transportation (DOT-T-94-18).

14. Turnbull, K.F., and Hanks, J.W. (1990). Final report: A description of high-occupancy vehicle facilities in North America July 1990. Report prepared for the Office of Planning, Urban Mass Transportation Administration, Washington, DC and Texas State Department of Highways and Public Transportation, Austin, TX. Washington, DC: US Department of Transportation (DOT-T-91-05)

15. Leman, C.K., Schiller, P.L., and Pauly, K. (1994). Re-thinking HOV: High occupancy vehicle facilities and the public interest. Annapolis, MD: The Chesapeake Bay Foundation.

APPENDIX A

LITERATURE REVIEW AND ANALYSIS

Introduction

The subject of this literature review is transitway safety. The Transitway which connects the Minneapolis and St. Paul; campuses of the University of Minnesota, providing bus transportation for students, is sufficiently unique that we could find no published reports on safety issues for similar roadways. We had hoped that private roads on industrial "campuses" might have provided relevant information, but we could not find any reports covering such circumstances. Perhaps the fact that we could find no "transitway safety" published reports is in itself a significant finding. An easy assumption is that if there are no reports of "transitway safety" problems, then there are no such problems. We are reluctant to make such an assumption since there are no grounds on which to base it. Even if we did assume this, we would be left with the conclusion that Transitway safety at the University of Minnesota is unique. That is, the problem here at the University is still quite real even though it may be unique.

An approach to relating relevant past experience to Transitway safety, is to find an analogous situation for which there is data from which we can generalize to the Transitway. Such a situation is provided by railroad grade crossings. At a grade crossing it is completely clear that trains have the right-of-way. Not only are trains threatening because of their mass, speed and inability to stop (at 55 mph it takes an average size train about one mile to stop) or take evasive maneuvers, but there are signs and signals and sometimes gates which warn of their potential or actual presence at the crossing. For many crossings an approaching train's presence is sensed and this activates signals at the crossing. Cars and trucks are warned in advance that they are approaching a crossing by unique signing (yellow circular sign with a black X). For the transitway, signs make it clear that this roadway is only for buses and that buses have the right-of-way. On the streets intersecting the transitway which have traffic signals, the presence of the approaching bus is sensed and the light turns green for the bus and red for the cross traffic. At other intersecting streets there are conventional STOP signs. A final point is that there is a surprisingly large number (over 100) of train - vehicle accidents each year in Minnesota and correspondingly there is also a surprisingly high number of accidents between the transitway buses and vehicles crossing the transitway.

Fortunately there is an excellent 1990 review of the literature on grade crossing accidents with heavy emphasis on human factors concerns.[1] A summary of that review with annotation which points to the analogy follows. It will be apparent that the analogy between Transitway and grade crossings is imperfect. However, it will also be clear that there many lessons to be learned for Transitway safety from a consideration of the grade crossing literature.

The main topics of Lerner's report are: Contributing Factors, Driver Characteristics, Countermeasures, and Conclusions. These topics all contain material that is analogous to Transitway safety improvement.

Contributing Factors

Lerner organizes his analysis of the literature around the Positive Guidance model developed by Post, Alexander and Lunenfeld in 1981[2]. This is the model used to describe driver requirements in the "Railroad-Highway Grade Crossing Handbook" prepared by Tustin, Richards, McGee and Patterson in 1986[3], as well as in other reports. This model provides a frame of reference for considering the demands that a rail-highway crossing imposes on the driver. These demands are perceptual and cognitive involving seeing, comprehending, and making decisions. The model focuses on the driver's process of acquiring and using the needed information. This model could be used equally well to describe the driver approaching the Transitway on one of the intersecting streets. Lerner also created a description of drivers who are approaching grade crossings that applies equally well to drivers approaching the Transitway. This description is given later in this report.

Five information handling zones are defined: the advance zone (precedes the demands of the hazard), approach zone (defined by the decision sight distance), non-recovery zone (defined by the

---

[1] Lerner, N. (1990). Driver behavior at rail-highway crossings. Prepared by the Comsis Corp. Federal Highway Administration Report No. FHWA-SA-90-008.

[2] Post, T.J. and Lunenfeld, H. (1981). A users' guide to positive guidance (2nd ed.) Report No. FHWA-TO-81-1, Washington, D.C., U.S. Department of Transportation, Federal Highway Administration.

[3] Tustin, B.H., Richards, H., McGee, H. and Patterson, R. (1986) Railroad-Highway Grade Crossing Handbook (2nd ed.), Report No. FHWA-TS-86-215). Washington, D.C., U.S. Department of Transportation, Federal Highway Administration

stopping sight distance), hazard zone (about 15 feet from the nearest track) and downstream zone (beyond the hazard). The engineering definition of these zones is arbitrary depending on how conservatively we define response time, braking distance, vehicle length, visibility conditions, sight distance and other conditions.

Comprehension

In their investigation of causal factors in railroad-highway crossing accidents, Berg, Knoblauch and Hucke, 1982[4], found that both recognition errors and decision errors occurred frequently along the path to the crossing. However, there was no single error path that accounted for the majority of the accidents. Failures in perception and decision making occurred all along the path.

Driver expectancy is another important issue for understanding the causes of grade crossing accidents. Expectancy may be based on long-term experience with driving as in expecting freeway exits to be on the left. Similarly, drivers might well believe that a bus would rarely be in the vicinity when they are crossing the Transitway. There are also short term expectancies. For example when driving on a winding road we come to expect the next curve but we would be surprised if this happened on a long straight highway. Drivers' expectancies at a crossing can influence what they see and how they interpret what they see (likelihood that a train will be in the vicinity, the warning time provided by flashing signals, length of delay caused by the train, probability of being caught violating crossing laws, willingness to take risks, etc.)

There are many studies to show the extent to which people understand the meanings of the traffic control devices (TCDs) associated with rail-highway crossings. Results vary and there are many reasons for the variance; both content and method. In general drivers understand that the TCDs mean that there is crossing nearby and that there may be a train present or approaching. The exact meaning implied by the TCDs is often difficult for motorists to comprehend. Drivers may interpret the lack of an active signal at a crossing as meaning that it is safe to cross. Sanders et al (1973) interviewed over one thousand drivers just after they had driven over a grade crossing. At active crossings, 23% of drivers thought that all crossings had signals or gates. At passive crossings 15% also thought this. Tidwell and

---

[4] Berg, W.D., Knoblauch, K. and Hucke, W. (1982). Causal factors in railroad-highway grade crossing accidents. Transportation Research Record, 847, 47-54. Washington, D.C. Transportation Research Board.

Humphreys' (1981) survey at a license renewal site found that when applicants were shown a picture of a flashing signal array for a grade crossing over half stated that the signal was rarely or never used. In a later study, Richards and Heatherington (1988) found this figure to be 23%. In both these studies almost all drivers understood that flashing lights meant that a train was coming. Drivers crossing the Transitway are unlikely to demonstrate this poor level of understanding of the signs and signals used, although some could be confused because of the novelty of the situation.

In spite of many studies related to detection and recognition of grade crossing TCDs there is no evidence to show a clear correlation between drivers' understanding of TCDs and accident frequencies. For example, there is no evidence to show that just because many drivers believe that the crossbuck means "stop, look and listen" that these same drivers have more crossing-related accidents. We can only speculate that lack of understanding of the meaning of TCDs or laws leads to accidents. Similarly for the Transitway, we too could only speculate on the effect on accident rate of possible misunderstandings of signs and signals.

We can also speculate that failure to understand that trains cannot make sudden collision avoidance maneuvers. In the Richards and Heatherington survey (1988) 45% of respondents felt that when the train driver saw cars crossing the track, the train driver should slow or stop the train. About 10% of drivers did not know whether it took a greater distance to stop a train or a large truck. Based on such information it is not unreasonable to assume that drivers' inability to estimate the time available to cross the tracks could lead to accidents. Similarly, drivers crossing the Transitway, may not always correctly estimate the amount of time available to safely cross. However, for grade crossings many drivers do not realize that one train is masking the second train and that when they attempt to cross after the first train has passed they collide with the second train and this not likely to be the case on the Transitway with one bus masking another. Lack of visibility due to geometry and sight-line obstructions has been documented as a contributor to accidents. While buses are much more maneuverable than trains, they are not as maneuverable as most smaller vehicles. As discussed in the Task 3 Report, sight distances could play a role in accident causation.

