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A Study of Traffic Safety at Three Intersections in Worcester

An Interactive Qualifying Project Report
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Abstract

This paper discusses problems with the traffic flow in the area around the WPI campus, specifically for the intersections on Park Avenue. Various studies were performed to determine traffic volume and accident frequency, and were then analyzed to determine what could be done to benefit the drivers. Problems were found with the intersections, some serious and some just minor. Recommendations were made to the city of Worcester for solutions to these problems, and we hope that they will be implemented.

Acknowledgements

We thank these people for all the help and guidance that they have given us to get this project to where it is now. Without all of these people, we could not have come up with such a comprehensive analysis.

Professor Balgobin Nandram

Professor Nandram has helped us along the way, given us our primary guidance on how to complete this project, and most importantly, put up with our problems as a group. He was also able to refer us to our contacts at the Worcester DPW, and answer all of our questions over the course of a school year.

Mr. James Kempton

James Kempton was a fantastic help to us when we were performing our accident analysis, giving us full access to all of the information we needed at the DPW office. He was also able to help us out with charts and statistics to facilitate our traffic volume calculations, and advise us on better methods for analyzing these intersections

Professor Malcom H. Ray

Professor Ray was a great source of help for when we just needed a quick heads up on civil engineering related problems, such as where to find the equations we needed to come up with MUTCD warrants. The material he taught in CE 3050: Introduction to Transportation Engineering was invaluable for all of our data analysis.

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Chapter 1: Introduction

Traffic safety is an important issue in the city of Worcester. The volume of traffic driving around and through the city is very large, and there are many accidents. Last year alone, there were over seven thousand accidents in Worcester that were reported to the DPW. There are many causes for traffic accidents, such as weather, driver distractions, careless driving, and poor road and intersection design.

This report will focus on the design of intersections, and try to find a way to make any necessary improvement to three intersections on Park Avenue. These intersections were suggested for analysis by James Kempton of the Worcester DPW, based on their traffic volume and direct influence on the WPI area. Park Avenue has an extremely high daily traffic rate of about 15,000 vehicles per day. The intersection with Highland Street has been known to be especially hazardous to drivers as they attempt to make turns against heavy traffic. The safety of these intersections is important to the WPI community and the local residents.

The intersections of Highland, Institute, and Salisbury Streets with Park Avenue will be analyzed in several different ways. Problems that exist will be identified, and if possible within the realm of reasonable solutions, solved. Several studies will be made, considering accidents, traffic volume, and signal timing. The opinions of those who use these intersections will also be taken into consideration.

All of this information will be compiled and analyzed, and several different improvements may be recommended. Possible remedies may include adding left turn lanes and signals, widening the streets, lengthening or shortening the signal times, or additional signs to make the intersection easier and safer for drivers to navigate.

Chapter 2: Studies Performed

There are many studies that can be done on traffic traveling through an intersection. Some of these studies are more relevant than others, and some require special equipment to perform them. The studies performed for this report were the most feasible and useful out of the many that could have been done. Turning movement counts were made for each intersection, accident analysis was performed, and surveys were conducted. These methods allow the congestion and safety of the intersection to be analyzed and compared to national standards. These data can help determine what can be done to make the area safer and more pleasant to those passing through.

By far the most important study that can be done when analyzing an intersection is the turning movement count, which will show the total traffic volume moving through the intersection and type of movement each vehicle is making. This will help compare the accident data to determine accident rates, as well as where the traffic is overly congested.

For each intersection, two 15 minute counts are made, both during morning and evening rush hour. These methods are taught at WPI in the Civil Engineering curriculum by Professor Malcolm Ray, in the class CE 3050: Introduction to Transportation Engineering. Cars and trucks are counted separately, and vehicles are divided into categories of left turns, right turns, and straight through movements. The two counts are then averaged in order to account for small variations and to make the data more consistent. These data are then input to a spreadsheet and can be analyzed to come up with average daily traffic (ADT) rates, as well as equivalent straight through traffic. The equivalent straight through number factors trucks and turning vehicles to come up with a number which can be more easily compared to other intersections.

An accident study is equally important as, yet meaningless, without the volume study. In order to tabulate the accident data for each intersection, spreadsheets were obtained from the city of Worcester listing every accident in the local area for each year. These spreadsheets can be seen in Appendix B. Relevant accidents were identified, and the reports for these accidents were pulled from the files at the Worcester DPW, with the help of James Kempton, PE, a Worcester traffic engineer. The DPW keeps a detailed report of each accident that is reported to the Worcester Police, and usually includes a full diagram as well as the accounts of any witnesses and all of the parties involved. The reports were then individually analyzed, and relevant aspects of each accident, such as weather conditions, time of day, etc were copied down. Accidents were then marked down on a diagram for each intersection, denoting the location of the accident and the direction that each involved vehicle was traveling. These diagrams make it simple to quickly look at the results and see where the most serious problems are.

An interview was conducted with a WPI police officer in order to be able to see the problems with the traffic flow in these intersections from a different point of view. The officer was asked several questions pertaining to problems and recommendations for solutions to these problems. Any safety or congestion issues were brought up, and his input will influence our final recommendations.

A survey was distributed to commuters and local business owners in order to find problems that affect them directly, and safety issues that cannot be observed through statistical analysis. The questions determined how frequently and at what time he or she passes through the given intersection. They were then asked what problems they have observed, such as speeding, running of red lights, cutting others off, etc. The drivers were asked for their

suggestions as to what they think would help improve the intersection. With a sufficiently large number of surveys taken, any major problems should be easy to identify.

Chapter 3: The Area

Park Avenue is a very busy road, with many busy, confusing, and sometimes dangerous intersections. This study analyzes the three closest to WPI, in order from north to south: the intersection with Salisbury Street, Institute Road, and finally Highland Street, also known as Route 9. This section of Park Avenue is also part of Route 12, and joins Route 9 at the intersection with Highland Street. Both of these are major state highways, with many drivers passing through as they drive across the state. Full diagrams for each of these intersections may be found in Appendix B.

The intersection of Salisbury Street (Figure 1, below) is at a mild angle, and is very nearly flat. Traffic approaching from the west comes down a hill immediately before the intersection. Both the northbound and southbound approaches have left turning lanes and signals. Eastbound and westbound traffic face a staggered green signal, allowing each side a protected left turn without necessitating an additional turning lane. Both Salisbury Street and Park Avenue have two travel lanes in each direction passing through this intersection. There are signs barring drivers on Salisbury Street from making a right turn on red, but none on Park Avenue. Bordering this intersection on the southeast side is a church with parking lot entrances on both streets. The entrance located on Park Avenue is blocked with a chain at all times due to a persistent problem of drivers cutting through the lot to avoid the lengthy red light. Institute Park is located on the northeast side of the intersection, and the other two sides are residential.

Figure 1 - Aerial photo of Salisbury Street and Park Avenue (MapQuest)

The intersection of Institute Road and Park Avenue (Figure 2) is approached on two sides at a downhill angle. Both eastbound and westbound traffic approach this intersection on a downgrade, thus increasing stopping distances. Westbound traffic on Institute has a right turn bypass for the light, allowing traffic to move smoothly onto Park Avenue. The signal is a simple two cycle system, with no left turn signal or staggered green light for either side. Park Avenue has two travel lanes for each direction, and Institute Road has 1 lane for each direction. There is a Mobil station on the southeast corner of the intersection with a considerable flow of traffic in and out, especially at rush hour when customers frequently have to wait in the road for a pump to

open up. The WPI football field is located on the northeast corner, and the remaining corners are residential.

Figure 2 - Aerial photo of Institute Road and Park Avenue (MapQuest)

The intersection of Highland Street and Park Avenue (Figure 3) is approached at a mild downgrade from the west, and is flat on the other three sides. Traffic on Highland Street in both directions has a left turning lane, one travel lane, and the eastbound traffic has a right turn bypass. Park Avenue is two lanes in each direction, and has a right turning lane for southbound traffic. The light cycle involves a left turn signal for vehicles on Highland, but no protection for turning vehicles on Park Avenue. Price Chopper supermarket is located on the northeast corner

of the intersection, Elm Park occupies both the southeast and southwest corners, and the northwest corner is residential.

Figure 3 - Aerial photo of Highland Street and Park Avenue (MapQuest)

The intersection of Highland Street and Park Avenue (Figure 3) is approached at a mild downgrade from the west, and is flat on the other three sides. Traffic on Highland Street in both directions has a left turning lane, one travel lane, and the eastbound traffic has a right turn bypass. Park Avenue is two lanes in each direction, and has a right turning lane for southbound traffic. The light cycle involves a left turn signal for vehicles on Highland, but no protection for turning vehicles on Park Avenue. Price Chopper supermarket is located on the northeast corner

of the intersection, Elm Park occupies both the southeast and southwest corners, and the northwest corner is residential.

Chapter 4: Results

Turning movement studies were performed on each of the three intersections on Park Avenue, starting with the intersection at Highland Street, Route 9. Two morning rush hour counts and two evening rush hour counts were performed for 15 minutes each. The counts were then tabulated on a spreadsheet, and hourly traffic volumes were obtained by multiplying the average of the 15 minute counts by 4. Daily traffic numbers were then found using hourly adjustment factors obtained from James Kempton at the Worcester DPW. This table allows for the increase in traffic at peak hours, and using the factors results in a very close estimation to the total amount of traffic passing through the intersection in a 24 hour period.

The equivalent daily flow was then calculated, and the results can be seen in the graph below. The equivalent flow is also obtained using the turning movement counts, using several factors. This number accounts for the difference between left turning cars, straight through traffic, and trucks. The result represents the approximate flow that the intersection would be sustaining if all of the vehicles were cars moving straight through the intersection. A factor of 2 is added to all straight moving trucks, a factor of 3 for cars making a left turn into opposing traffic, and a factor of 4 for trucks doing the same. These numbers can be used to more accurately compare the congestion sustained by each of these intersections. These numbers can be used to more accurately compare the congestion sustained by each of these intersections, as seen in Figure 4 below.

The traffic counting data, found in Appendix A, can be mildly confusing. The first four columns on each spreadsheet refer to the raw data obtained from the 15 minute counts. There are two columns following that with the average of the two, and from this the number of vehicles per hour is obtained, which is the next set of columns. These numbers are used to perform the

calculations for the MUTCD warrants further on in the study. The second to last set of columns is for the Average Daily Traffic (ADT), which is based on benchmark counts made by the Worcester DPW. The final column is the equivalent straight through volume, which is discussed below.

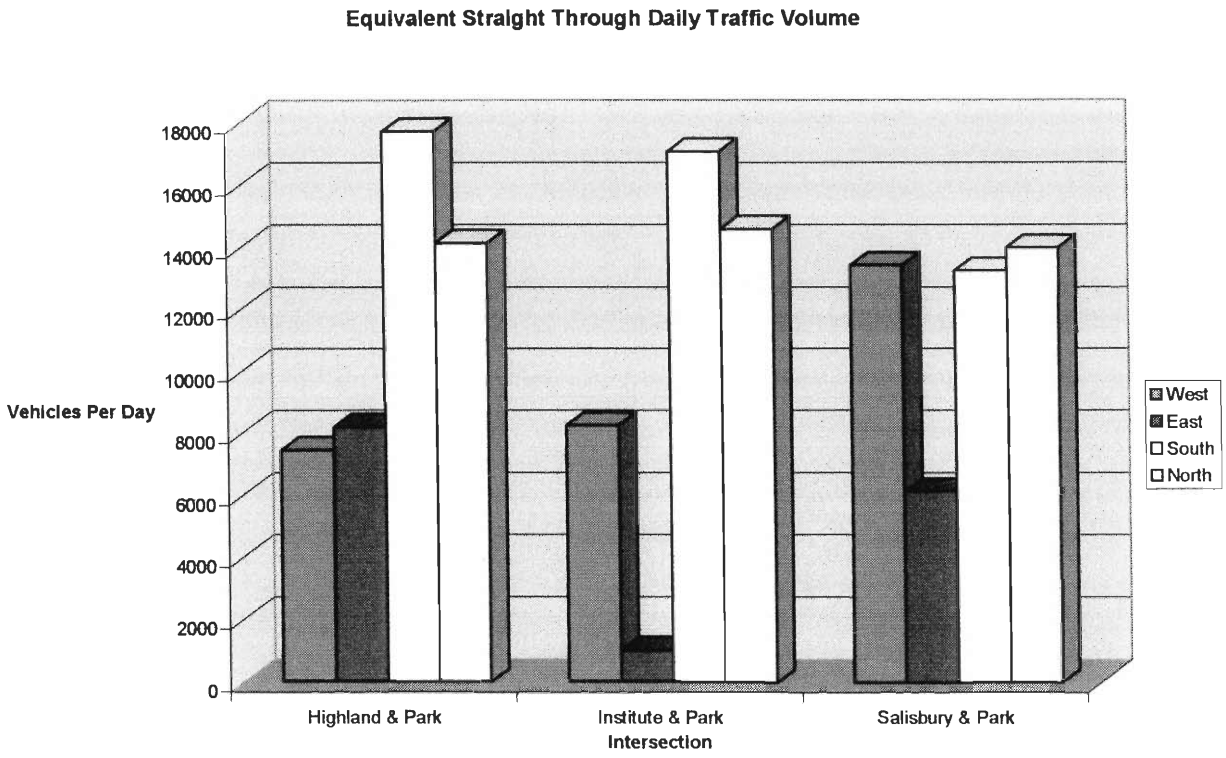

Figure 4 - Adjusted Traffic Volume

It is clear looking at the graph above that Park Avenue maintains a very consistent level of traffic between each intersection. Highland Street has the largest eastbound volume and Salisbury Street has the highest westbound volume of all of the cross streets.

