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dissertation entitled

Development of an Interactive Traffic Accident Geographic Information (ITAGI) System and a Multimedia Left-Turn Control Strategies Expert System

presented by

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has been accepted towards fulfillment of the requirements for

Ph.D. degree in Civil Engineering

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Date 7/2/96

DEVELOPMENT OF AN INTERACTIVE TRAFFIC ACCIDENT GEOGRAPHIC INFORMATION (ITAGI) SYSTEM AND A MULTIMEDIA LEFT-TURN CONTROL STRATEGIES EXPERT SYSTEM

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Civil and Environmental Engineering

1996

ABSTRACT

DEVELOPMENT OF AN INTERACTIVE TRAFFIC ACCIDENT GEOGRAPHIC INFORMATION (ITAGI) SYSTEM AND A MULTIMEDIA LEFT-TURN CONTROL STRATEGIES EXPERT SYSTEM

By

Shung Kung Wu

The Intelligent Vehicle Highway System (IVHS) project in Oakland County, Michigan, is a major federally-funded demonstration project of the real-time traffic adaptive signal system called SCATS (Sydney Coordinated Adaptive Traffic System). SCATS was installed in a part of the City of Troy (in Oakland County, Metropolitan Detroit, Michigan) in June 1992 and in the remainder of the city in November 1993. The role of the universities involved in this project is to evaluate the impact of this system. There are several criteria being analyzed in this evaluation including the number, type and severity of traffic accidents, the level of service (LOS), and the average speed on the major arterials.

A program, the Interactive Traffic Accident Geographic Information (ITAGI) system was designed to assist the analyst in evaluating the safety and delay (travel speed) effects of SCATS. The results of the accident analyses conducted in this project using the ITAGI system are described. From this database system, statistical analyses of any specific location or group of locations, both intersections and midblock areas in the city, can be conducted. The ITAGI system consists of a traffic accident geographic

information system (GIS), quality control charts of accident rates developed by using the Monte Carlo simulation algorithm, and a safest path (through the network) algorithm.

Finally, after integrating the ITAGI system and a knowledge-based system, a multimedia left-turn control expert system was developed. The ITAGI system is a decision support tool for the multimedia left-turn control expert system. This expert system provides knowledge-based and user-friendly information to the user. It can help the operator in the traffic operations center analyze conditions and select left-turn control strategies in real time. In addition, it utilizes the computer-based multimedia techniques to store video images, audio voices, pictures, and graphics for CD-ROM computer use. The rules contained in the multimedia left-turn control expert system have been calibrated with a consistency check and a Turing test.

This paper, an integration of GIS and multimedia left-turn control expert systems, first describes the development of the ITAGI system, then highlights how the ITAGI system supports the actual safety and travel speed analysis before and after installation of SCATS. Second, this paper illustrates the development of the multimedia left-turn control expert system. It focuses on how the ITAGI system is used as a decision support tool to the multimedia left-turn control expert system, on how the expert system generates inductive rules by using the ID3 algorithm, and on how the expert system is calibrated with a consistency check and a Turing test.

I dedicate this dissertation to my parents, sister, and my friends.

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my advisor, Dr. William C. Taylor, for his continuous advice and encouragement throughout the work as well as his financial support during the study. I also want to thank my guidance committee: Dr. Richard Lyles, Dr. Thomas Maleck and Dr. Raoul LePage for their comments during my defense. I would like to give special thanks to Dr. Richard Lyles for his advice in the expert system development, and Dr. Raoul LePage for his technical support in statistics. Also thanks are due to my girl friend, Pei-Chun Hsieh, for her encouragement while I was working on my dissertation.

I would also like to thank Dr. William C. Taylor, Dr. Richard Lyles, and Dr. Thomas Maleck from Department of Civil and Environmental Engineering at Michigan State University, Mr. James Neve who served as a district traffic engineer for the Michigan Department of Transportation (MDOT), Dave Allyn and Mohammed Lutfi from the Oakland County Road Commission, and William Savage, a traffic engineering consultant, for their participation as experts in developing the left-turn control knowledge base. Thank you all.

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

The Intelligent Vehicle Highway System (IVHS) project in the city of Troy, Michigan, is a unique federal demonstration project of the real time traffic adaptive signal system called SCATS (Sydney Coordinated Adaptive Traffic System). This system changes cycle length and the green and red phases based on current traffic demand. The role of the universities involved in this project is to evaluate the impact of SCATS. There are several measures of effectiveness (MOEs) being analyzed in this evaluation including the number, type and severity of traffic accidents, the level of service (LOS) at each intersection, and the average speed on the major arterials.