Lerner summarizes this topic by stating that there are factors which are related to accident potential and drivers should be, but often are not, aware of these. Drivers should understand: 1) the meaning of information communicated by TCDs; 2) the responsibilities of drivers; and 3) the factors that can contribute to accidents at grade crossings. The same conclusions may apply equally well for the Transitway.

There is adequate evidence to show that some fraction of drivers fail on one or more of the above points. However, while there is speculation there is no evidence linking this failure to accident frequencies.

The next three subtopics considered in the Comprehension of rail-highway accidents context were detection and recognition, perception, and decision making.

Detection and recognition

The topic of detection and recognition is considered under the following headings:

- Dependent measures of detection. (The three common measures are head movements, characteristics of the vehicles speed profile on the approach to the crossing and perception-brake response time.)
- Conspicuity of TCDs (The characteristics of not just the sign but the sign in its environment.)
- Detection and recognition of: Advance warning devices, crossings, active warning devices, trains at the crossing, approaching trains.

There are significant problems associated with detection and recognition. A difficult problem for the driver is the recognition of the meaning of the round warning sign. This sign does not tell the motorist whether there is an active warning device at the crossing nor does it indicate distance from the crossing nor does it speak to the visibility of the crossing. If it is night, the intersection without lighting and with a passive warning device but with an approaching train may first become visible in the non-recovery zone, particularly if there is a difficult geometry.

One of the strategies might be to combine visual, tactile and auditory stimuli since such combinations are known to improve signal detectibility. One could use rumble strips, the sounds from the train, and active or passive signals to ensure grade crossing detection. One could also add high intensity lamps or strobe lights to increase detectibility. Four-quadrant gates decreased perceptual-braking response times compared two quadrant gates.

Perception

In the present context perception refers to the processing of the data obtained during detection and recognition. This processing might take the form of estimation or evaluation. Perceptual processes come into play at both grade crossings and the Transitway.

After the crossing and the approaching train are detected, drivers still need to make higher order perceptual judgments which will form the basis from a decision about whether to cross the tracks. The perceptual judgments are complex. For example these judgments involve estimating the time to arrival of the train based on the both the train's speed and the motorist's speed, the distances to be traversed by both, the smoothness of the pavement, the grade of the road, the length of the vehicle, the number of tracks and other factors. Accident data makes it clear that not all drivers stop even when there is a doubt about the outcome suggesting that some drivers have been too willing to take risks. We believe that this is a salient problem at the Transitway intersections.

The topic of perception was treated under the following headings:

- The perception problem.
- The difficulty of the perception problem is increased by darkness, short sight distances, and other factors which serve to decrease the time remaining to make a decision.
- Motion and gap problem.

There was no literature directly relevant to the grade crossing problem, however, there have been studies on the gap problem. Gap time is the time between two successive vehicles on a road. Lag time is a special case of gap time and is the time from arrival of the driver's car at an intersection to the arrival of the first car on the intersecting road. Ebbesen and Haney (1973)[5] found that the probability of turning into traffic at an intersection (accepting the gap) was a normal function of the logarithm of the temporal distance. The OECD (1974)[6] found that gap acceptance corresponded to a lognormal distribution of gap times with a median value of 7.3 seconds; an 85th percentile of 10 seconds; and a

---

[5] Ebbesen, E.B., and Haney, M. (1973). Flirting with death: Variables affecting risk taking at intersections. Journal of Applied Social psychology, 3 (4), 303-324.

[6] OECD Road Research Group (1974, November). Capacity of at-grade junctions. Organization for Economic Cooperation and Development.

15th percentile of 4 seconds. As traffic volume increased, acceptable gap size decreased and this impatience factor might well operate at grade crossings.

When a vehicle is approaching (as in passing or as in viewing an on-coming train), the major visual cue is expansion of the retinal image, also called "looming." Because the size of the retinal image is a tangent function of its distance, the size of the image grows exponentially as the train or vehicle approaches at constant speed. As the distance halves, the visual angle subtended is doubled. As a train approaches from 5,000 feet away to 1000 feet away, the image size changes relatively little; but inside about 500 feet looming increases dramatically. Thus the difficulty of in perceiving the rate of approach from a target at a distance is inherent in the geometry of the situation.

In passing experiments Gordon and Mast (1976)[7] found that the percent of drivers underestimating the distance required to pass increased as speed increased. Judgments about passing, just as judgments made on an approach to a grade crossing, are subject to errors of estimation on each of the variables involved such as speeds and distances. The judgment of the perceived distance and motion of large trucks is related to the extent of patterning and delineation with a fully outlined pattern seen as much closer. Henderson, Zeidman, Burger and Cavey (1983)[8] have reviewed the literature relevant to this topic. Minimal patterning, particularly at night may be typical of trains where the outline of the approaching locomotive is not distinct. This could lead drivers to believe that the train is farther away than it actually is.

- Unique problems in the perception of trains.

The most serious of the unique problems in the perception trains are related to the large object illusion, Leibowitz (1985)[9]. In this illusion large objects seem to move more slowly than small objects. An example is large vs. small jet aircraft landings. The larger planes seem to be going much more slowly then the small planes when in fact they are landing at the same speeds. A classic effect in motion perception is "velocity transposition" which states that the perceived velocities of moving targets are related to the relative sizes of the targets and visual fields in which they move Brown (1931)[10].

---

[7] Gordon, D. and Mast, T.M. (1976). Driver's judgment in overtaking and passing. Human Factors, 18, 53-62.

[8] Henderson, R.L., Zeidman, K., Burger, W.J. and Cavey, K.E. (1983) Motor vehicle conspicuity. In <u>Crash Avoidance, SP-544</u> (pp 145-188). Warrendale, PA: Society of Automotive Engineers, Inc.

[9] Leibowitz, H.W. (1985). Grade crossing accidents and human factors engineering. American Scientist, 73, 558-562.

[10] Brown, J.F. (1931). The visual perception of velocity. Psychologische Forschung, 14, 199-232.

- Other sensory modalities.

Vision is the predominant modality with audition related to train whistles of much less importance.

The relationship of detection and recognition for grade crossing to the Transitway is obvious. The same factors come into play. In fact most of the data comes from studies of roadway intersections rather than grade crossings.

Decision making

Under this subtopic, decision-making errors, risk perception and risk taking are discussed.

Knoblauch, Hucke and Berg (1982)[11] classified decision errors and gave their frequencies as follows:

For flashing light sites:

- Driver recognizes signal from approach zone, does not detect train. 18%
- Driver recognizes signal from approach zone, does not stop, recognizes train from non-recovery zone, attempts to stop. 17%
- Driver recognizes signal from approach zone, does not stop, recognizes train from non-recovery zone, does not stop. 22%
- Driver recognizes signal from approach zone, brakes to stop, recognizes train, attempts to cross. 5%

For crossbuck-only sites:

- Driver recognizes train from approach zone, does not stop. 7%
- Driver recognizes train from approach zone, enters non-recovery zone, attempts to stop. 8%
- Driver recognizes train from approach zone, brakes to stop, attempts to cross. 3%

About 20 % of the accidents did not fall into these categories and this included cases involving alcohol. Note that only 8% of the accidents occurred after the driver had stopped. The definition of a decision-making error was narrow and did not consider such factors as weather, pavement, other signs or markings or driver familiarity. The same logic can be applied to Transitway intersections.

Risk taking refers to willingness to accept a potential for harm. Risk perception refers to a person's ability to perceive harm for whatever benefits might accrue. For a driver to take a risk means that the hazard must be detected, the degree of risk (probability and severity of consequence) perceived and the potential consequences of an action accepted. A special issue of the journal "Ergonomics" (April 1988, Volume 31, No. 4) was devoted to "Risky Decision-Making in Transport Operations."

Many surveys have shown that drivers are poor at estimating risks. Sight distances and approach speeds may be related to willingness to take risks. However, it could be that when sight distances are greater, drivers approach crossings at higher speeds.

Factors in decision making errors at crossings are discussed under the following heading: information limitations and ambiguity; information credibility; expectancies regarding trains; expectancies regarding crossings, costs of compliance; temporal constraints; competing inputs; decision making as a disruptive activity; recognition of capabilities and biases; conflicting messages; avoidance of effort; social influences; and emotional reactions. Drivers approaching the Transitway may also be assessing the risk of crossing with fully complying with messages provided by the signs and signals.