The Manual on Uniform Traffic Control Devices (MUTCD) is the universally accepted guide in the United States for the design of intersections and signals. Accepted by the Federal

Highway Administration and the US Department of Transportation, it is used by engineers to determine necessary guidelines for the design of roads, highways, and all types of intersections.

There are four warrants for a left turn signal in a signalized intersection given in the MUTCD. If any one of these four are met, then it is highly recommended that such a signal be installed to prevent further accidents. These warrants include:

1. *Left turn volume times opposite volume* > 100000 *vph*
2. More than 2 vehicles still waiting at the end of the phase.
3. More than 50 vph during the peak hour and an approach speed > 45 mph
4. 5 or more left turn crashes in a year.

Using the first MUTCD warrant, which multiplies the hourly left turn volume times volume of vehicles opposing that turn, a left turn signal or staggered light is justified for north and southbound traffic on Park Avenue at Highland Street. It would also help on Park Ave south only at Institute Road. The values for Park Avenue north and south at Highland Street based on the evening peak traffic volume were, respectively, 193,600 and 214,500 vehicles per hour. At the intersection with Institute Road, the values were 12,600 and 262,100. The signal is justified based on this warrant if this value exceeds 100,000, which in 3 out of 4 of these it does. These numbers show an extreme need for a protected left turn, as they are more than double the warrant level for a signal.

The Salisbury Street intersection has protected left turn signals for all four directions, thus no changes are necessary in this respect. Institute Road and Park Avenue has the simplest type of signal, with only two cycles and no turning signals. There is sufficiently little left turning traffic however that no changes are necessary there either. Highland Street and Park Avenue do have left turn signals and lanes for traffic turning onto Park Avenue, yet vehicles turning onto Highland Street from Park have no such protection, and this is where it seems most necessary, looking at the data discussed above. The volume of opposing traffic is quite high, and drivers

must cross two lanes when making a left turn. On average during the evening rush hour there are about eighty vehicles per hour attempting to turn left from Park Ave south onto Highland Street east, and they must fight against approximately 800 vehicles per hour in the opposing direction.

Figure 5 - Traffic backs up as a vehicle waits to turn left.

There are two possible ways that a protected left turn may be accomplished. The first is to add a left turning lane on Park Avenue and install an additional signal. This method is the safest and most efficient for the maximum volume for an intersection, but it is also considerably expensive. New signals must be installed, and the road must be widened, necessitating the movement of the sidewalks and any signs, electrical boxes, etc that line the intersection. The second and more cost effective option would be to adjust the signal pattern to a staggered green system. This can be seen in the intersection with Salisbury Street for vehicles moving east and west. The light would only allow the northbound traffic to flow at first, thus allowing cars to turn freely onto Highland Street westbound, and then it would reverse. The major problem with

this far safer setup is that it will restrict traffic flow somewhat by causing longer delays on all four sides of the intersection. Some of this delay is negated by the lack of stopped cars waiting in the left lane for a break in traffic. These vehicles can frequently cause long lines of cars to back up. The effectiveness of this method in reducing traffic can be easily seen by comparing the frequency of left turning accidents at this intersection to that of Salisbury Street. The few such accidents that do take place are mainly the result of careless and rushed drivers illegally running the red light.

The accident data was obtained through the City of Worcester DPW. Using a large spreadsheet containing information about each of the more than seven thousand accidents in Worcester, the file numbers of the accidents pertaining to this area of Park Avenue were obtained for the years 1999, 2000, and 2001. Reports for each of these accidents were then pulled from the files at the main office, and were compiled, as can be seen in the graph below. Due to a combination of possible filing errors and pending court cases, not all of the files were located. Those that were on file however we marked down on a diagram for the relevant intersection, and pertinent factors such as weather, direction of travel, and time of day were recorded. The diagrams clearly show the problem areas of each intersection. This data was then entered into a spreadsheet, and categorized by the type of accident, location, and year. The most frequent type of accident was rear-end, followed by left turn accidents. The left turn accidents are both more serious in nature and can be prevented using better intersection design. Most rear-end accidents tend to be the result of driver inattention, so there are fewer steps that can be taken to prevent them.

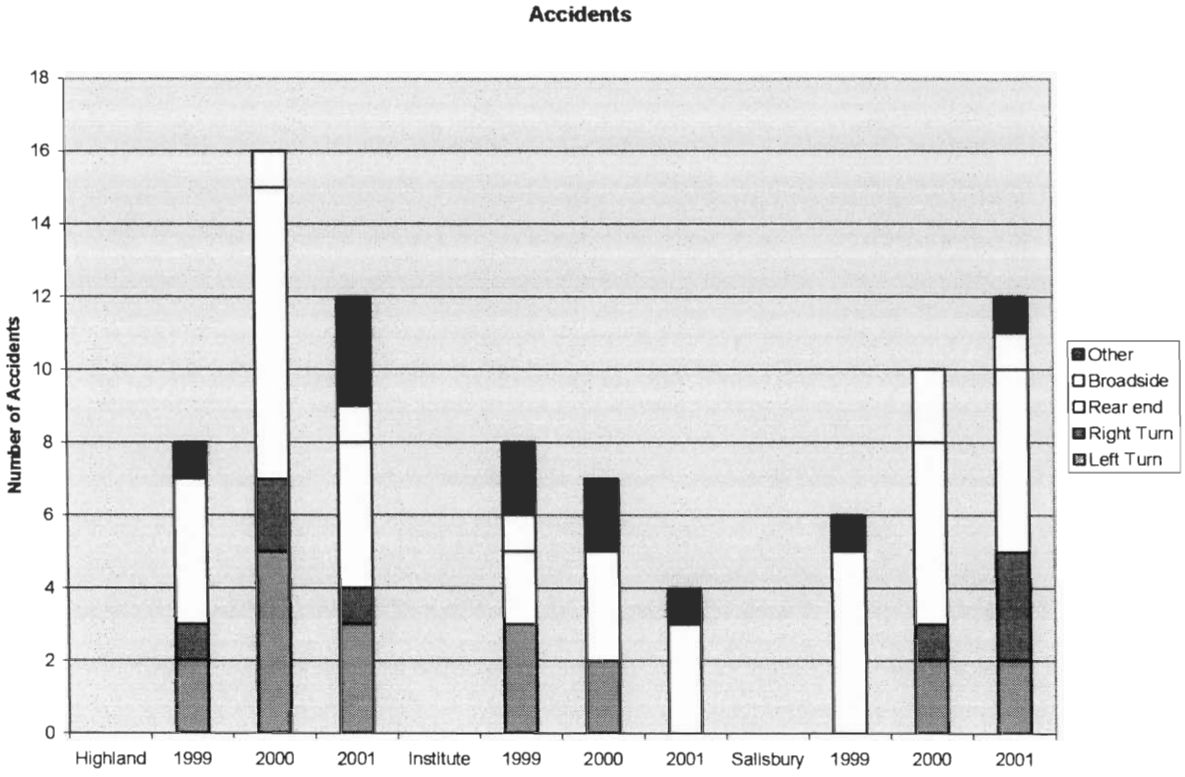

Figure 6 - Accidents by year and intersection

Chapter 5: Interviews and Surveys

On April 18, 2002, an interview as conducted with Seargent Steve Desy of the WPI police. He was able to give us another view on the difficulties of navigating these intersections, as well as some suggestions for improvements. The most prominent problem that he and other officers on the force have observed both themselves and in other drivers is left turns at Highland Street and sometimes Institute as well. All three of the intersections studies are within the radius of campus that they regularly patrol, so they pass through frequently and at all hours of the day. Sgt Desy also noted the frequency of drivers running the red lights. There is an especially large problem with drivers running the lights at Salisbury Street, simply because the cycle is extremely long, sometimes taking more than 2 minutes for a green light. Drivers tend to make illegal right turns on red, and accelerate when the yellow light comes on. There is little that the WPI police officers can do about problems like this because they do not have jurisdiction to pull over vehicles on Worcester's public streets.

The officers have, however, responded in assistance to the Worcester Police Department (WPD) for accidents at these intersections several times in the past. The most serious accidents are those resulting from the left turns, but the most frequent accidents are rear end collisions. The damage and personal injury that he has observed is usually much less in the rear end collisions, which usually result from drivers being unable to stop on time, and thus are low speed in nature.

Sgt Desy was not sure what the best course of action would be to remedy this situation, but did mention that he would like to see a left turn signal of some sort at Highland Street. He also noted that although it less of a safety issue than one of convenience, he would suggest

shortening the cycle time at Salisbury Street, which sometimes angers drivers to the point of road rage.

The surveys conducted, the full results of which can be found in Appendix D, show that people are very unsatisfied with the current situation in terms of safety at these intersections. All of those surveyed complained of problems, there were no people who thought that no changes are necessary. The most common problems brought up by the drivers were a lack of signaling for lane changes and turns, as well as stopping unexpectedly. Several people also cited road rage as a major problem. Drivers passing through these intersections frequently have near misses with turning and stopping vehicles, and short tempered drivers can get very irrational, thus causing further problems.

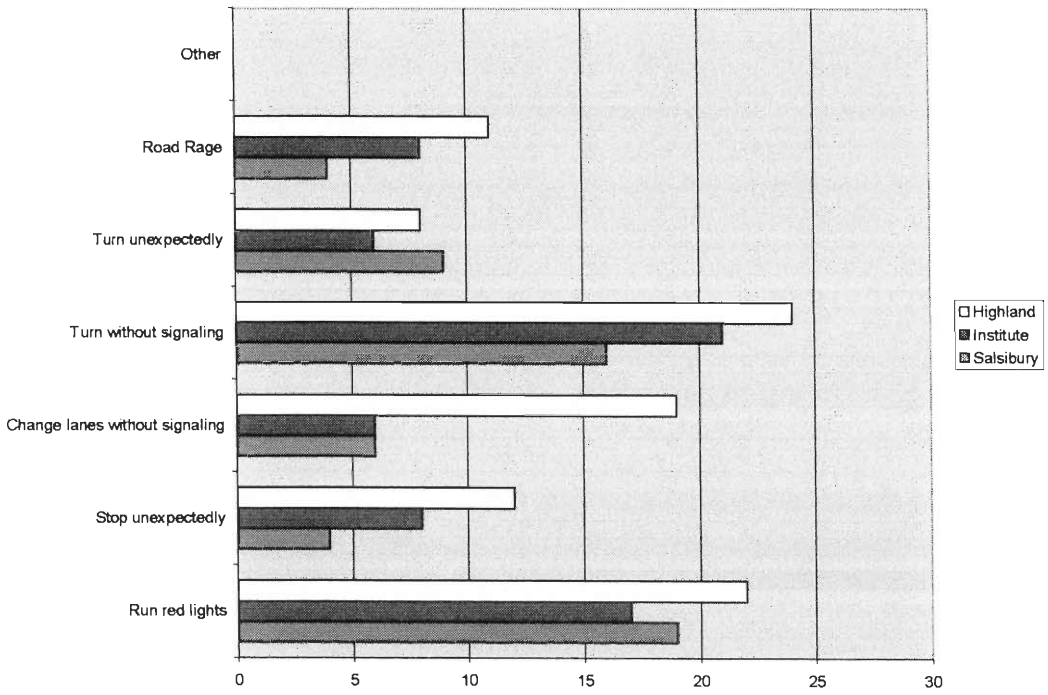

Figure 7 - Problems with other drivers

The most common recommendations for improvement were for additional lanes and turning signals, especially at Institute Road and Highland Street, as well as warning signs, which was the most frequent recommendation for Salisbury Street Drivers are frequently confused as to whether the left turn onto Park Avenue is protected or not, which it is. The majority of the problems were at Highland Street, which generated far more complaints and requests for turning signals.

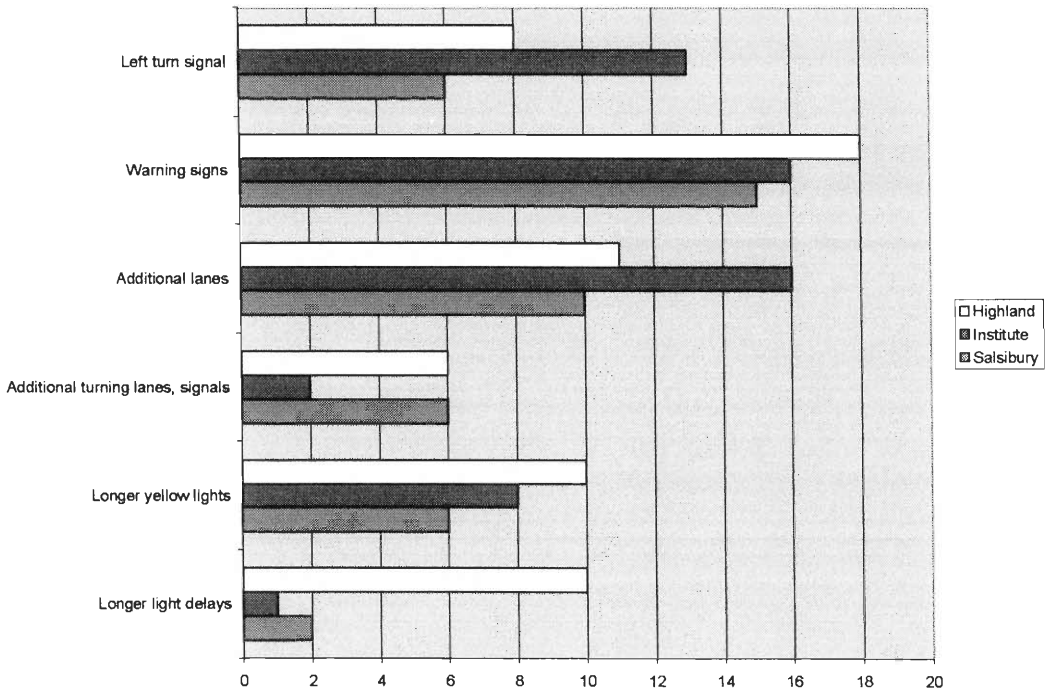

Figure 8 - Improvements recommended

The data also shows a much higher ratio of people are turning left at Highland Street than at either of the other two intersections, and this can be seen in the pie charts below.