To facilitate the evaluation, the Department of Civil and Environmental Engineering, Michigan State University has constructed an Interactive Traffic Accident Geographic Information (ITAGI) System to analyze the impact of the SCATS on traffic accidents. As a further development, the ITAGI system has been expanded to include a multimedia left-turn control expert system. The relationship between the ITAGI system and the multimedia left-turn control expert system is depicted in Figure 1.1. The important features of the ITAGI system include accident location capability using a limited geographic information system (GIS) for Troy, graphic interface capability, determination of multiple (or group) intersections or midblocks characteristics and a safest path searching capability.

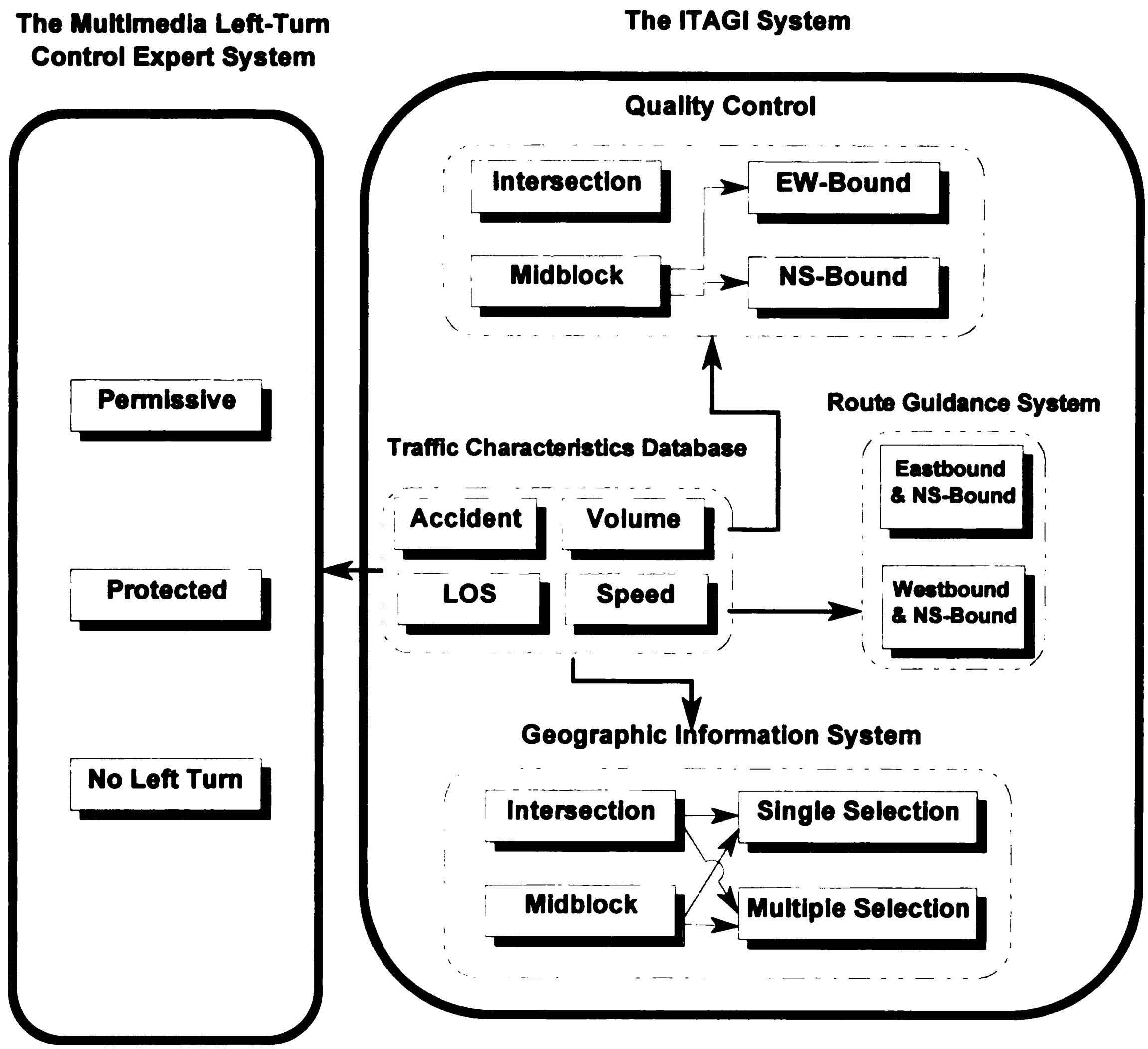

Figure 1.1 The Relationship between the ITAGI System and Multimedia Left-Turn Control Expert System