Compliance

This section deals with actions which the driver knows to be illegal and risky; that is, most cases of non-compliance are intentional. For example Knoblauch, et al (1982) determined that in more than half the cases at flashing light crossings, the driver had seen the signal sufficiently in advance, but did not stop. Other studies were cited which confirmed this study. Drivers are sensitive to the length and reasonableness of the warning times and this influences compliance. Other factors which influence compliance are discussed under the heading of inconvenience; driver familiarity with the crossing; social behavior and norms, enforcement and conflicting concerns. (As an aside, "conflicting concerns" may well have been a factor in the 1995 crossing accident involving a school bus in Fox River Grove, IL.)

---

[11] Knoblauch, K., Hucke, W. and Berg, W. (1982). Rail highway crossing accident causation study. Vol. II: Technical report FHWA-RD-81-83. Washington D.C., U.S. Department of Transportation, Federal Highway Administration.

Impairment

This section of Lerner's report deals with alcohol, drugs and fatigue and these are not of interest in the context of the Transitway project since we will not be doing any screening of drivers crossing the Transitway..

Driver Characteristics

The issues of interest in this section on driver characteristics are familiarity and risk taking. The findings on crossing familiarity could be summarized by the adage that "familiarity breeds contempt." Risk taking of one kind has often been correlated with other forms of risk taking in individuals; such as risk taking at crossings is correlated with risk taking in other driving situations such as at the Transitway.

Countermeasures

Most countermeasures have not been evaluated, only suggested. There are no global countermeasures that would solve all problems at crossings. Even if a counter measure would be found to be effective in modifying behavior in a limited way, there is no guarantee that this would result in a reduction in accidents. Furthermore, even if accidents were reduced the countermeasure might not be cost-effective. The thousand or so deaths occurring at crossings each year testifies to the difficulty in implementing broadly effective countermeasures.

The major subsections in this Countermeasures section mirror those found in Contributing Factors: Comprehension; Detection and Recognition; Perception; Decision Making; and Compliance.

Comprehension

The NCHRP Report 50, "Factors Influencing Safety at Grade Crossings"" (Schoppert and Hoyt 1968)[12] was over 20 years old when Lerner wrote his review in 1990 and Lerner could state that neither the grade crossing problems nor the proposed countermeasures were new. Lerner points out the classes of possible countermeasures. The most effective intervention is either to close the crossing or implement grade separation. Next in order of effectiveness is automatic four quadrant then two

---

[12] Schoppert, D.W. and Hoyt, D.W. (1968). Factors influencing safety at highway-rail grade crossings. (NCHRP Report 50). Washington, D.C. Highway Research Board.

quadrant gates because it simplifies drivers options and reduces decision making. Active crossing signals are more effective than passively protected crossings. Passive protection places the greatest demands on driver comprehension, detection, perception, and decision making. The relative virtues in terms of driver behavior are clear. The issues relate to cost of installation and maintenance, cost effectiveness and resource allocation.

Many studies have suggested some form of educational or public awareness efforts to reduce grade crossing accidents (Richards and Heatherington, 1988[13]; Knoblauch et al. 1982; Haga 1988)[14]. Some educational efforts have been directed toward improving drivers' understanding of their own perceptual limitations (Knoblauch et al. 1982[15]; Leibowitz 1985[16]; Leibowitz and Owens 1986[17]; McGinnis 1979[18]). Most of these efforts, including Operation Life Saver have not been formally evaluated for effectiveness. In the evaluations which have been done no correlations were found between educational programs and improved driver behavior at crossings. The Cerro Gordo County Iowa effort was another example of type of program which initially had a beneficial effect on drivers' behavior but this effect dissipated within six months.

Detection and recognition

Under detection and recognition the subtopics are: Advance Warning Signs; Active Advance Warning Devices; Rumble Strips, Crossbucks; Active Warning Devices; and Trains.

Advance warning signs

Many studies have been done to improve advance warning signs. These studies have involved changing the size, shape, color, symbols, messages, locations and number (redundancy). Some show

---

[13] Richards, S.H. and Heathering, K.W. (1988). Motorists understanding of railroad-highway grade crossing traffic control devices and associated traffic laws. Paper presented at the 67th Annual Meeting of the Transportation Research Board. Washington, D.C.

[14] Haga, S. (1988). Prevention of accidents at road-rail level crossings protected with automatic barriers pp. 933-937. Proceedings of the Human Factors Society 32nd Annual Meeting Vol. 2. Santa Monica, CA: The Human Factors Society.

[15] Knoblauch et al. 1982. op. cit.

[16] Leibowitz, H.W. 1985. op. cit.

[17] Leibowitz, H.W. and Owens, D.A. (1986). We drive by night. Psychology Today, 20(1), 55-58.

[18] McGinnis, R.G. (1979). The benefits and costs of a program to reflectorize the U.S. fleet of railroad rolling stock, Report No. FRA-OPPD-79-12. Washington, D.C.: Federal Highway Administration.

slight enhancement but none have shown substantial effects on drivers' behavior and potential effects on driver behavior are unknown.

Active advance warning devices (AAWDs)

AAWDs have been proposed for both active and passive crossings particularly those with limited sight distances (geometry or weather) and high vehicle speeds (perhaps due to downgrades.) The rationale behind activating the AAWD prior to activation of the crossing device is to provide sufficient time for drivers located between the AAWD and the crossing to clear the crossing before activation of the crossing signals. When AAWDs have been tested at active crossings with limited sight distances, they appeared to facilitate driver detection of the activated crossing signal, but primarily under daytime viewing conditions. In a field test (Ruden et al., 1982) using flashing lights on the approach to the crossing. About half of the drivers recognized that this signaled the approach of a train while the other half wanted to know whether or not the lights flashed continuously. This latter response was caused by familiarity with continuously flashing lights such as those at rural intersections or at construction zones. The TRAIN WHEN CROSSING and the neon R X R GATE AAWDs have been shown to be effective. Acoustic warning signals have been tested and found to result in some improvements, however, neighbor's complaints limit their applicability. Various authors have suggested in-vehicle warning messages but this advanced concept has not been adequately tested and usage would need to be nearly universal before this technology could replace conventional AAWDs. Thus AAWDs have been shown to provide a benefit, particularly when they are only active when a train is present.

Rumble strips

Rumble strips have shown to have advantages over purely visual warning signals in alerting drivers to the crossing and also the detection of other warning signals. Painted rumble strips cause speed reduction even before the strips are reached. The most serious disadvantage is the avoidance behavior of drivers familiar with the crossing. The consensus is that rumble strips should be used only at crossings with special hazards such as limited sight distances, unusual geometries or excessive vehicle speeds

Crossbucks

There are many studies which have evaluated size, shape and color of crossbuck signs since the standard crossbuck has limited conspicuity. Overall, the case for changing the standard crossbuck is not strong.

Active warning devices

Even under ideal viewing conditions the standard narrow-beam lights used for active crossing signals are not readily detected by drivers at short distances from the crossing (Hopkins and White, 1977[19]; Lindberg, 1971[20]). Efforts to increase the conspicuity of crossing signals have included manipulations of intensity, beam size, size color, flash rate, placement and source of light such as incandescent or strobe.

Most attempts at improvements have involved the addition of strobe lights and most of these efforts have been at least partly effective. The major drawbacks have been that some drivers attend to the strobe light rather than the train or the other signals which signal the presence of a train. It appears that strobe lights have more value at urban crossings where conspicuity is an issue. In addition to strobe lights, studies have considered the use of traffic control signals at grade crossings. The advantage is that these signals are familiar to drivers. However, traffic control signals have not been shown to be superior to flashing lights.

Of all the active warning devices studied, strobe lights seem to offer the greatest promise. However, whether strobes will maintain their attention getting properties if they come into widespread use is not known.

Trains

Countermeasures for increasing the conspicuity of trains fall into two categories: at the crossing or before the train reaches the crossing. Accident data shows that in 10% of crossing accidents the driver could have stopped safely if he had detected the train when it was at the crossing. This type of accident could be reduced by increasing the visibility of the train when it is at, or about to enter, the crossing.

---

[19] Hopkins, J.B. and White, E. (1977). Improvement of the effectiveness of motorist warnings at railroad-highway grade crossings. Report No. DOT-TSC-FRA--76-25). Washington, D.C.:USDOT, FHWA.