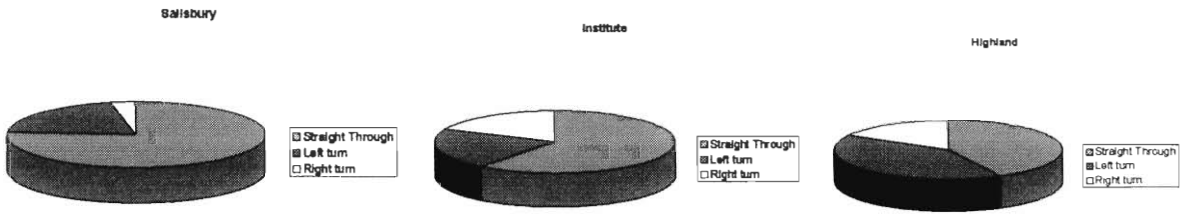

Figure 9 - Turning movements by intersection

This survey data gives an important human aspect to compare to the numbers generated thus far by traffic and accident studies. The numbers do not always tell the whole story, and it is important to compare the data with what the people on the street think. In our case, the two sides agree. People find driving through these intersections, especially Highland Street, to be quite an ordeal. The data does not show as clear a need for a left turn signal at Institute as it does for Highland, but the surveys tell a different story here. Drivers do not feel safe making that turn, as the traffic moving past in the other direction is frequently moving quite fast. The drivers moving straight through also face problems frequently, as people may make sudden left turns in the intersection without bothering to use a signal. Many near accidents are caused by this problem, and this statistic cannot, for obvious reasons, be quantified.

Chapter 6: Recommendations

The first and foremost recommendation is for a left turn signal or staggered green system for traffic in both directions on Park Avenue at Highland Street. This is clearly necessary both by looking at the traffic volume data and by looking at the accident data. The risk to drivers is simply unacceptable. The least expensive solution would be the staggered green system, as widening the road to include an additional turning lane would most likely prove to be unfeasible. Construction costs would be very high, as the lights themselves would have to be moved further away from the edge of the road, new sidewalks installed, and the entire intersection resurfaced. The intersection would, however, be far safer as a result.

Figure 10 - Sample left turn signal and lane (Salisbury Street and Park Avenue

Another problem was found for cars turning left from Park Ave south onto Institute Road east. This problem is not nearly as serious as that of Highland Street, but nonetheless still does

rate a left turn signal by MUTCD standards. The accident rate is not nearly as serious, however, so the need is less urgent. Survey data does, however, show as great a need as at Highland Street. The majority of the drivers turning left at this point are WPI staff members, students, and visitors, and thus it would benefit the school greatly to make this intersection safer and more passable.

Signs should also be installed at the intersection of Salisbury Street and Park Ave for the vehicles passing through on Salisbury indicating that the cycle is staggered, allowing for a protected left turn. Drivers frequently do not realize this immediately, and as a result they may stop unexpectedly, to be sure that it is safe to turn. These stopping vehicles can cause rear end collisions, and for a completely trivial reason. A simple sign could avert this problem completely, making the drivers more informed. This sign would also be necessary at Highland Street and Institute Road if such a system were implemented there.

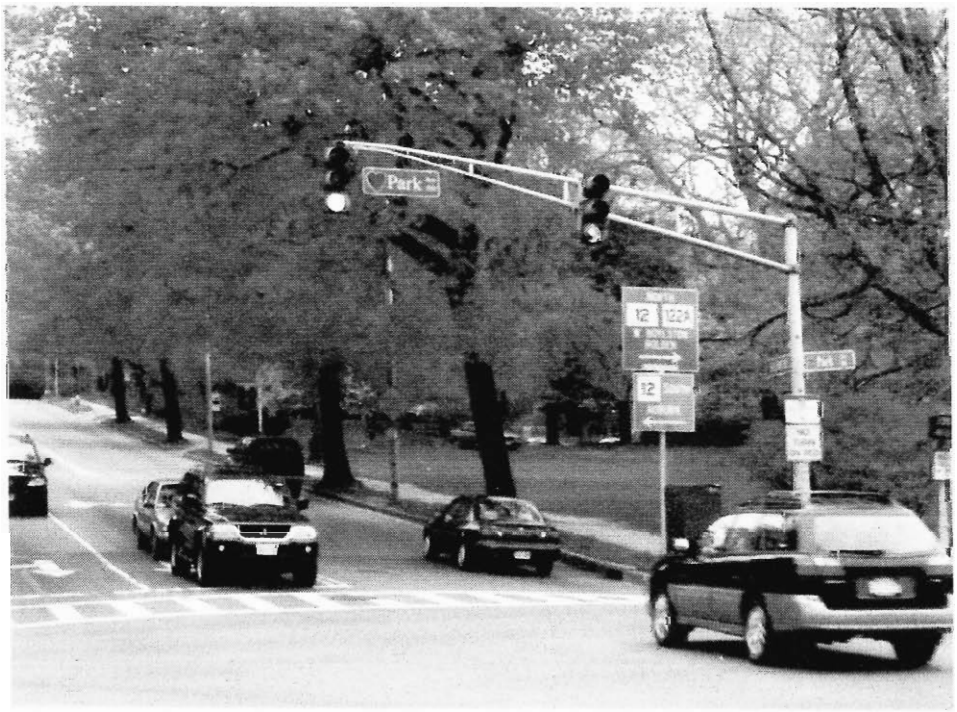

Figure 11 - Staggered green light at Salisbury Street

Another significant problem we have observed is for trucks, as they turn right from Highland Street west onto Park Avenue north. The turn is sharper than ninety degrees, and is also quite tight. There is a large electrical box installed on that corner, as well as the traffic signal, so if a truck driver misjudges the corner, he/she is likely to sideswipe the box or the light pole. It is quite clear that drivers frequently have trouble making the corner, as there are many tire marks left on the curb and sidewalk in the corner.

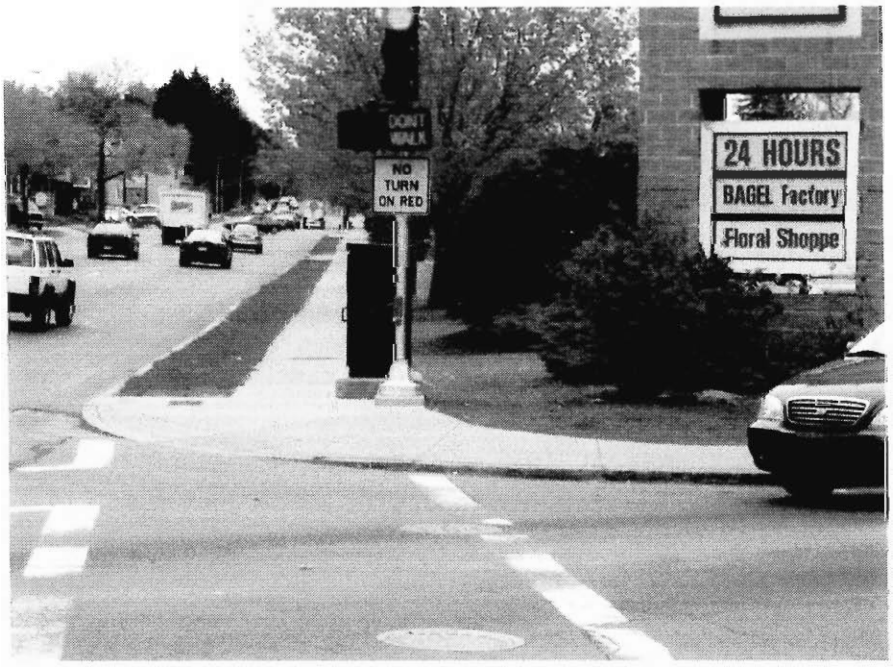

Figure 12 - Sharp right turn, observe tire marks on the sidewalk

Simply moving the structures back and perhaps increasing the radius of the turn would solve the problem, and it would be fairly inexpensive to complete. The other, more expensive solution, would be to install a right turn cut through, which is in place diagonally across the intersection where the turn would otherwise be equally as sharp. This makes the corner far wider, and also allows drivers making a right turn to skip past the red light. This solution would also involve moving the large Price Chopper sign and decreasing the size of their parking lot.

Chapter 7: Conclusion

Over the course of 8 months for this project, we have conducted several types of studies, from counting cars to interviewing police officers. We have put together a thorough analysis of this data in order to find where the greatest problems lie for drivers on Park Avenue passing through the intersections with Salisbury Street, Institute Road, and Highland Street. Some significant problems were found, based on National Highway design standards, as well as simple common sense.

It is clear that the intersections with Highland Street and Institute Road are unsafe for drivers, especially those that are turning left, as well as oncoming traffic. Options for making these intersections safer have been presented, and they range from the simple installation of a sign to the full blown resurfacing and widening of Park Avenue. The latter may not be feasible for the city, but it all depends on their budget and how serious the problem is compared to everything else that they must deal with citywide. Hopefully some of these recommendations will be implemented, as it will affect our safety in the WPI community as well as those that we live and work with.

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Appendix A

Traffic counting data

Table 1 – Turning Movement Counts

Highland Street and Park Avenue - Morning												
	First count		Second Count		Average		Vehicles per hour		ADT		Equivalent Flow	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	(VPH)	(ADT)
Highland Street (West)												
Right Turn	9	0	3	0	6	0	24	0	392	0	24	
Straight Through	54	4	58	0	56	2	224	8	3658	131	240	
Left Turn	17	0	23	2	20	1	80	4	1306	65	88	
Highland Street (East)											**352**	5748
Right Turn	120	1	84	4	102	2.5	408	10	6663	163	428	
Straight Through	145	4	145	2	145	3	580	12	9471	196	604	
Left Turn	8	1	3	0	5.5	0.5	22	2	359	33	26	
Park Ave (South)											**1058**	17277
Right Turn	49	0	52	0	50.5	0	202	0	3299	0	202	
Straight Through	102	3	95	3	98.5	3	394	12	6434	196	418	
Left Turn	6	0	2	1	4	0.5	16	2	261	33	56	
Park Ave (North)											**676**	11039
Right Turn	19	3	19	1	19	2	76	8	1241	131	92	
Straight Through	153	4	143	7	148	5.5	592	22	9667	359	636	
Left Turn	7	0	3	0	5	0	20	0	327	0	60	
											788	12868

Highland Street and Park Avenue - Evening												
	First count		Second Count		Average		Vehicles per hour		ADT		Equivalent Flow	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	(VPH)	(ADT)
Highland Street (West)												
Right Turn	4	0	4	2	4	1	16	4	212	53	24	
Straight Through	92	1	92	2	92	1.5	368	6	4870	79	380	
Left Turn	43	1	35	0	39	0.5	156	2	2065	26	160	
Highland Street (East)											**564**	7465
Right Turn	5	0	6	0	5.5	0	22	0	291	0	22	
Straight Through	89	1	88	1	88.5	1	354	4	4685	53	362	
Left Turn	50	1	66	0	58	0.5	232	2	3071	26	236	
Park Ave (South)											**620**	8206
Right Turn	101	0	100	0	100.5	0	402	0	5320	0	402	
Straight Through	187	3	154	1	170.5	2	682	8	9026	106	698	
Left Turn	29	0	11	0	20	0	80	0	1059	0	240	
Park Ave (North)											**1340**	17735
Right Turn	34	0	50	3	42	1.5	168	6	2223	79	180	
Straight Through	178	1	171	1	174.5	2	698	8	9238	106	714	
Left Turn	13	0	15	1	14	0.5	56	2	741	26	176	
											1070	14161

Table 2 – Turning Movement Counts

Institute Road and Park Avenue - Morning												
	First count		Second Count		Average		Vehicles per hour		ADT		Equivalent Flow	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	(VPH)	(ADT)
Institute Road (West)												
Right Turn	8	0	11	0	9.5	0	38	0	621	0	38	
Straight Through	8	1	16	0	12	0.5	48	2	784	33	52	
Left Turn	2	0	4	0	3	0	12	0	196	0	36	
Institute Road (East)											**126**	2058
Right Turn	2	0	4	0	3	0	12	0	196	0	12	
Straight Through	43	0	32	1	37.5	0.5	150	2	2450	33	154	
Left Turn	6	0	4	0	5	0	20	0	327	0	60	
Park Ave (South)											**226**	3691
Right Turn	3	0	3	0	3	0	12	0	196	0	12	
Straight Through	146	5	129	2	137.5	3.5	550	14	8982	229	578	
Left Turn	14	0	12	1	13	0.5	52	2	849	33	164	
Park Ave (North)											**754**	12313
Right Turn	58	1	51	2	54.5	1.5	218	6	3560	98	230	
Straight Through	230	3	234	9	232	6	928	24	15154	392	976	
Left Turn	1	0	1	0	1	0	4	0	65	0	12	
											1218	19890