[20] Lindberg, V.L. (1971). How to make crossing signals more observable to drivers. Railway Signal Controls, 2(1), 24-30.

However, for the majority, about 90%, of accidents, the train was still approaching the crossing when was at the decision point. For these accidents the counter measure is to increase the sight distances and train conspicuity. Lerner discusses these factors under the following headings: illumination at the crossing, reflectorization of railcars, reflectorization of trackside objects and on-train devices.

Perception

Improving perceptual judgments by the use of illusions have been proposed but not tested. Leibowitz (1985)[21] has suggested that the apparent size of an approaching train should be reduced since smaller objects appear to have a greater speed than larger objects. Leibowitz also suggested that the looming effect should be increased to make drivers more conservative in there estimation of the train's distance from the intersection and the train's speed of approach. In general the potential benefits from perceptual countermeasures are untested.

Decision making

Decision making concerns the ways in which drivers deal with the information available to them. Issues involve the kind of information, its credibility, when and where it is received and the results compared to alternative decisions. Decision making was covered under five main headings: enhanced information content in advanced warnings; enhanced information content at the crossing; information credibility; distribution of information; and the costs of alternative actions.

Enhanced information for advance warnings

Advance warning only inform the driver that there is a crossing ahead. More information could be provided. Active vs. passive crossings might benefit from different information; at least notification of which kind of crossing is ahead. Active advanced warnings provide additional information which could be especially valuable when sight distances are short. Different sight distances may require different search strategies on the part of the driver and this could be indicated in advance of the crossing. Advisory signs relating to approach speed, path, and braking have been suggested.

---

[21] Leibowitz, H.W. (1985) op. cit.

Enhanced information at the crossing

The information presented at the crossing now is well known. Other information could be given such as “Do Not Stop On Tracks” or some form of “It Is Safe To Proceed” sign. Information about circuitry malfunction could also be provided. An amber warning could precede the red signal light. The direction of the approaching train could be indicated but not by an arrow sign which could confuse the driver since the meaning of train is approaching from the left vs. train is heading to your left is ambiguous. Studies have shown that many drivers go through the red flashing signal and cross in front of the approaching train when the train still distant (14 seconds on average in one study). Yield signs at passive crossings (other than the crossbuck) have been proposed but improved performance has not been demonstrated.

Information credibility

Signs which state that a crossing exists are credible because the crossing does in fact exist. However, warning signs may have a credibility problem. The reason is that the frequency of trains at the crossing is low. Extended warning times and false alarms also help to lower credibility. Constant Warning Time (CWT) circuitry is the countermeasure for this problem. There is evidence to show the effectiveness of CWT on driver behavior and accident rates.

Overall, little has been identified in the way of promising decision-error countermeasures that address the relative costs of safe vs. unsafe actions.

Compliance

To improve drivers’ compliance with crossing laws and devices the following categories of countermeasures have been suggested: enforcement; crossing traffic control device validity; use of intersection-related traffic control devices with better compliance rates; and the perceived reasonableness of driver requirements.

Enforcement is sporadic; officers are not routinely stationed at grade crossings although their presence would undoubtedly improve compliance.

One program to improve traffic control device compliance is the "800" number posted at the crossing for reporting signal malfunctions (Lamkin, 1985)[22]. In one year this program received 5,000 calls and 84 per cent of them concerned false alarms. False alarms reduce credibility. Lerner devoted a short section to perceived reasonableness pointing out that drivers are more apt to obey traffic control devices if they think they are reasonable.

An Appropriate View of the Driver

This section has particular significance for the Transitway safety project.

Lerner believes that our view of drivers involved in accidents includes ideas of inattention, inappropriate speed, unnecessary risk-taking, disregard of signs and signals and the like. That is accidents are completely assignable to avoidable driver error. Lerner presents different view quoted as follows:

"The image of the more typical driver is that of a reasonable rational, if imperfect, decision maker, who is trying to optimize his situation based on his knowledge and the facts at hand. He brings to this task a variety of perceptions and opinions based on personal experience, and these have some validity. He is not just relying on the formal information provided by the traffic engineer and the railroad. This driver is probably quite familiar with the crossing site and has expectancies about its geometric, operational, and hazard characteristics. At a personal level, the relative importance of some benefits or costs may not be weighted the same as they would be for a highway safety specialist form his perspective; 'wrong' actions could thus result not from errors as much as from different decision criteria. Viewing the driver in this way, one can place potential safety treatments in the full context of the driver's decision making task."

Lerner points out that for an average crossing, a driver could cross safely twice a day for fifteen years even if the driver was deaf and blind to everything but the pavement directly in front of the vehicle and even the worst driver would not be as oblivious as the hypothetical driver. This illustration may partly explain the lack of correlation between accidents and knowledge of signs, signals and laws. At the other end of the spectrum consider a driver who is completely concerned with compliance with

---

[2222] Lamkin, J. (1985). The Texas grade crossing signal notification program: Call 1-800. Proceedings, 1985 National Conference on Highway-Rail Safety. Kansas City, MO, July 1985.

signs, signals, laws and crossing safety. This driver at least partially accounts for the statistic which shows that for every train related accident at a crossing there are two non-train related accidents.

In the quotation above Lerner describes a driver as a decision maker with a difficult task. The following quote from Lerner suggests a countermeasure for aiding this driver. “Given the view of the driver as a reasonably rational decision maker facing a complex task under information constraints, what are the implications for countermeasures? First, it would de-emphasize the approach of trying to instill greater safety motivation or knowledge of rules and laws. While this is not to imply that there is not merit in such efforts, they do not attack the crux of the decision making problem. Similarly it would place less emphasis on passive signage that generally describes a desired action (e.g., slowing, looking) that the driver may already recognize as an option. Again, this is not to imply such signs may be without benefit; rather, the suggested view of the driver as a decision maker considering a variety of information sources and behavioral option means that one cannot presume mechanistic compliance with such signs. What is suggested by this perspective of the driver is that the roadway approach to the crossing be viewed in a decision context, and that the decision task itself be as well-structured as possible. The desired action should be obvious; other options should be eliminated or made less desirable; extraneous concerns should not be present; and influence should be exerted early in the decision chain.”

Sight Distance

All three types of sight distance are targets for countermeasures: visibility ahead to the crossing; visibility along the track on the approach to the crossing (from the decision zone); and visibility along the track when stopped at the crossing. Instead of a distance problem, sight distance can be considered as a speed control problem. The sight distance required by the driver is determined by the train’s speed and the vehicle’s speed and braking ability. A posted speed limit does not require a predetermined sight distance. This viewpoint places difficult burdens on the driver and is not ideal from the driver’s behavioral standpoint. Effective counter measures to address the sight distance problem need to adopt realistic expectations about what drivers will do, what information they need and will use, and what expectancies they bring to the situation. The Positive Guidance model might a useful tool for addressing the sight distance problem.

Driver Familiarity with The Crossing

Most accidents involve victims that were familiar with the crossing. This suggest that passive information will not be helpful because it will lose its salience. An intermittent police presence might be a successful if impractical countermeasure.

Directed Visual Attention

Drivers detect trains visually and there are many factors which interfere with acquiring a train visually. There is also the problem that visually searching for a train will divert attention from vehicle control possibly resulting in single or multiple vehicle accidents at the crossing. Redundant information using different sensory modes is a possible countermeasure. Rumble strips are a possibility but they suffer the disadvantage of all passive devices in that they are present whether or not there is a train.

A System Perspective

The idea of a system perspective is that introducing CWT at a crossing may have a favorable effect on credibility that drivers will generalize to other crossings. There is also a negative consequence. For example as more active devices are added at crossings drivers may tend to believe that all crossings have active devices.

Comparison of Flashing Light Signals with Traffic Control Signals

This comparison is reported in the form of a four page table. This table suggests that relative to the traffic control signal, the railroad crossing flashing light presents a more ambiguous message about appropriate driver actions.

APPENDIX B

Data Collection Sheet for Motorist Behavior at Intersections

1. Date:									
2. Time of Day:									
3. Intersection:									
23rd Ave									
25th Ave									
29th Ave									
30th Ave									
Malcolm									
Westgate									
Energy Park Dr									
Como Ave									
4. Direction of Travel:									
North or South									
5. Type of Vehicle:									
Car									
Light Truck									
Commercial Truck									
Semi-Truck									
6. Type of Stop									
Complete									
Yield (rolling)									
Ran It									
Green Light									
7. Did Motorist Look Both Ways?									
Yes									
No									
Unable to See									
8. How Many Buses Were in Sight?									
0, 1, 2, 3									
9. Was There an Incident?									
Yes of No									
10. Were Others Present on the Transitway?									
Bicyclist									
Pedestrians									
Inline Skaters									

Police										
Other										

(This page intentionally left blank)

APPENDIX C

Summaries of Transitway Accidents

04-14-92

to

06-01-98

Provided by Roger Huss,

Parking and Transportation Services

Formatting by Lowell A. Benson,

Center for Transportation Studies

Appendix C-1 Transitway Accidents Sorted by date

Medicine Lakes Line Bus unless otherwise noted.

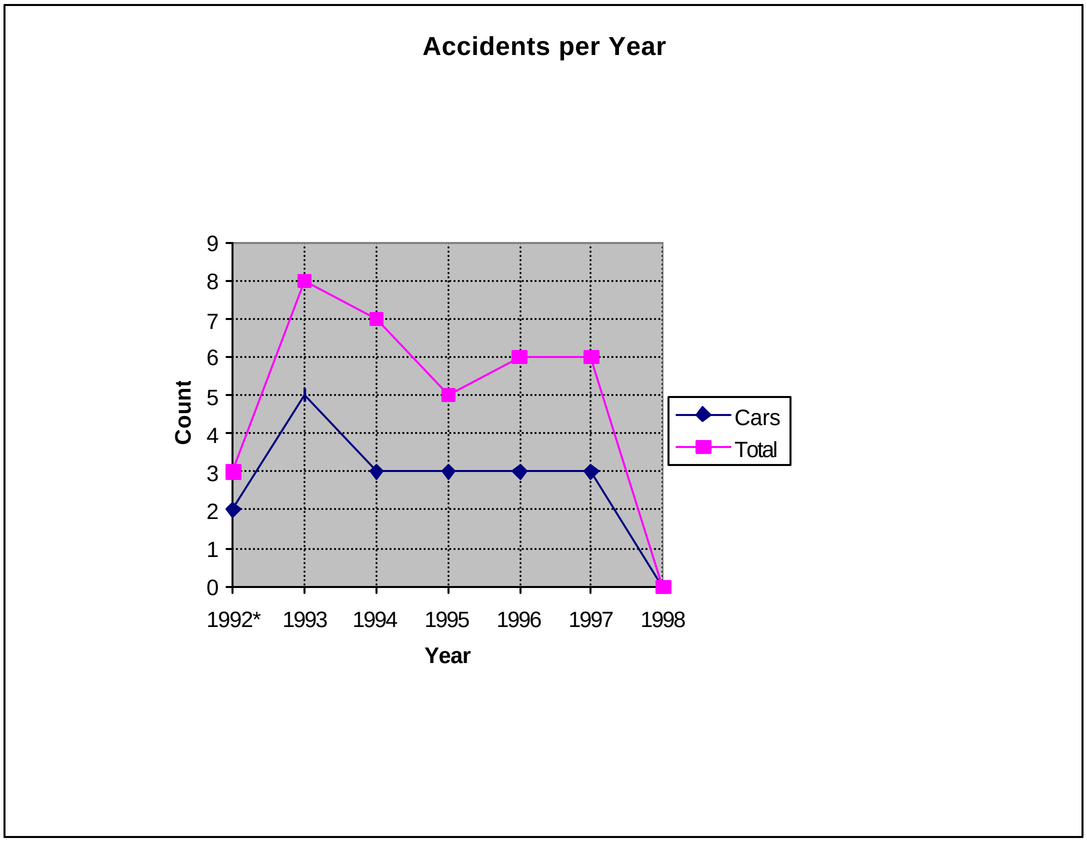
No.	Date	Time	Day	Location	Bus Struck	Other Vehicle Type	Action	Notes
1	04/14/92	7:15	Tues	Malcolm	Other	Car	Straight	
2	04/17/92	13:27	Fri	25th Ave. SE	By	Car	Straight	
3	06/02/92	16:05	Tues	30th Ave. SE	By	Co-Truck	Straight	
4	01/13/93	9:50	Wed	29th Ave. SE	Other	Pickup	Straight	
5	02/12/93	16:55	Fri	Oak St. SE	Other	Car	Straight	
6	03/05/93	15:00	Fri	Malcolm	By	Car	Straight	
7	08/03/93	13:41	Tues	Westgate Drive	Other	Car	Stopped	
8	11/05/93	9:00	Fri	Oak St. SE	Other	Car	Straight	
9	11/05/93	15:00	Fri	Westgate Drive	Other	Pickup	Straight	
10	11/24/93	7:05	Wed	Como Ave.	By	Car	Passing	
11	01/13/94	8:59	Thurs	Como Ave.	By	Car	Straight	
12	03/01/94	13:25	Tues	Como Ave.	Other	Car	Straight	
13	05/02/94	9:05	Mon	Westgate Drive	Other	Pickup	Straight	
14	07/28/94	9:15	Thurs	25th Ave. SE	Other	Pickup	Straight	
15	09/26/94	10:10	Mon	Malcolm	Other	Semi-Truck	Straight	
16	10/11/94	9:25	Tues	Transit Park Lot	Other	Car	Straight	
17	01/09/95	16:07	Mon	Malcolm	By	Sport Utility	Straight	
18	01/10/95	12:40	Tues	Westgate Drive	Other	Car	Straight	
19	02/02/95	5:30	Thurs	Energy Park Drive	Other	Car	Straight	
20	02/22/95	16:45	Wed	Energy Park Drive	By	Pickup	Following	
21	11/27/95	15:15	Mon	Energy Park Drive	By	Car	Straight	
22	02/27/96	7:45	Tues	Como Ave.	Other	Pickup	Straight	
23	03/15/96	7:40	Fri	29th Ave. SE	Other	Semi-Truck	Straight	
24	06/11/96	9:10	Tues	Malcolm	By	Semi-Truck	Straight	
25	10/11/96	16:46	Fri	Energy Park Drive	By	Car	Straight	
26	10/15/96	14:39	Tues	Energy Park Drive	By	Car	Straight	
27	11/22/96	17:55	Fri	Westgate Drive	Other	Car	Straight	
28	01/08/97	13:04	Wed	Malcolm	By	Car	Straight	
29	01/10/97	10:30	Fri	Como Ave.	By	Car	Straight	
30	01/24/97	9:45	Fri	Westgate Drive	By	Car	Straight	
31	07/11/97	13:30	Fri	Westgate Drive	Other	Car	Straight	
32	10/20/97	10:05	Mon	Transit Park Lot	Other	Roller Blader	Straight	
34	12/01/97	7:57	Mon	Malcolm	By	Co-Truck	Straight	Metro Transit**
33*	09/05/94	16:05	Mon	Malcolm	Other	Co-Truck	Straight	MCTO**
35*	11/15/93	17:02	Mon	Westgate Drive	Other		Straight	PhyPlant

*Not counted in initial analysis data

**Metropolitan Council Transit Operations became Metro Transit in 1997

Year	Cars	Total
1992*	2	3
1993	5	8
1994	3	7
1995	3	5
1996	3	6
1997	3	6
1998	0	0

Note that Official operation began March 30, 1992
Chart below is through June 1998