Institute Road and Park Avenue - Evening												
	First count		Second Count		Average		Vehicles per hour		ADT		Equivalent Flow	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	(VPH)	(ADT)
Institute Road (West)												
Right Turn	16	0	10	0	13	0	52	0	688	0	52	
Straight Through	51	1	65	0	58	0.5	232	2	3071	26	236	
Left Turn	31	0	25	0	28	0	112	0	1482	0	336	
Institute Road (East)											**624**	8259
Right Turn	3	0	3	0	3	0	12	0	159	0	12	
Straight Through	6	0	9	0	7.5	0	30	0	397	0	30	
Left Turn	3	0	3	0	3	0	12	0	159	0	36	
Park Ave (South)											**78**	1032
Right Turn	14	0	9	0	11.5	0	46	0	609	0	46	
Straight Through	237	5	250	3	243.5	4	974	16	12891	212	1006	
Left Turn	19	0	21	0	20	0	80	0	1059	0	240	
Park Ave (North)											**1292**	17100
Right Turn	19	0	21	0	20	0	80	0	1059	0	80	
Straight Through	230	1	272	1	251	1	1004	4	13288	53	1012	
Left Turn	0	0	2	0	1	0	4	0	53	0	12	
											1104	14611

Table 3 – Turning Movement Counts

Salisbury Street and Park Avenue - Morning												
	First count		Second Count		Average		Vehicles per hour		ADT		Equivalent Flow	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	(VPH)	(ADT)
Salisbury Street (West)												
Right Turn	0	0	4	1	2	0.5	8	2	106	26	12	
Straight Through	75	5	108	4	91.5	4.5	366	18	4844	238	402	
Left Turn	24	0	22	0	23	0	92	0	1218	0	92	
Salisbury Street (East)											**506**	8263
Right Turn	7	2	23	0	15	1	60	4	794	53	68	
Straight Through	155	1	179	1	167	1	668	4	8841	53	676	
Left Turn	64	0	53	0	58.5	0	234	0	3097	0	234	
Park Ave (South)											**978**	15971
Right Turn	13	0	13	0	13	0	52	0	688	0	52	
Straight Through	112	5	129	4	120.5	4.5	482	18	6379	238	518	
Left Turn	36	1	26	0	31	0.5	124	2	1641	26	128	
Park Ave (North)											**698**	11398
Right Turn	33	0	28	0	30.5	0	122	0	1615	0	122	
Straight Through	192	8	213	5	202.5	6.5	810	26	10720	344	862	
Left Turn	27	2	17	0	22	1	88	4	1165	53	96	
											1080	17636

Salisbury Street and Park Avenue - Evening												
	First count		Second Count		Average		Vehicles per hour		ADT		Equivalent Flow	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks	(VPH)	(ADT)
Salisbury Street (West)												
Right Turn	6	0	13	1	9.5	0.5	38	2	621	33	42	
Straight Through	188	1	209	2	198.5	1.5	794	6	12966	98	806	
Left Turn	43	0	41	0	42	0	168	0	2743	0	168	
Salisbury Street (East)											**1016**	13447
Right Turn	5	0	19	0	12	0	48	0	784	0	48	
Straight Through	81	0	80	1	80.5	0.5	322	2	5258	33	326	
Left Turn	16	0	29	0	22.5	0	90	0	1470	0	90	
Park Ave (South)											**464**	6141
Right Turn	41	0	30	0	35.5	0	142	0	2319	0	142	
Straight Through	198	0	200	0	199	0	796	0	12999	0	796	
Left Turn	13	1	17	0	15	0.5	60	2	980	33	64	
Park Ave (North)											**1002**	13261
Right Turn	31	0	26	0	28.5	0	114	0	1862	0	114	
Straight Through	191	0	189	2	190	1	760	4	12411	65	768	
Left Turn	48	0	40	0	44	0	176	0	2874	0	176	
											1058	14003

Appendix B

Sample accident spreadsheets
Intersection diagrams

Sample accident spreadsheets from the DPW files,

used to find initial accident data

INC #	D ACC	TIME	ST #	STREET	TYPE	D	L	R	INTERSEC	LMARK	OBJ	TYP	V2	RS	RC	C	LT	W	PJ	PA	INJ
I99B8842	10/1/99	0720	26-X	HIGHLAND ST	ACC	R	4	N	HIGHLAND ST @ HARVARD S		Other (n	MVT	A	D	1	D	1		0	0	0
I99C2732	10/10/99	1835		HIGHLAND ST	ACI	R	2	N	SOMERSET ST			MVT	H	W	1	3	3		0	0	2
I99E2447	11/29/99	1749		HIGHLAND ST	ACI	R	2	N	WACHUSETT ST			MVT	R	D	1		3		0	0	3
I99A6219	9/2/99	0916	95	HIGHLAND ST	ACH	A		N	95 HIGHLAND ST			MVT	R	D	1		1		0	0	1
I9985890	7/18/99	2131	67-X	HIGHLAND ST	ACH	R	2	N	GOULDING ST		Other (n	MVP	R	D	1	D	3		0	0	0
I99D3345	11/6/99	0931	179	HIGHLAND ST	ACC	R	2	N	HIGHLAND ST @ EINHORN ST		Other (n	MVP	A	D	1	D	3		0	0	0
I99C1734	10/8/99	1220	221	HIGHLAND ST	ACC	R	2	N			Other (n	MVT	A	D	1	D	1		0	0	0
I9966329	6/7/99	1256	199	HIGHLAND ST	NSF	G	2	N	199 HIGHLAND ST			MVT	R	D	1		1		0	0	1
I99B8974	9/6/99	1331		HIGHLAND ST	ACI	R	2	N	PRICE CHOPPER PARKING L		.		A	W	6		1	4	0	0	1
I99B5132	9/22/99	1419	45	HIGHLAND ST	ACC	R	2	N	LANCASTER ST		Other (n	MVT	A	D	1	D	1		0	0	0
I99E0148	11/23/99	1735	322	HIGHLAND ST	ACI	R	2	N		ACROSS FR DOH		MVT	R	D	1		2		0	0	2
I9906002	1/15/99	2309	274-X	HIGHLAND ST	ACC	R	2	N				MVT	H	WSI			3		0	0	1
I9981921	7/9/99	2137	141-X	HIGHLAND ST	ACI	R	2	N	WEST ST			MVT	A	W	1		3		0	0	4
I99E0977	11/23/99	1430	255	HIGHLAND ST	ACC	R	2	N	HIGHLAND ST @ PARK AVE	STOP 'N' SHOP		MVT	A	D	1		1		0	0	0
I99D4048	11/8/99	0706	312-X	HIGHLAND ST	ACC	R	2	N	298 HIGHLAND ST		Other (n	MVT	A	D	1	D	1		0	0	0
I99C2096	10/9/99	0800	298	HIGHLAND ST	ACC	R	2	N				MVT	R	W	1		1		0	0	0
I9983969	7/14/99	1652	45-X	HIGHLAND ST	ACH	N	4	N	HIGHLAND ST @ LANCASTER			MVT	R	D	1		1		0	0	0
I9936026	3/30/99	0457	45	HIGHLAND ST	ACC	R	2	N	LANCASTER ST			MVT	R	D	1		2		0	0	0
I9953688	5/11/99	0805	299	HIGHLAND ST	ACC	R	2	N			Other (n	MVT	A	D	1	D	1		0	0	0
I99C2205	10/9/99	1302	255	HIGHLAND ST	ACI	R	4	N	PARK AV		Other (n	MVT	R	D	1	D	1		0	0	2
I9968342	6/11/99	1727	342	HIGHLAND ST	ACC	R	2	N	NEWTON AV		Other (n	MVT	A	D	1	D	1		0	0	0
I9999503	8/18/99	0014	141	HIGHLAND ST	ACC	R	2	N	WEST ST			MVT	A	D	1		3		0	0	0
I99F0607	12/21/99	1820		HIGHLAND/BOYNTON	ACC	R	2	N		BOYTON PARKIN		MVP	A	D	1		3		0	0	0
I99C6937	10/6/99	1000		HIGHLAND/LANCASTER	ACH	R		N	LANCASTER			MVT	A	D	1		1		0	0	0
I99C6841	10/14/99	1600		HIGHLAND/LINCOLN	ACH	R	3	N				MVT	A	D	1		1		0	0	0
I99B3496	9/7/99	1200		HIGHLAND/PARK AV	ACI	R		N											0	0	1
I9973855	6/19/99	1615		HIGHLAND/WEST ST	ACC	R	2	N				MVT	R	D	1		1		0	0	1
I9983460	7/2/99	1600		HILL ST	ACC	R		N	WEBSTER ST			MVT	R	D	1		1		0	0	1
I99C0312	10/4/99	1856		HILLSIDE ST	ACH	R	2	N			Other (n	MVP	H	W	1	D	3		0	0	0
I9903002	12/29/99	0000	11	HILLSIDE ST	ACC	R		N			Other (n	MVP	R	SI		D	1		0	0	0
I99D5353	11/11/99	1333	36	HILTON AV	ACH	R	2	N	IN FRONT OF HOUSE			MVP	A	DW	1		3		0	0	0
I99D8470	11/11/99	0000		HILTON AV	ACH	R	2	N				MVP			2				0	0	0
I9920975	2/20/99	0005	28	HITCHCOCK	ACI	R	2	N				MVT	A	D	1		3		0	0	1
I9998104	8/14/99	2008	66-X	HITCHCOCK RD	ACC	R	1	N	FREELAND ST			MVT	A	W	1		3	4	0	0	0
I9957829	4/25/99	1117		HITCHCOCK RD	ACH	R	2	N						D	1		2		0	0	0
I99A4022	8/28/99	0832	9	HITCHCOCK RD	ACH	R	2	N	9 HITCHCOCK RD			MVP	A	D	1		3		0	0	0
I99D0113	10/26/99	2330	1039	HITCHCOCK RD	ACH	R		N			Other (n	MVT	A	D	1	D	3		0	0	0
I9926840	3/6/99	2257	58	HITCHCOCK RD	ACC	R	1	N				MVP	A	I	1		3	6	0	0	0
I9905853	1/15/99	1749	29	HITCHCOCK RD	ACH	R	2	N		HAYNES ST		MVP	A	SI	1		3	5	0	0	0
I9963310	6/1/99	1232	5	HOCKANUM WA	ACC	R	1	N				MVP	A	D	1		1		0	0	0
I9957304	5/19/99	0517		HOLCOMBE ST	ACC	R	2	N	GRANITE ST			MVP	A	W	1		2		0	0	0
I9901003	1/3/99	1155	6-X	HOLCOMBE ST	ACC	R		N	WABASH AVE			MVT	H	I	6		1		0	0	0