APPENDIX C-2

Transitway Accidents Sorted by Day

No.	Date	Time	Day	Location	Bus Struck	Other Vehicle Type	Action
2	04/17/92	13:27	Fri	25th Ave. SE	By	Car	Straight
23	03/15/96	7:40	Fri	29th Ave. SE	Other	Semi-Truck	Straight
29	01/10/97	10:30	Fri	Como Ave.	By	Car	Straight
25	10/11/96	16:46	Fri	Energy Park Drive	By	Car	Straight
6	03/05/93	15:00	Fri	Malcolm	By	Car	Straight
8	11/05/93	9:00	Fri	Oak St. SE	Other	Car	Straight
5	02/12/93	16:55	Fri	Oak St. SE	Other	Car	Straight
30	01/24/97	9:45	Fri	Westgate Drive	By	Car	Straight
31	07/11/97	13:30	Fri	Westgate Drive	Other	Car	Straight
9	11/05/93	15:00	Fri	Westgate Drive	Other	Pickup	Straight
27	11/22/96	17:55	Fri	Westgate Drive	Other	Car	Straight
21	11/27/95	15:15	Mon	Energy Park Drive	By	Car	Straight
34	12/01/97	7:57	Mon	Malcolm	By	Co-Truck	Straight
15	09/26/94	10:10	Mon	Malcolm	Other	Semi-Truck	Straight
33*	09/05/94	16:05	Mon	Malcolm	Other	Co-Truck	Straight
17	01/09/95	16:07	Mon	Malcolm	By	Sport Utility	Straight
32	10/20/97	10:05	Mon	Transit Park Lot	Other	Roller Blader	Straight
13	05/02/94	9:05	Mon	Westgate Drive	Other	Pickup	Straight
35*	11/15/93	17:02	Mon	Westgate Drive	Other		Straight
14	07/28/94	9:15	Thurs	25th Ave. SE	Other	Pickup	Straight
11	01/13/94	8:59	Thurs	Como Ave.	By	Car	Straight
19	02/02/95	5:30	Thurs	Energy Park Drive	Other	Car	Straight
3	06/02/92	16:05	Tues	30th Ave. SE	By	Co-Truck	Straight
22	02/27/96	7:45	Tues	Como Ave.	Other	Pickup	Straight
12	03/01/94	13:25	Tues	Como Ave.	Other	Car	Straight
26	10/15/96	14:39	Tues	Energy Park Drive	By	Car	Straight
1	04/14/92	7:15	Tues	Malcolm	Other	Car	Straight
24	06/11/96	9:10	Tues	Malcolm	By	Semi-Truck	Straight
16	10/11/94	9:25	Tues	Transit Park Lot	Other	Car	Straight
18	01/10/95	12:40	Tues	Westgate Drive	Other	Car	Straight
7	08/03/93	13:41	Tues	Westgate Drive	Other	Car	Stopped
4	01/13/93	9:50	Wed	29th Ave. SE	Other	Pickup	Straight
10	11/24/93	7:05	Wed	Como Ave.	By	Car	Passing
20	02/22/95	16:45	Wed	Energy Park Drive	By	Pickup	Following
28	01/08/97	13:04	Wed	Malcolm	By	Car	Straight

Day	Count
Sat+Sun	0
Fri	11
Thurs	3
Wed	4
Tues	9
Mon	8

Note that the bus system does not operate during the weekends.

Appendix C-3

Transitway Accidents Sorted by Location

No.	Date	Time	Day	LOCATION	Struck	Vehicle Type	Direction
2	4/17/1992	13:27	Fri	**25th Ave. SE**	By	Car	Straight
14	07/28/94	9:15	Thurs	**25th Ave. SE**	Other	Pickup	Straight
23	03/15/96	7:40	Fri	**29th Ave. SE**	Other	Semi-Truck	Straight
4	01/13/93	9:50	Wed	**29th Ave. SE**	Other	Pickup	Straight
3	06/02/92	16:05	Tues	**30th Ave. SE**	By	Co-Truck	Straight
29	01/10/97	10:30	Fri	**Como Ave.**	By	Car	Straight
11	01/13/94	8:59	Thurs	**Como Ave.**	By	Car	Straight
22	02/27/96	7:45	Tues	**Como Ave.**	Other	Pickup	Straight
12	03/01/94	13:25	Tues	**Como Ave.**	Other	Car	Straight
10	11/24/93	7:05	Wed	**Como Ave.**	By	Car	Passing
25	10/11/96	16:46	Fri	**Energy Park Drive**	By	Car	Straight
21	11/27/95	15:15	Mon	**Energy Park Drive**	By	Car	Straight
19	02/02/95	5:30	Thurs	**Energy Park Drive**	Other	Car	Straight
26	10/15/96	14:39	Tues	**Energy Park Drive**	By	Car	Straight
20	02/22/95	16:45	Wed	**Energy Park Drive**	By	Pickup	Following
6	03/05/93	15:00	Fri	**Malcolm**	By	Car	Straight
34	12/01/97	7:57	Mon	**Malcolm**	By	Co-Truck	Straight
15	09/26/94	10:10	Mon	**Malcolm**	Other	Semi-Truck	Straight
33*	09/05/94	16:05	Mon	**Malcolm**	Other	Co-Truck	Straight
17	01/09/95	16:07	Mon	**Malcolm**	By	Sport Utility	Straight
1	04/14/92	7:15	Tues	**Malcolm**	Other	Car	Straight
24	06/11/96	9:10	Tues	**Malcolm**	By	Semi-Truck	Straight
28	01/08/97	13:04	Wed	**Malcolm**	By	Car	Straight
8	11/05/93	9:00	Fri	**Oak St. SE**	Other	Car	Straight
5	02/12/93	16:55	Fri	**Oak St. SE**	Other	Car	Straight
32	10/20/97	10:05	Mon	**Transit Park Lot**	Other	Roller Blader	Straight
16	10/11/94	9:25	Tues	**Transit Park Lot**	Other	Car	Straight
30	01/24/97	9:45	Fri	**Westgate Drive**	By	Car	Straight
31	07/11/97	13:30	Fri	**Westgate Drive**	Other	Car	Straight
9	11/05/93	15:00	Fri	**Westgate Drive**	Other	Pickup	Straight
27	11/22/96	17:55	Fri	**Westgate Drive**	Other	Car	Straight
13	05/02/94	9:05	Mon	**Westgate Drive**	Other	Pickup	Straight
35*	11/15/93	17:02	Mon	**Westgate Drive**	Other		Straight
18	01/10/95	12:40	Tues	**Westgate Drive**	Other	Car	Straight
7	08/03/93	13:41	Tues	**Westgate Drive**	Other	Car	Stopped

APPENDIX C-4

Transitway Accidents Sorted by Vehicle

No.	Date	Time	Day	Location	Bus Struck	Other Vehicle Type	Action
2	04/17/92	13:27	Fri	25th Ave. SE	By	Car	Straight
29	01/10/97	10:30	Fri	Como Ave.	By	Car	Straight
11	01/13/94	8:59	Thurs	Como Ave.	By	Car	Straight
12	03/01/94	13:25	Tues	Como Ave.	Other	Car	Straight
10	11/24/93	7:05	Wed	Como Ave.	By	Car	Passing
25	10/11/96	16:46	Fri	Energy Park Drive	By	Car	Straight
21	11/27/95	15:15	Mon	Energy Park Drive	By	Car	Straight
19	02/02/95	5:30	Thurs	Energy Park Drive	Other	Car	Straight
26	10/15/96	14:39	Tues	Energy Park Drive	By	Car	Straight
6	03/05/93	15:00	Fri	Malcolm	By	Car	Straight
1	04/14/92	7:15	Tues	Malcolm	Other	Car	Straight
28	01/08/97	13:04	Wed	Malcolm	By	Car	Straight
5	02/12/93	16:55	Fri	Oak St. SE	Other	Car	Straight
8	11/05/93	9:00	Fri	Oak St. SE	Other	Car	Straight
16	10/11/94	9:25	Tues	Transit Park Lot	Other	Car	Straight
27	11/22/96	17:55	Fri	Westgate Drive	Other	Car	Straight
30	01/24/97	9:45	Fri	Westgate Drive	By	Car	Straight
31	07/11/97	13:30	Fri	Westgate Drive	Other	Car	Straight
7	08/03/93	13:41	Tues	Westgate Drive	Other	Car	Stopped
18	01/10/95	12:40	Tues	Westgate Drive	Other	Car	Straight
3	06/02/92	16:05	Tues	30th Ave. SE	By	Co-Truck	Straight
33*	09/05/94	16:05	Mon	Malcolm	Other	Co-Truck	Straight
34	12/01/97	7:57	Mon	Malcolm	By	Co-Truck	Straight
14	07/28/94	9:15	Thurs	25th Ave. SE	Other	Pickup	Straight
22	02/27/96	7:45	Tues	Como Ave.	Other	Pickup	Straight
20	02/22/95	16:45	Wed	Energy Park Drive	By	Pickup	Following
9	11/05/93	15:00	Fri	Westgate Drive	Other	Pickup	Straight
13	05/02/94	9:05	Mon	Westgate Drive	Other	Pickup	Straight
4	01/13/93	9:50	Wed	29th Ave. SE	Other	Pickup	Straight
32	10/20/97	10:05	Mon	Transit Park Lot	Other	Roller Blader	Straight
23	03/15/96	7:40	Fri	29th Ave. SE	Other	Semi-Truck	Straight
15	09/26/94	10:10	Mon	Malcolm	Other	Semi-Truck	Straight
24	06/11/96	9:10	Tues	Malcolm	By	Semi-Truck	Straight
17	01/09/95	16:07	Mon	Malcolm	By	Sport Utility	Straight
35*	11/15/93	17:02	Mon	Westgate Drive	Other		Straight

APPENDIX C-5

Transitway Accidents Sorted by Month

No.	Date	Time	Day	Location	Bus Struck	Other Vehicle Type	Action
4	01/13/93	9:50	Wed	29th Ave. SE	Other	Pickup	Straight
11	01/13/94	8:59	Thurs	Como Ave.	By	Car	Straight
17	01/09/95	16:07	Mon	Malcolm	By	Sport Utility	Straight
18	01/10/95	12:40	Tues	Westgate Drive	Other	Car	Straight
28	01/08/97	13:04	Wed	Malcolm	By	Car	Straight
29	01/10/97	10:30	Fri	Como Ave.	By	Car	Straight
30	01/24/97	9:45	Fri	Westgate Drive	By	Car	Straight
5	02/12/93	16:55	Fri	Oak St. SE	Other	Car	Straight
19	02/02/95	5:30	Thurs	Energy Park Drive	Other	Car	Straight
20	02/22/95	16:45	Wed	Energy Park Drive	By	Pickup	Following
22	02/27/96	7:45	Tues	Como Ave.	Other	Pickup	Straight
6	03/05/93	15:00	Fri	Malcolm	By	Car	Straight
12	03/01/94	13:25	Tues	Como Ave.	Other	Car	Straight
23	03/15/96	7:40	Fri	29th Ave. SE	Other	Semi-Truck	Straight
1	04/14/92	7:15	Tues	Malcolm	Other	Car	Straight
2	04/17/92	13:27	Fri	25th Ave. SE	By	Car	Straight
13	05/02/94	9:05	Mon	Westgate Drive	Other	Pickup	Straight
3	06/02/92	16:05	Tues	30th Ave. SE	By	Co-Truck	Straight
24	06/11/96	9:10	Tues	Malcolm	By	Semi-Truck	Straight
14	07/28/94	9:15	Thurs	25th Ave. SE	Other	Pickup	Straight
31	07/11/97	13:30	Fri	Westgate Drive	Other	Car	Straight
7	08/03/93	13:41	Tues	Westgate Drive	Other	Car	Stopped
33*	09/05/94	16:05	Mon	Malcolm	Other	Co-Truck	Straight
15	09/26/94	10:10	Mon	Malcolm	Other	Semi-Truck	Straight
16	10/11/94	9:25	Tues	Transit Park Lot	Other	Car	Straight
25	10/11/96	16:46	Fri	Energy Park Drive	By	Car	Straight
26	10/15/96	14:39	Tues	Energy Park Drive	By	Car	Straight
32	10/20/97	10:05	Mon	Transit Park Lot	Other	Roller Blader	Straight
8	11/05/93	9:00	Fri	Oak St. SE	Other	Car	Straight
9	11/05/93	15:00	Fri	Westgate Drive	Other	Pickup	Straight
35*	11/15/93	17:02	Mon	Westgate Drive	Other		Straight
10	11/24/93	7:05	Wed	Como Ave.	By	Car	Passing
21	11/27/95	15:15	Mon	Energy Park Drive	By	Car	Straight
27	11/22/96	17:55	Fri	Westgate Drive	Other	Car	Straight
34	12/01/97	7:57	Mon	Malcolm	By	Co-Truck	Straight

APPENDIX C-6

Transitway Accidents Sorted by Time of Day

					Bus	Other Vehicle	
No.	Date	Time	Day	Location	Struck	Type	Action
19	02/02/95	5:30	Thurs	Energy Park Drive	Other	Car	Straight
10	11/24/93	7:05	Wed	Como Ave.	By	Car	Passing
1	04/14/92	7:15	Tues	Malcolm	Other	Car	Straight
23	03/15/96	7:40	Fri	29th Ave. SE	Other	Semi-Truck	Straight
22	02/27/96	7:45	Tues	Como Ave.	Other	Pickup	Straight
34	12/01/97	7:57	Mon	Malcolm	By	Co-Truck	Straight
11	01/13/94	8:59	Thurs	Como Ave.	By	Car	Straight
8	11/05/93	9:00	Fri	Oak St. SE	Other	Car	Straight
13	05/02/94	9:05	Mon	Westgate Drive	Other	Pickup	Straight
24	06/11/96	9:10	Tues	Malcolm	By	Semi-Truck	Straight
14	07/28/94	9:15	Thurs	25th Ave. SE	Other	Pickup	Straight
16	10/11/94	9:25	Tues	Transit Park Lot	Other	Car	Straight
30	01/24/97	9:45	Fri	Westgate Drive	By	Car	Straight
4	01/13/93	9:50	Wed	29th Ave. SE	Other	Pickup	Straight
32	10/20/97	10:05	Mon	Transit Park Lot	Other	Roller Blader	Straight
15	09/26/94	10:10	Mon	Malcolm	Other	Semi-Truck	Straight
29	01/10/97	10:30	Fri	Como Ave.	By	Car	Straight
18	01/10/95	12:40	Tues	Westgate Drive	Other	Car	Straight
28	01/08/97	13:04	Wed	Malcolm	By	Car	Straight
12	03/01/94	13:25	Tues	Como Ave.	Other	Car	Straight
2	04/17/92	13:27	Fri	25th Ave. SE	By	Car	Straight
31	07/11/97	13:30	Fri	Westgate Drive	Other	Car	Straight
7	08/03/93	13:41	Tues	Westgate Drive	Other	Car	Stopped
26	10/15/96	14:39	Tues	Energy Park Drive	By	Car	Straight
6	03/05/93	15:00	Fri	Malcolm	By	Car	Straight
9	11/05/93	15:00	Fri	Westgate Drive	Other	Pickup	Straight
21	11/27/95	15:15	Mon	Energy Park Drive	By	Car	Straight
3	06/02/92	16:05	Tues	30th Ave. SE	By	Co-Truck	Straight
33*	09/05/94	16:05	Mon	Malcolm	Other	Co-Truck	Straight
17	01/09/95	16:07	Mon	Malcolm	By	Sport Utility	Straight
20	02/22/95	16:45	Wed	Energy Park Drive	By	Pickup	Following
25	10/11/96	16:46	Fri	Energy Park Drive	By	Car	Straight
5	02/12/93	16:55	Fri	Oak St. SE	Other	Car	Straight
35*	11/15/93	17:02	Mon	Westgate Drive	Other		Straight
27	11/22/96	17:55	Fri	Westgate Drive	Other	Car	Straight