3 High

1 st / Paris Sails / Park
High / Park

INC	DIAGC	TIME	ST #	STREET	TYPE	D	L	R	INTERSEC	LMARK	OBJ	TYP	V2	RS	RC	C	LT	W	PJ	PA	INJ
I9972522	6/20/99	1014	37-X	HOWLAND TER	ACC	R	2	N	HOWLAND/NEVADA		Other (n	OBJ		D	1	D	1		0	0	0
I9986467	7/20/99	1021	37-X	HUDSON ST	ACN	O	2	N	ELM STREET			MVT	A	D	1		1		0	0	0
I99E4533	12/5/99	1359	14	HUDSON ST	ACI	R	2	N	TOWNSEND ST		Other (n	MVT	A	D	1	D	1		0	0	2
I0051179	12/29/99	1340		HUDSON ST	ACH	R						OTH	A	D	1		1		0	0	0
I9959633	5/24/99	1022	18	HUDSON ST	ASC	R	2	N				OTH	H	D	1				0	0	0
I9912891	1/25/99	0000	11	HUNTHURST CIR	ACH	R		N	11 HUNTHURST CIRC			MVP							0	0	0
I9911828	1/15/99	1700		HUNTINGTON AV	ACC	R		N			Other (n			I	1	D	3		0	0	0
I99E8381	12/17/99	0852	1-X	HUNTINGTON AV	ACC	R	2	N	WEST BOYLSTON		Other (n	MVP	A	D	1	D	1		0	0	0
I9924992	2/25/99	0810		HUNTINGTON AV	ACC	R	2	N		WEST BOYLSTO	.	MVP	A	S	1		1	5	0	0	0
I9983047	7/12/99	1515	2-X	HUNTINGTON AV	ACI	R	2	N	74 WEST BOYLSTON			MVP	A	D	1		1		0	0	1
I99A9478	9/7/99	1000		HUNTLY/MYDLAND	ACH	R		N	HUNTLEY/MYDLAND			MVP		D	1		1		0	0	0
I99B7106	9/27/99	0740		I 290 EXIT 16	ACI	H	3	N				MVT	R	D	1		1		0	0	1
I9946500	4/24/99	1226		I 290 W.EXIT 18	ACI	R	2	N	LINCOLN ST			MVT	A	D	1		1		0	0	1
I9961396	5/28/99	0952		I190	ACC	R	2	N	I 290 ON RAMP			MVT	A	D	1		1		0	0	0
I9951004	4/29/99	1545		I190 S @ 290 W	ACC	R	4	N				MVT	A	D	1		1		0	0	0
I9942087	4/5/99	1523		I290	ACC	R	3	N	EXIT 12 BROSNIHAN SQ			MVT	R	D	1		1		0	0	0
I99A0067	8/12/99	0911		I290	ACI	R			PLANTATION ST			OTH	R	D	1		1		0	0	1
I9939426	3/25/99	1905		I290	ACC	R	3	N				MVT		D	1		3		0	0	0
I99E8982	12/18/99	2339		I290 OFF RAMP	ACC	R	2	N	VERNON ST			MVT	A	D	1		3		0	0	0
I9950846	5/4/99	2159	1-A	IDALLA AV	ACH	R	1	N				MVP	H	DW	1		3	4	0	0	0
I9972574	6/20/99	1257	1-X	IDALLA RD	ACI	R	2	N	W. BOYLSTON ST			MVT	A	D	1		1	2	0	0	0
I9984222	7/15/99	0803	67	ILLINOIS ST	ACC	R	2	N		APT. BUILDING		MVT	A	D	1		1		0	0	0
I9982278	7/10/99	1901	111	ILLINOIS ST	ACC	R		N	111 ILLINOIS ST			MVT	A	D	1		1		0	0	1
I9989910	7/27/99	1912	37	ILLINOIS ST	ACC	R	1	N				MVP	A	D	1		1		0	0	0
I9911166	1/8/99	2200		ILLINOIS ST	ACH	R	2	N	CRYSTAL ST			MVP	A	WSI			2	5	0	0	0
I99D4808	11/10/99	0120	63	ILLINOIS ST	ACC	N	2	N			Other (n	MVT	A	D	1	D	3		0	0	0
I9906181	1/16/99	1035	108	ILLINOIS ST	ACI	R	2	N		RICHARDS ST		MVT	R	I	1		1		0	0	1
I99C4656	10/15/99	1604	39	ILLINOIS ST	ACC	R	2	N				MVT	A	D	1		1		0	0	0
I9996283	7/10/99	1830		ILLINOIS ST	ACI	R	2	N				MVP	A	D			1		0	0	0
I99E1404	11/26/99	2233	43	ILLINOIS ST	ACC	R	1	N				MVP	H	D	1		3		0	0	0
I9950331	5/3/99	1703	121-X	ILLINOIS ST	ACH	R	2	N	RICHARDS ST			MVT	A	D	1		1		0	0	0
I99E6189	12/10/99	2105	121-X	ILLINOIS ST	ACC	R	2	N	RICHARDS ST		Other (n	MVT	A	W	1	D	3		0	0	0
I99B7978	9/29/99	0740	2	IMPERIAL RD	ACI	R	2	N	SHREWSBURY ST			MVT	A	D	1		1		0	0	1
I9998426	8/15/99	1615	7	INDIAN LAKE PKWY	ACP	R		N	926 W. BOYLSTON ST			PED		W	1		1	4	0	0	0
I99E9580	12/20/99	2018	230-X	INGLESIDE AV	ACC	R	2	N	GRAFTON/INGLESIDE			MVT	A	W			3		0	0	0
I9958373	5/21/99	1446	90	INGLESIDE AV	ACC	R	1	N		HAMILTON ST	Other (n	MVP	R	D	2	D	1		0	0	0
I99C9291	10/27/99	1329	19-X	INSTITUTE RD	ACH	R		N	PARKING LOT		Other (n	MVP	A	D	1	D	1		0	0	0
I99B1465	9/13/99	1955	53	INSTITUTE RD	ACH	R	2	N			Other (n	MVP	A	O	6	D	1		0	0	0
★ I99B2546	9/16/99	1601	123	INSTITUTE RD	ACC	R	4	N	PARK AVE		Other (n	MVT	A	W	1	D	1	4	0	0	0
I9911965	1/17/99	1800		INSTITUTE RD	ACC	R		N	WEST LAND ST			MVP		I	1		4		0	0	0
I9913881	2/3/99	1112	123	INSTITUTE RD	ARR	A	2	N	3 MASSACHUSETTS AVE			OBJ	A	D	1	B	1		0	0	0
★ I99E3271	12/1/99	2256	123-X	INSTITUTE RD	ACC	R	4	N	PARK AV		Other (n	MVT	A	D	1	D	3		0	0	1

35

2 In

Diagrams of the three intersections studied,

from the files of the Worcester DPW.

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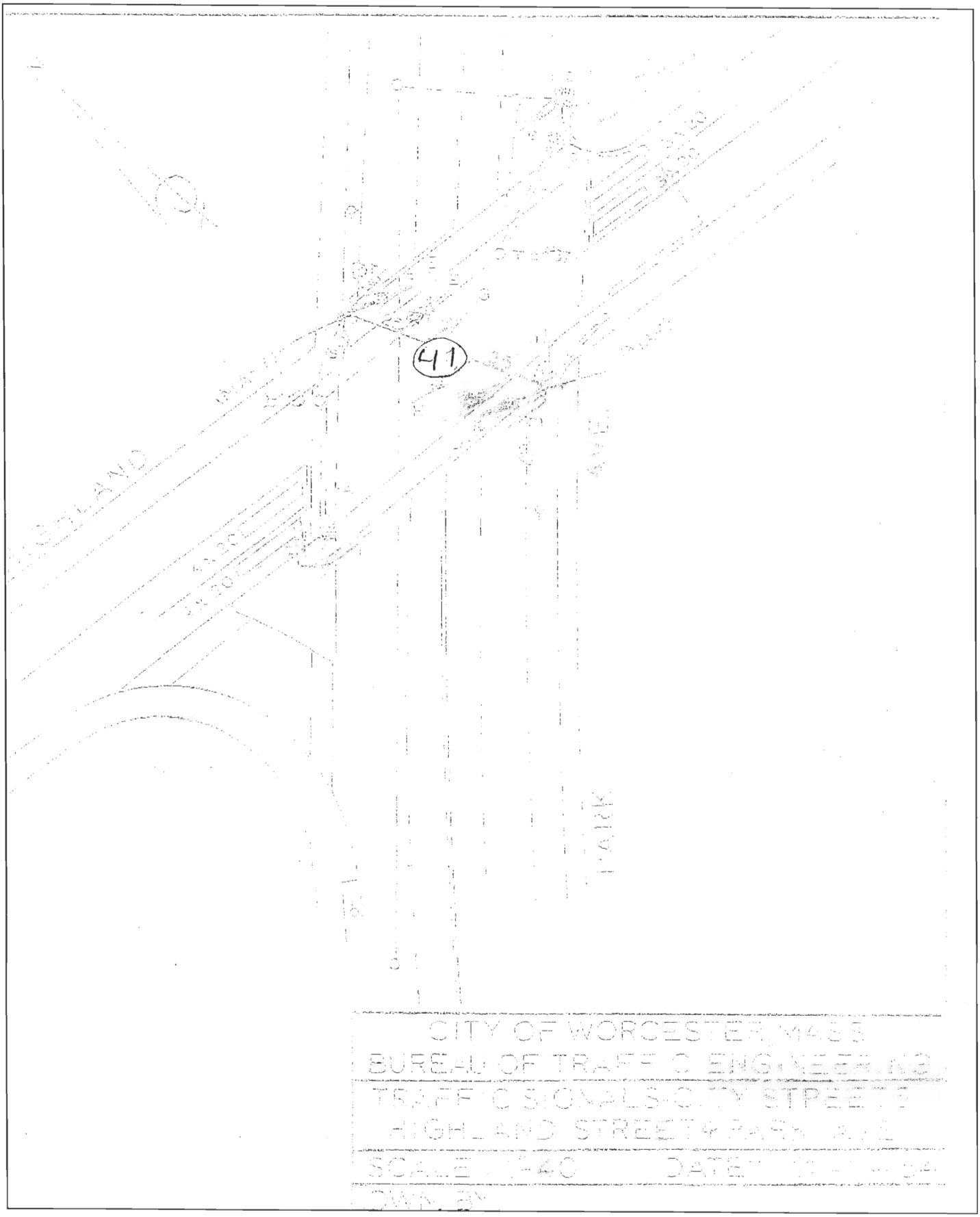
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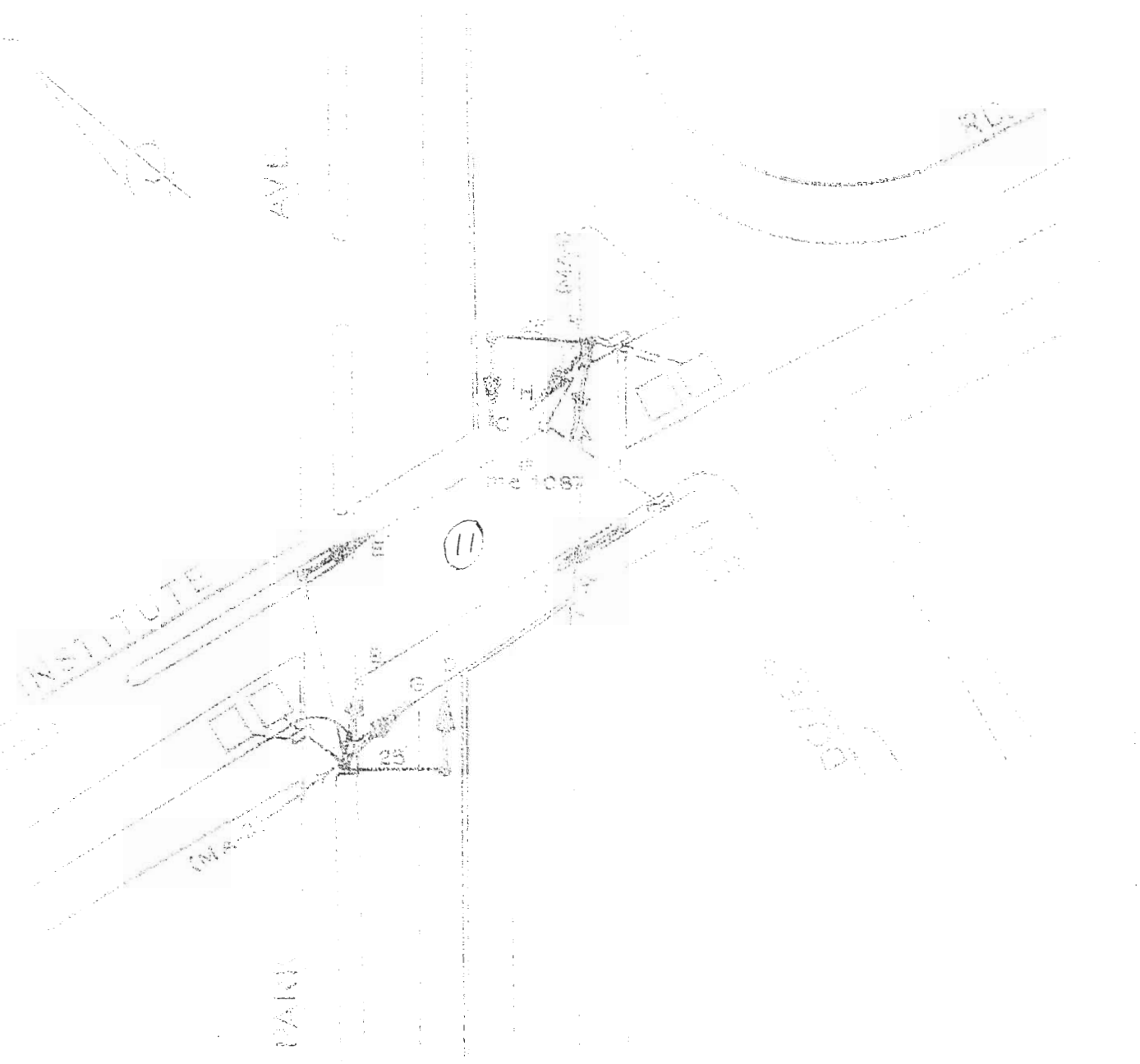
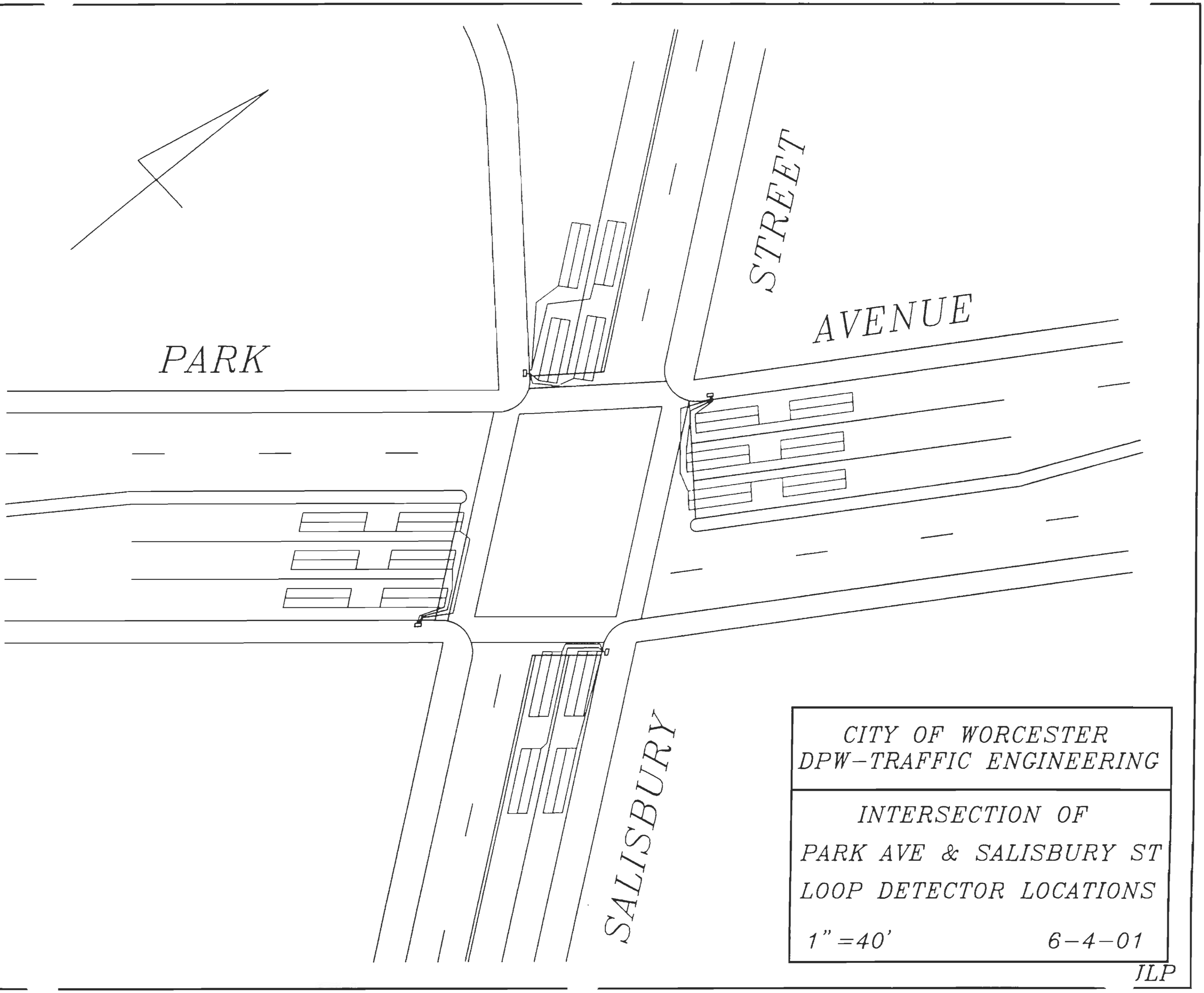
CITY OF WORCESTER, MASS.
BUREAU OF TRAFFIC ENGINEERING
TRAFFIC SIGNALS-CITY STREETS
HIGHLAND STREET & PARK AVE.
SCALE 1"=40'
DATE



CITY OF WORCESTER, MASS.
BUREAU OF TRAFFIC ENGINEERING
TRAFFIC SIGNAL SYSTEM
INSTITUTE RD. AND PARK AVE.
SCALE: 1"=40' DATE: 7-28-72
DWN. BY: J.S.B.


PARK
AVENUE
STREET
SALISBURY
CITY OF WORCESTER
DPW–TRAFFIC ENGINEERING
INTERSECTION OF
PARK AVE & SALISBURY ST
LOOP DETECTOR LOCATIONS
1" =40'
6–4–01
JLP

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Appendix C

Accident diagrams by intersection and year
Accident Data

Accident diagrams depicting where each accident

Took place, sorted by year and Intersection

Table 4 - Total number of accidents sorted by intersection

Intersection	Year	Type of Accident					Total
		Left Turn	Right Turn	Rear end	Broadside	Other	
Highland	1999	2	1	4	0	1	8
	2000	5	2	8	1	0	16
	2001	3	1	4	1	3	12
Institute	1999	3	0	2	1	2	8
	2000	2	0	3	0	2	7
	2001	0	0	3	0	1	4
Salisbury	1999	0	0	5	0	1	6
	2000	2	1	5	2	0	10
	2001	2	3	5	1	1	12

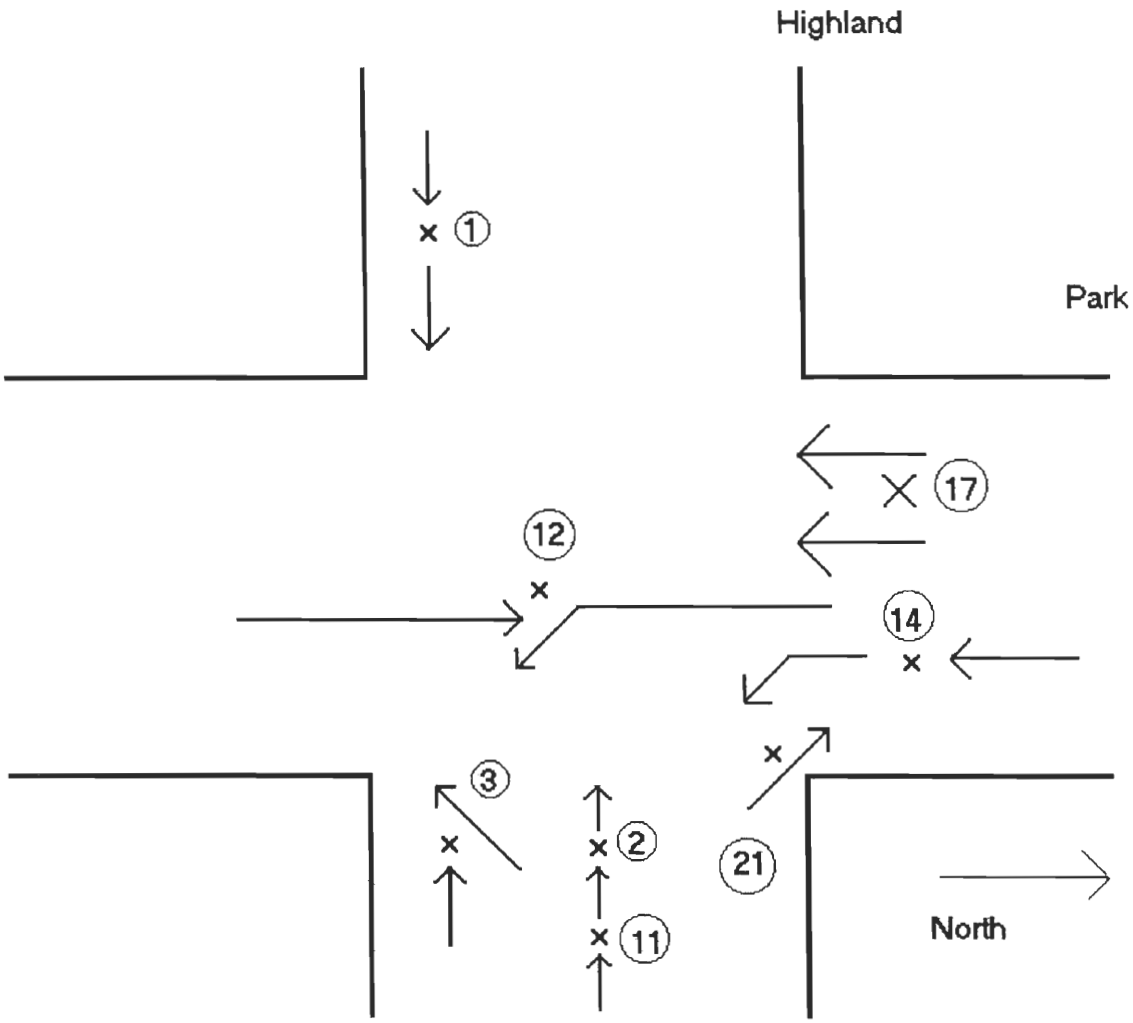

Figure 13 - 1999 Accidents at Highland Street

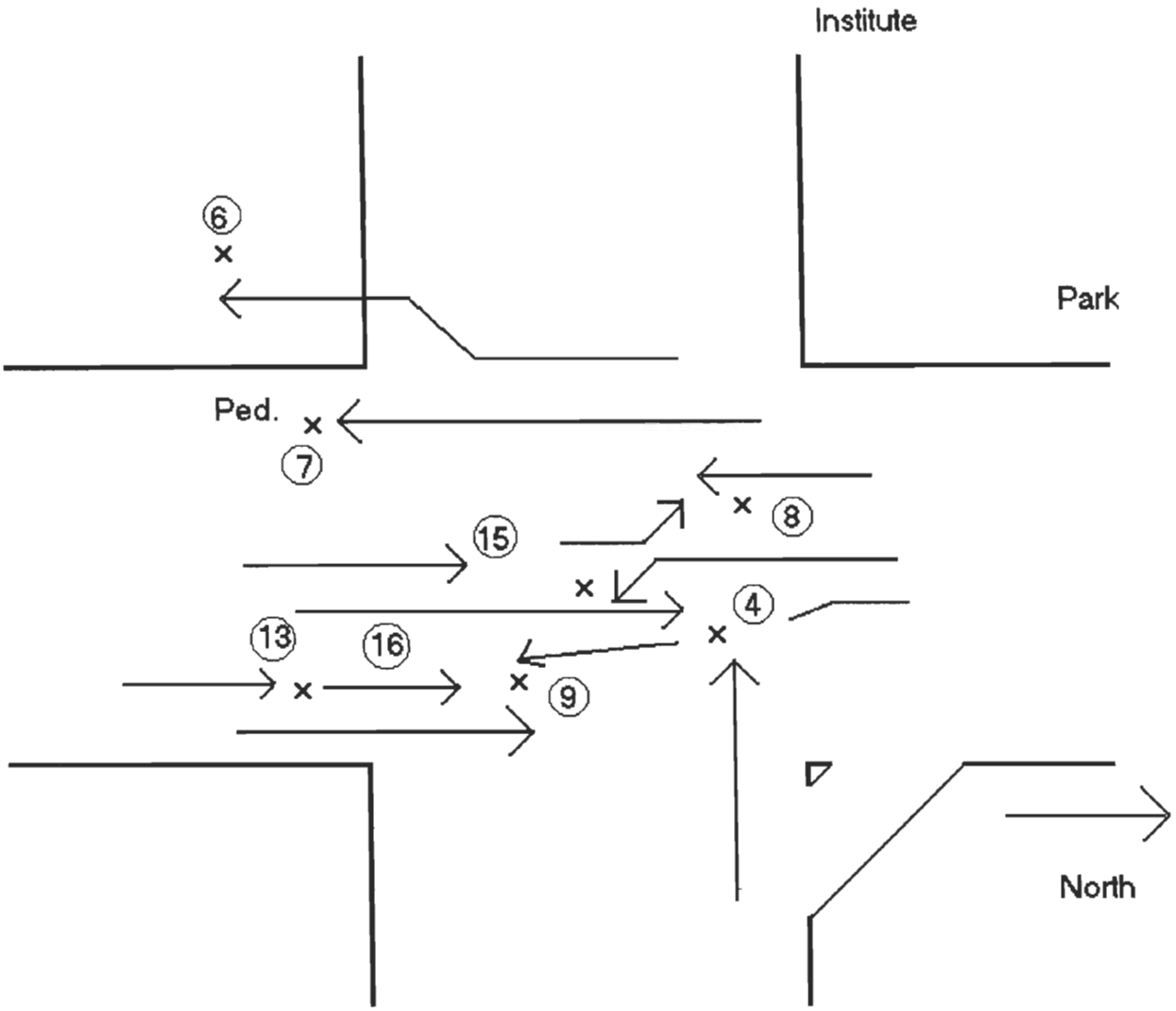

Figure 14 - 1999 Accidents at Institute Road

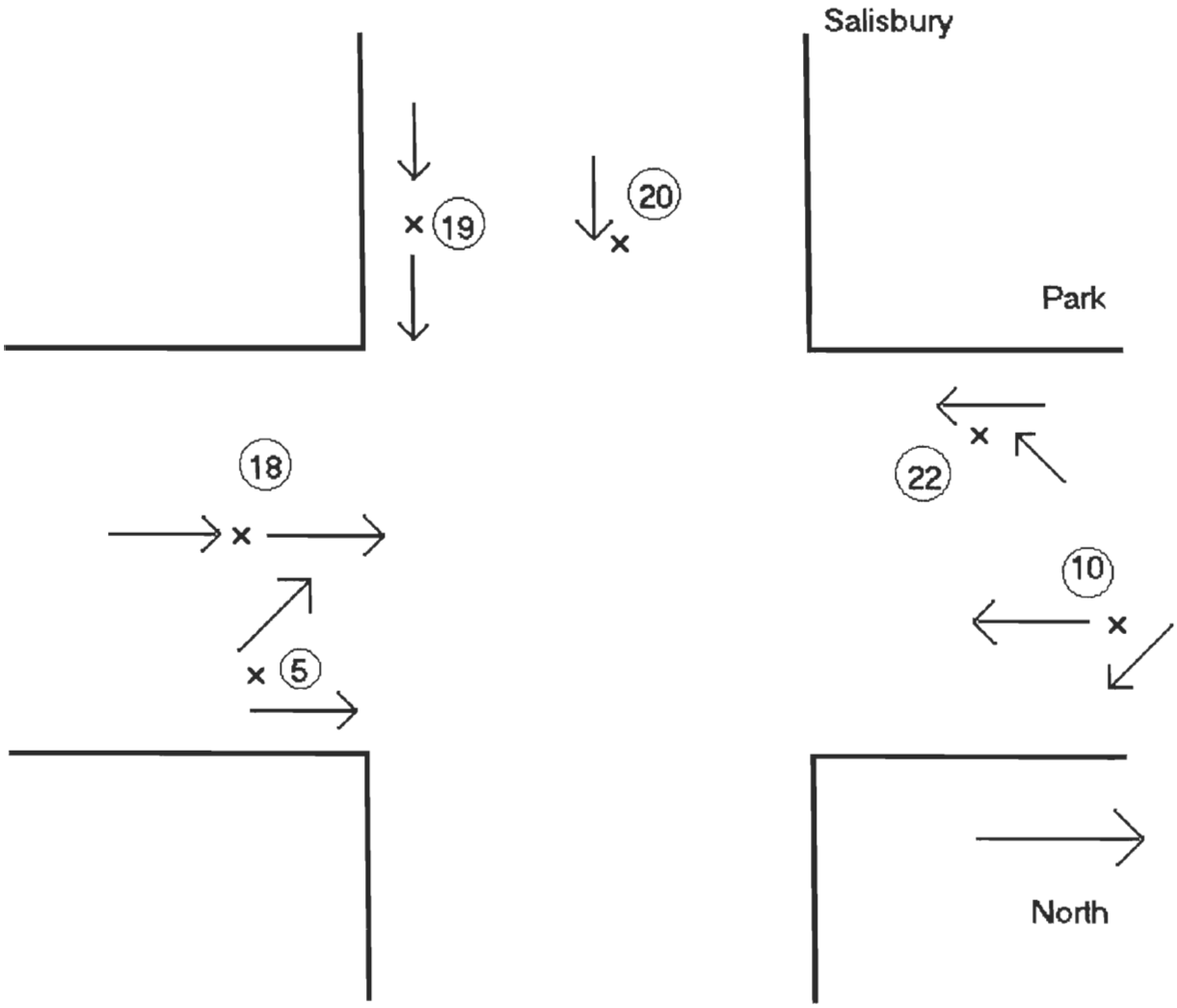

Figure 15 - 1999 Accidents at Salisbury Street

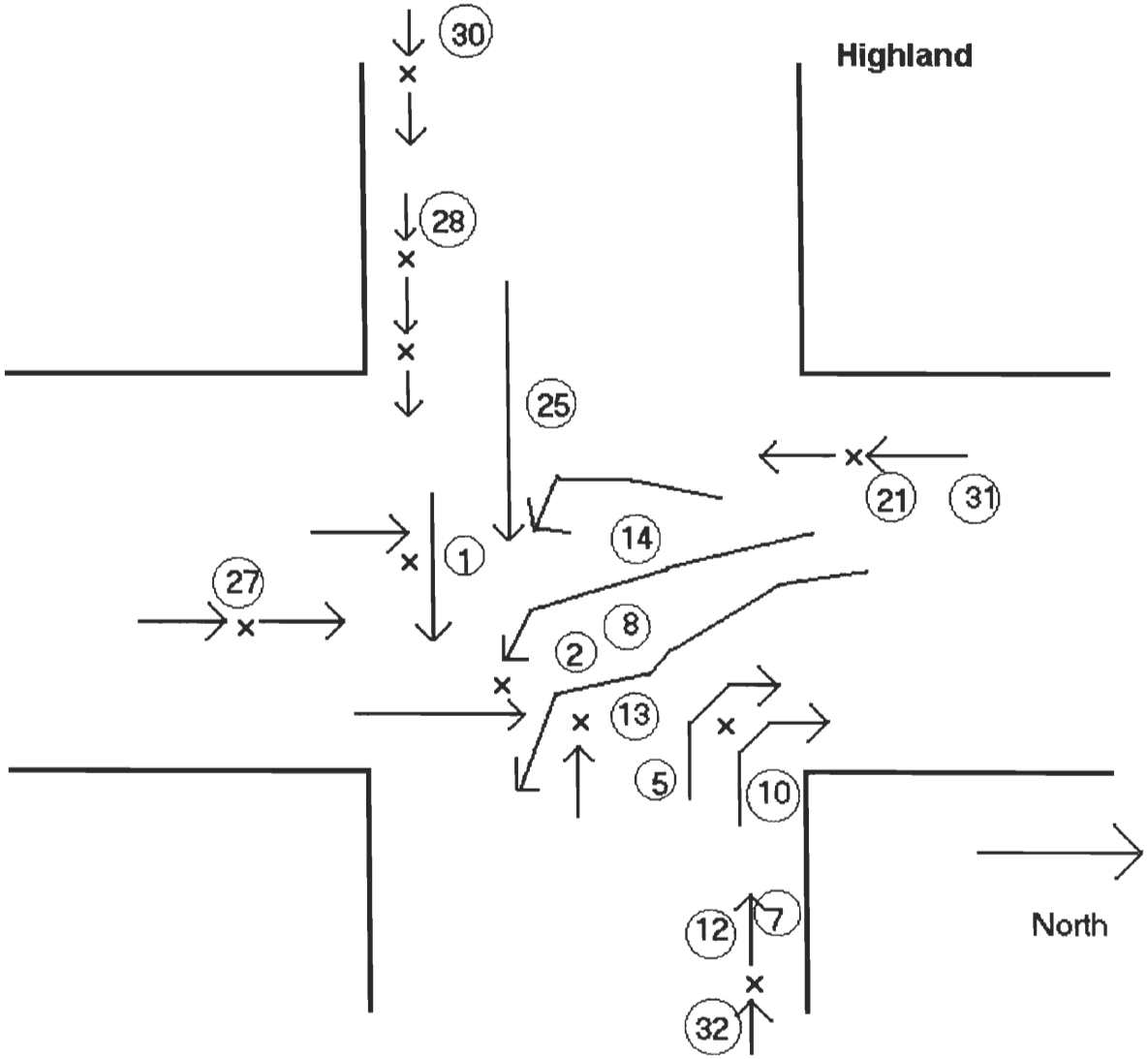

Figure 16 - 2000 Accidents at Highland Street

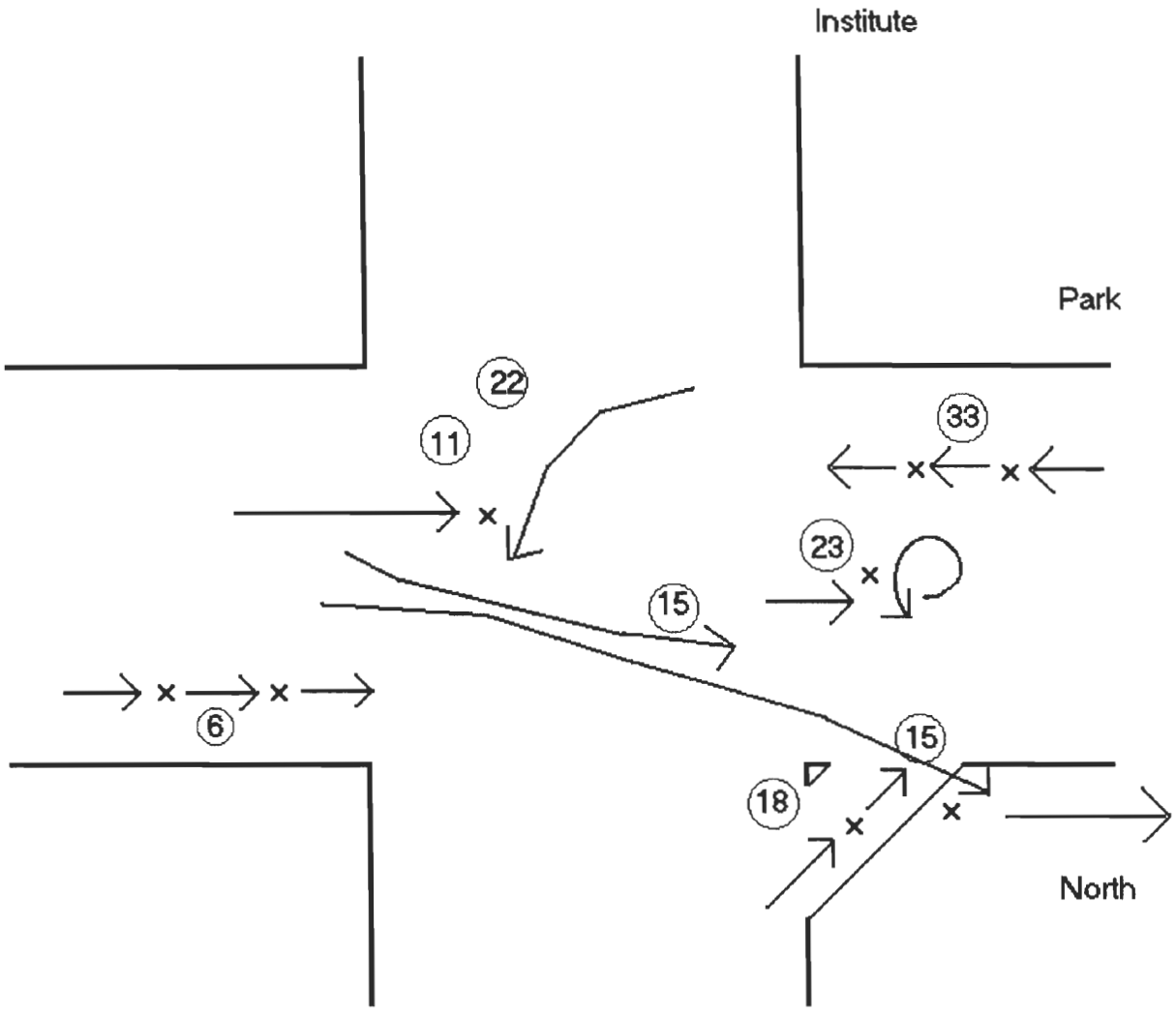

Figure 17 - 2000 Accidents at Institute Road

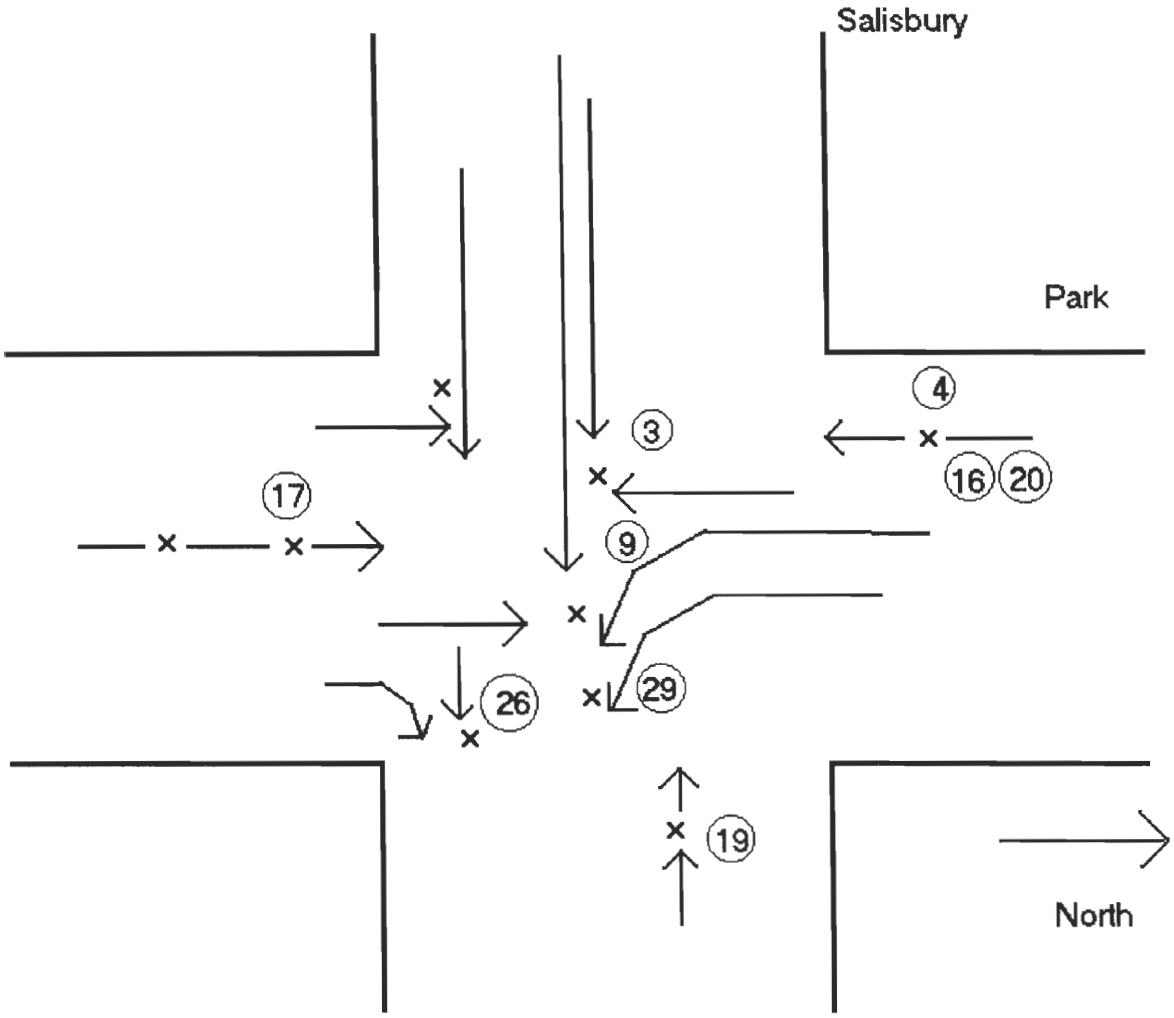

Figure 18 - 2000 Accidents at Salisbury Street

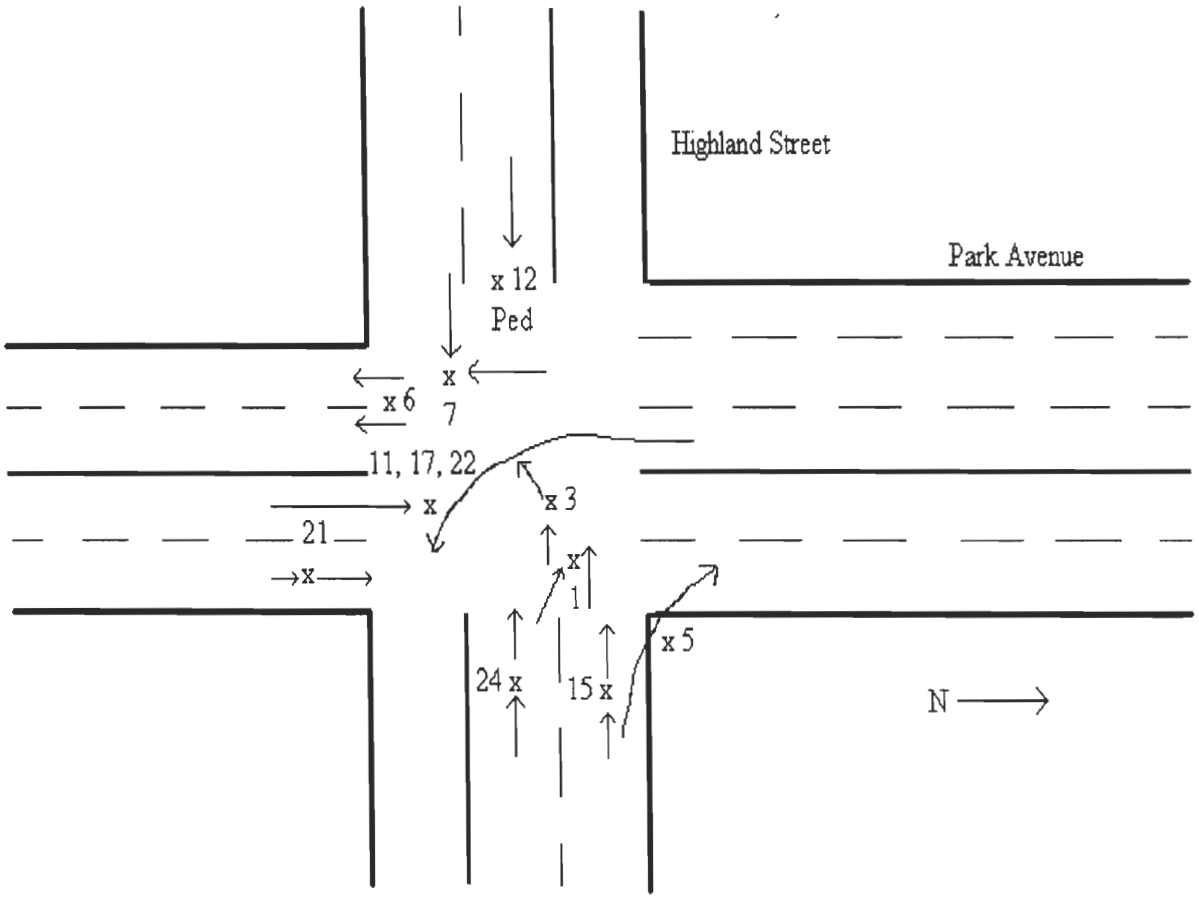

Figure 19 - 2001 Accidents at Highland Street

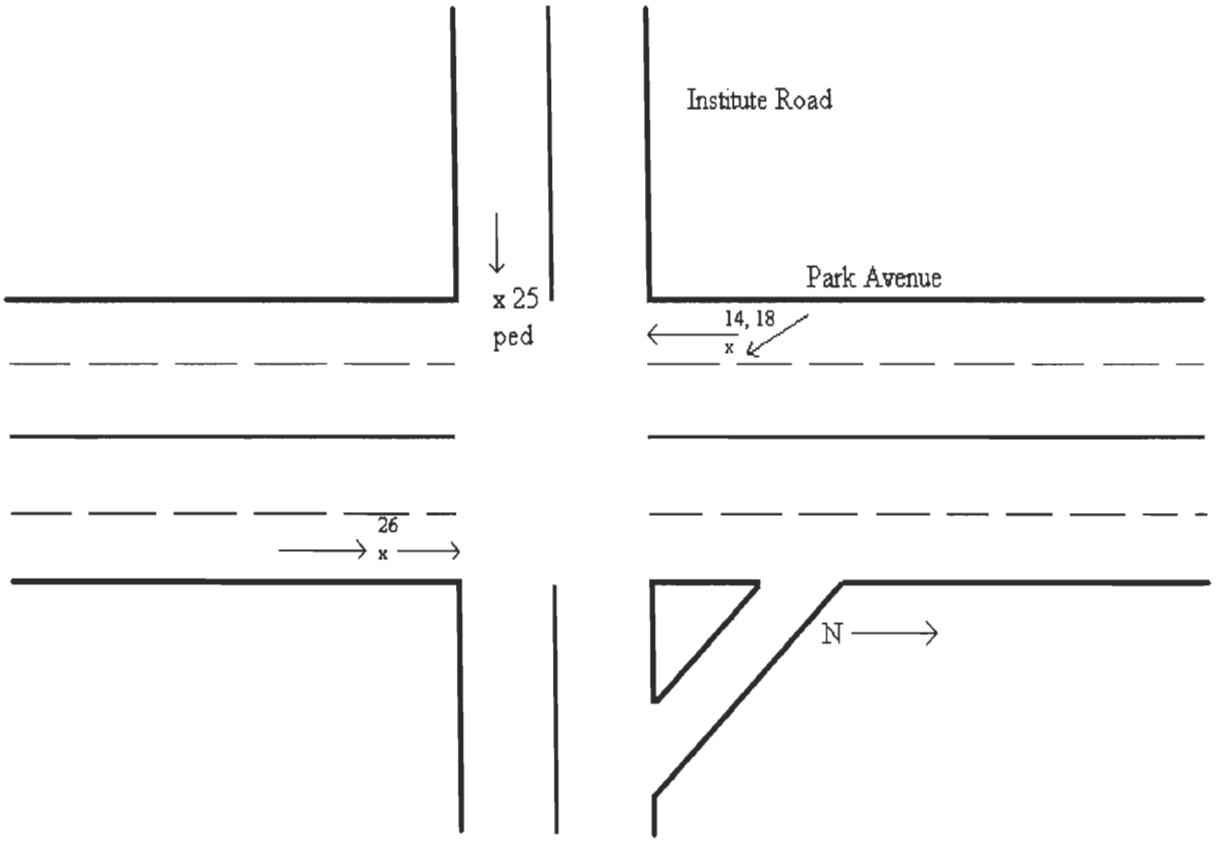

Figure 20 - 2001 Accidents at Institute Road

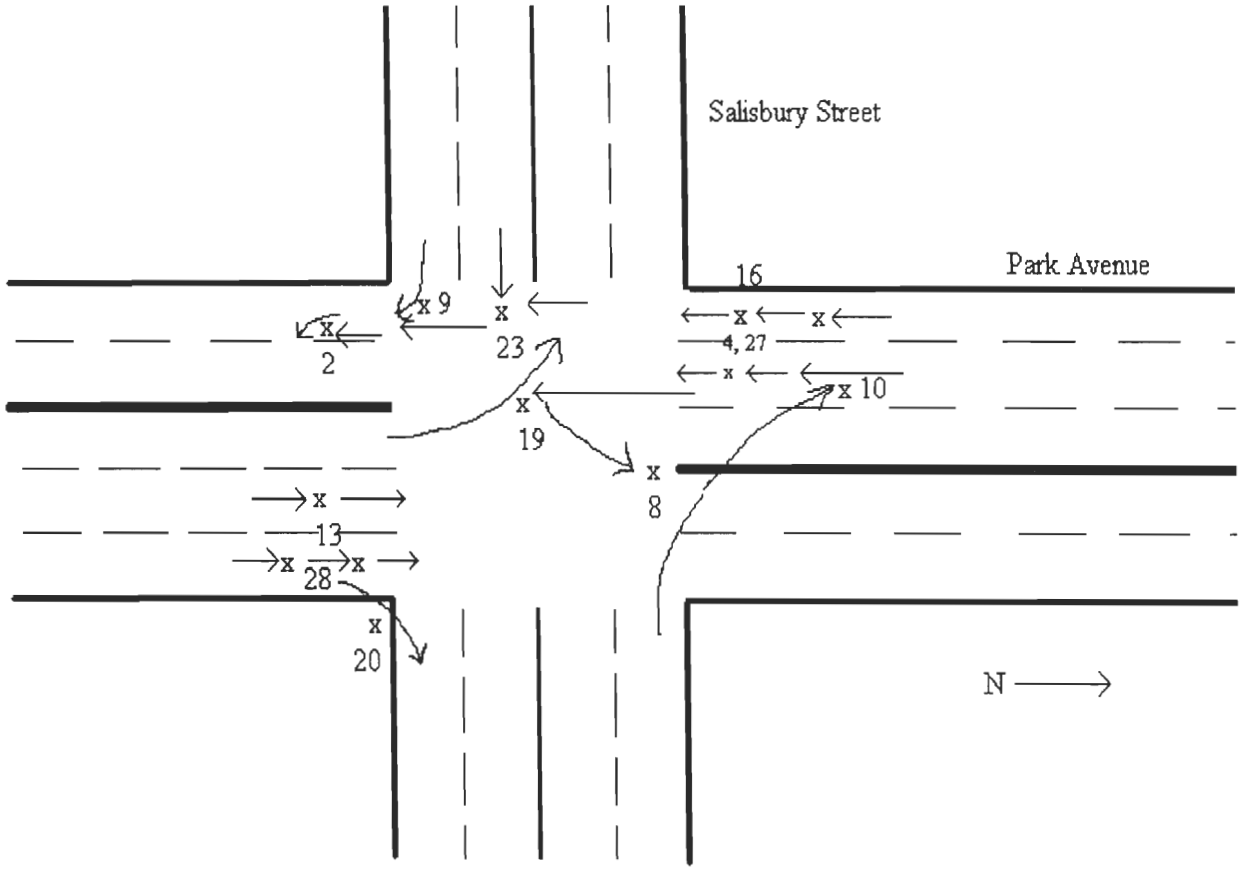

Figure 21 - 2001 Accidents at Salisbury Street

Appendix D

Survey Results

Sample survey

Table 1 - Survey results sorted by intersection, each number represents the number of respondents marking that selection