APPENDIX C-7

Transitway Accidents Sorted by Action of the Crossing Vehicle

No.	Date	Time	Day	Location	Bus Struck	**Other Vehicle** Type	**Action**
20	02/22/95	16:45	Wed	Energy Park Drive	By	Pickup	**Following**
10	11/24/93	7:05	Wed	Como Ave.	By	Car	**Passing**
7	08/03/93	13:41	Tues	Westgate Drive	Other	Car	**Stopped**
2	04/17/92	13:27	Fri	25th Ave. SE	By	Car	**Straight**
14	07/28/94	9:15	Thurs	25th Ave. SE	Other	Pickup	**Straight**
23	03/15/96	7:40	Fri	29th Ave. SE	Other	Semi-Truck	**Straight**
4	01/13/93	9:50	Wed	29th Ave. SE	Other	Pickup	**Straight**
3	06/02/92	16:05	Tues	30th Ave. SE	By	Co-Truck	**Straight**
29	01/10/97	10:30	Fri	Como Ave.	By	Car	**Straight**
11	01/13/94	8:59	Thurs	Como Ave.	By	Car	**Straight**
12	03/01/94	13:25	Tues	Como Ave.	Other	Car	**Straight**
22	02/27/96	7:45	Tues	Como Ave.	Other	Pickup	**Straight**
25	10/11/96	16:46	Fri	Energy Park Drive	By	Car	**Straight**
21	11/27/95	15:15	Mon	Energy Park Drive	By	Car	**Straight**
19	02/02/95	5:30	Thurs	Energy Park Drive	Other	Car	**Straight**
26	10/15/96	14:39	Tues	Energy Park Drive	By	Car	**Straight**
6	03/05/93	15:00	Fri	Malcolm	By	Car	**Straight**
33*	09/05/94	16:05	Mon	Malcolm	Other	Co-Truck	**Straight**
15	09/26/94	10:10	Mon	Malcolm	Other	Semi-Truck	**Straight**
17	01/09/95	16:07	Mon	Malcolm	By	Sport Utility	**Straight**
34	12/01/97	7:57	Mon	Malcolm	By	Co-Truck	**Straight**
1	04/14/92	7:15	Tues	Malcolm	Other	Car	**Straight**
24	06/11/96	9:10	Tues	Malcolm	By	Semi-Truck	**Straight**
28	01/08/97	13:04	Wed	Malcolm	By	Car	**Straight**
5	02/12/93	16:55	Fri	Oak St. SE	Other	Car	**Straight**
8	11/05/93	9:00	Fri	Oak St. SE	Other	Car	**Straight**
32	10/20/97	10:05	Mon	Transit Park Lot	Other	Roller Blader	**Straight**
16	10/11/94	9:25	Tues	Transit Park Lot	Other	Car	**Straight**
9	11/05/93	15:00	Fri	Westgate Drive	Other	Pickup	**Straight**
27	11/22/96	17:55	Fri	Westgate Drive	Other	Car	**Straight**
30	01/24/97	9:45	Fri	Westgate Drive	By	Car	**Straight**
31	07/11/97	13:30	Fri	Westgate Drive	Other	Car	**Straight**
35*	11/15/93	17:02	Mon	Westgate Drive	Other		**Straight**
13	05/02/94	9:05	Mon	Westgate Drive	Other	Pickup	**Straight**
18	01/10/95	12:40	Tues	Westgate Drive	Other	Car	**Straight**

APPENDIX C-8

Transitway Accidents Sorted by the Object Struck

					Bus	**Other Vehicle**	
No.	Date	Time	Day	Location	Struck	Type	Action
2	04/17/92	13:27	Fri	25th Ave. SE	By	Car	Straight
3	06/02/92	16:05	Tues	30th Ave. SE	By	Co-Truck	Straight
29	01/10/97	10:30	Fri	Como Ave.	By	Car	Straight
11	01/13/94	8:59	Thurs	Como Ave.	By	Car	Straight
10	11/24/93	7:05	Wed	Como Ave.	By	Car	Passing
25	10/11/96	16:46	Fri	Energy Park Drive	By	Car	Straight
21	11/27/95	15:15	Mon	Energy Park Drive	By	Car	Straight
26	10/15/96	14:39	Tues	Energy Park Drive	By	Car	Straight
20	02/22/95	16:45	Wed	Energy Park Drive	By	Pickup	Following
6	03/05/93	15:00	Fri	Malcolm	By	Car	Straight
17	01/09/95	16:07	Mon	Malcolm	By	Sport Utility	Straight
34	12/01/97	7:57	Mon	Malcolm	By	Co-Truck	Straight
24	06/11/96	9:10	Tues	Malcolm	By	Semi-Truck	Straight
28	01/08/97	13:04	Wed	Malcolm	By	Car	Straight
30	01/24/97	9:45	Fri	Westgate Drive	By	Car	Straight
14	07/28/94	9:15	Thurs	25th Ave. SE	Other	Pickup	Straight
23	03/15/96	7:40	Fri	29th Ave. SE	Other	Semi-Truck	Straight
4	01/13/93	9:50	Wed	29th Ave. SE	Other	Pickup	Straight
12	03/01/94	13:25	Tues	Como Ave.	Other	Car	Straight
22	02/27/96	7:45	Tues	Como Ave.	Other	Pickup	Straight
19	02/02/95	5:30	Thurs	Energy Park Drive	Other	Car	Straight
33*	09/05/94	16:05	Mon	Malcolm	Other	Co-Truck	Straight
15	09/26/94	10:10	Mon	Malcolm	Other	Semi-Truck	Straight
1	04/14/92	7:15	Tues	Malcolm	Other	Car	Straight
5	02/12/93	16:55	Fri	Oak St. SE	Other	Car	Straight
8	11/05/93	9:00	Fri	Oak St. SE	Other	Car	Straight
32	10/20/97	10:05	Mon	Transit Park Lot	Other	Roller Blader	Straight
16	10/11/94	9:25	Tues	Transit Park Lot	Other	Car	Straight
9	11/05/93	15:00	Fri	Westgate Drive	Other	Pickup	Straight
27	11/22/96	17:55	Fri	Westgate Drive	Other	Car	Straight
31	07/11/97	13:30	Fri	Westgate Drive	Other	Car	Straight
35*	11/15/93	17:02	Mon	Westgate Drive	Other		Straight
13	05/02/94	9:05	Mon	Westgate Drive	Other	Pickup	Straight
7	08/03/93	13:41	Tues	Westgate Drive	Other	Car	Stopped
18	01/10/95	12:40	Tues	Westgate Drive	Other	Car	Straight

APPENDIX C-9

Transitway Accidents sorted by Count

No.	Date	Time	Day	Location	Bus Struck	Other Vehicle Type	Action	Notes
1	04/14/92	7:15	Tues	Malcolm	Other	Car	Straight	
2	04/17/92	13:27	Fri	25th Ave. SE	By	Car	Straight	
3	06/02/92	16:05	Tues	30th Ave. SE	By	Co-Truck	Straight	
4	01/13/93	9:50	Wed	29th Ave. SE	Other	Pickup	Straight	
5	02/12/93	16:55	Fri	Oak St. SE	Other	Car	Straight	
6	03/05/93	15:00	Fri	Malcolm	By	Car	Straight	
7	08/03/93	13:41	Tues	Westgate Drive	Other	Car	Stopped	
8	11/05/93	9:00	Fri	Oak St. SE	Other	Car	Straight	
9	11/05/93	15:00	Fri	Westgate Drive	Other	Pickup	Straight	
10	11/24/93	7:05	Wed	Como Ave.	By	Car	Passing	
11	01/13/94	8:59	Thurs	Como Ave.	By	Car	Straight	
12	03/01/94	13:25	Tues	Como Ave.	Other	Car	Straight	
13	05/02/94	9:05	Mon	Westgate Drive	Other	Pickup	Straight	
14	07/28/94	9:15	Thurs	25th Ave. SE	Other	Pickup	Straight	
15	09/26/94	10:10	Mon	Malcolm	Other	Semi-Truck	Straight	
16	10/11/94	9:25	Tues	Transit Park Lot	Other	Car	Straight	
17	01/09/95	16:07	Mon	Malcolm	By	Sport Utility	Straight	
18	01/10/95	12:40	Tues	Westgate Drive	Other	Car	Straight	
19	02/02/95	5:30	Thurs	Energy Park Drive	Other	Car	Straight	
20	02/22/95	16:45	Wed	Energy Park Drive	By	Pickup	Following	
21	11/27/95	15:15	Mon	Energy Park Drive	By	Car	Straight	
22	02/27/96	7:45	Tues	Como Ave.	Other	Pickup	Straight	
23	03/15/96	7:40	Fri	29th Ave. SE	Other	Semi-Truck	Straight	
24	06/11/96	9:10	Tues	Malcolm	By	Semi-Truck	Straight	
25	10/11/96	16:46	Fri	Energy Park Drive	By	Car	Straight	
26	10/15/96	14:39	Tues	Energy Park Drive	By	Car	Straight	
27	11/22/96	17:55	Fri	Westgate Drive	Other	Car	Straight	
28	01/08/97	13:04	Wed	Malcolm	By	Car	Straight	
29	01/10/97	10:30	Fri	Como Ave.	By	Car	Straight	
30	01/24/97	9:45	Fri	Westgate Drive	By	Car	Straight	
31	07/11/97	13:30	Fri	Westgate Drive	Other	Car	Straight	
32	10/20/97	10:05	Mon	Transit Park Lot	Other	Roller Blader	Straight	
34	12/01/97	7:57	Mon	Malcolm	By	Co-Truck	Straight	Metro Transit**
33*	09/05/94	16:05	Mon	Malcolm	Other	Co-Truck	Straight	MCTO**
35*	11/15/93	17:02	Mon	Westgate Drive	Other		Straight	PhyPlant

- Not counted in initial analysis data
- **Metropolitan Council transit Operations became Metro Transit in 1997

Back of last page,

Deliberately left blank