	Salisbury	Institute	Highland
Frequency			
Never	13	8	5
Weekly	4	9	12
Daily	6	7	10
2 or 3 times daily	10	14	15
4+ times daily	12	9	8
Type of Movement			
Straight Through	26	23	20
Left turn	7	8	19
Right turn	1	7	8
Time of day			
4 AM - 7 AM	2	6	4
7 AM - 10 AM	14	16	17
10 AM - 1 PM	10	8	12
1 PM - 4 PM	15	16	15
4 PM - 7 PM	18	25	21
7 PM - 10 PM	14	10	10
10 PM - 1 AM	7	6	3
1 AM - 4 AM	0	0	0
Problems			
Run red lights	19	17	22
Stop unexpectedly	4	8	12
Change lanes without signaling	6	6	19
Turn without signaling	16	21	24
Turn unexpectedly	9	6	8
Road Rage	4	8	11
Other	0	0	0
Improvements			
Longer light delays	2	1	10
Longer yellow lights	6	8	10
Additional turning lanes, signals	6	2	6
Additional lanes	10	16	11
Warning signs	15	16	18
Left turn signal	6	13	8

Park Avenue Traffic Survey

With this survey, we hope to gather information about the public's usage of three local intersections in Worcester, as well as search for potential problems.

Please answer the following questions for each junction.

1. How often, on average, do you travel through the following junctions?

SALISBURY – PARK	INSTITUTE – PARK	HIGHLAND – PARK
a. Never	a. Never	a. Never
b. Weekly	b. Weekly	b. Weekly
c. Daily	c. Daily	c. Daily
d. 2 or 3 times daily	d. 2 or 3 times daily	d. 2 or 3 times daily
e. 4+ times daily	e. 4+ times daily	e. 4+ times daily

2. What action do you most frequently take when traveling through the intersection?

SALISBURY – PARK	INSTITUTE – PARK	HIGHLAND – PARK
a. Straight through	a. Straight through	a. Straight through
b. Left turn	b. Left turn	b. Left-turn
c. Right turn	c. Right turn	c. Right-turn

3. What time do you usually drive through this area? (Circle all that apply.)

SALISBURY – PARK	INSTITUTE – PARK	HIGHLAND – PARK
a. 4 AM – 7 AM	a. 4 AM – 7 AM	a. 4 AM – 7 AM
b. 7 AM – 10 AM	b. 7 AM – 10 AM	b. 7 AM – 10 AM
c. 10 AM – 1 PM	c. 10 AM – 1 PM	c. 10 AM – 1 PM
d. 1 PM – 4 PM	d. 1 PM – 4 PM	d. 1 PM – 4 PM
e. 4 PM – 7PM	e. 4 PM – 7 PM	e. 4 PM – 7 PM
f. 7 PM – 10 PM	f. 7 PM – 10 PM	f. 7 PM – 10 PM
g. 10 PM – 1 AM	g. 10 PM – 1 AM	g. 10 PM – 1 AM
h. 1 AM – 4 AM	h. 1 AM – 4 AM	h. 1 AM – 4 AM

4. What problems have you noticed with the other drivers? (Circle all that apply.)

SALISBURY – PARK	INSTITUTE – PARK:	HIGHLAND – PARK:
a. Run red lights	a. Run red lights	a. Run red lights
b. Stop unexpectedly	b. Stop unexpectedly	b. Stop unexpectedly
c. Change lanes without signaling	c. Change lanes without signaling	c. Change lanes without signaling
d. Turn without signaling	d. Turn without signaling	d. Turn without signaling
e. Turn unexpectedly	e. Turn unexpectedly	e. Turn unexpectedly
f. Road rage	f. Road rage	f. Road rage
g. Other, please specify:	g. Other, please specify:	g. Other, please specify:

5. What improvements do you think would make this a safer intersection?

SALISBURY – PARK	INSTITUTE – PARK	HIGHLAND – PARK
a. Longer light delays	a. Longer light delays	a. Longer light delays
b. Longer yellow lights	b. Longer yellow lights	b. Longer yellow lights
c. Additional turning lanes, signals	c. Additional turning lanes, signals	c. Additional turning lanes, signals
d. Additional lanes	d. Additional lanes	d. Additional lanes
e. Warning signs	e. Warning signs	e. Warning signs
f. Left turn signal	f. Left turn signal	f. Left turn signal