The ITAGI system consists of computer programs used to assist in the analysis of accidents and to display traffic accident characteristics, such as the type of accident at any specified intersection or midblock location. Through a user-friendly PC-based computerized database, the ITAGI system provides quick access to the data using menu-selection. Through a geographic information system (GIS) function, the ITAGI system allows the user to select data from any specified intersection(s) or road segment (s) directly from the map. Thus, rather than being limited to textual queries, it is possible to perform geographic queries. The user simply selects the desired points on the computer screen, and acquires the desired information.

The ITAGI system has already embedded several hundred customized maps, easily-understood color-coded graphics, and information associated with intersection or midblock locations in the system. The analyst or the user can examine traffic accident records (1989--1994) to determine high traffic accident locations (either at intersections or at road segments). The data includes lane configuration, traffic accident data stratified by location, type of accident and year. These and other data can be displayed on the screen at the request of the user.

The ITAGI system also allows the user to see the aggregate decrease or increase in the total number of accidents, or the percentage of various types of accidents on single locations or a group of locations(intersection or midblock locations). This capability is useful when a new traffic control strategy, such as SCATS, or when changing left-turn control strategy from permissive to protected, or from protected to prohibited, is implemented at specific locations.

In the FAST-TRAC federal demonstration program, Ali-Scout has been selected as the route guidance and in-vehicle navigation system for improving travel efficiency based on finding the minimum travel time path between any two points in the network. The ITAGI system was programmed to select the route between any two points which passes through intersections that had the lowest accident rates in the specified year. This is named the safest path.

After integrating the ITAGI system with a knowledge-based system, it can be used as an expert system for recommending left-turn control strategies. The procedure used to develop the left-turn control expert system included conducting a survey of traffic experts, and using the survey results to construct rules and facts to select the left turn control strategy at Troy's intersections. Integration of the knowledge-based expert system (KBES) into the traffic operations center provides the engineer with a high level of support in analyzing and recommending left-turn control strategies. In addition, integration of KBES provides a tool to supplement the experience of individual operators and reduce the potential for incorrect responses by traffic operations center staff. The ITAGI system is fully integrated with the left-turn control expert system.

The ITAGI system was compiled by the PDC PROLOG (Programming in Logic) program as a set of stand-alone executable files. PROLOG is a symbolic and artificial intelligence (AI) language based on predicate calculus, and was developed in 1972 by Colmerauer and Roussel. PROLOG is a declarative language that uses simple relations among facts, rules and queries [Teft, 1989]. A detailed introduction to the program is provided in chapter 3.

1.2 OBJECTIVES

In this study, there are four objectives:

1. To produce a graphic interface capability for the City of Troy. The ITAGI system has embedded several hundred customized maps, easily-understood color-coded graphics and information associated with specified intersection or road segment locations in the system. The data available to the user include: type of traffic accident, number of traffic lanes, level of service, average travel speed, delay, accident rate, traffic volume, and average travel speed on the major corridors. Any specified location(s) can be selected and the specified type of accident (angle, turn, rearend, and others) can be displayed in a bar chart, or pie chart format.

2. To develop a GIS capable of locating accidents in the City of Troy. A GIS is a useful decision support tool for transportation applications because it provides a visual display of a transportation network and associated spatial data. Therefore, via GIS, the operator can examine accident characteristics over the past six years. The ITAGI system provides a convenient format for the user to obtain the specified information from the map. Rather than being limited to textual queries, it is possible to perform geographic queries. The user simply selects the desired points on the computer screen, and acquires the desired information.

3. To demonstrate the use of the ITAGI system in evaluating a new traffic control system, such as SCATS. The ITAGI system provides the user with information on the aggregate decrease or increase in the total number of accidents, or the percentage of type of accidents at specified locations.

4. To use multimedia techniques to demonstrate how a knowledge-based expert system (KBES) can be made more vivid and more effective than plain text in the expert system or expert system shell. The ITAGI system provides the decision-maker information on which traffic control strategies can be based. In this system, not only can the expert knowledge be expressed by the computer in plain text format, but also in a video (multimedia) format on the computer screen as well.

1.3 METHODOLOGY

In this section, the five steps used in constructing the ITAGI system and the multimedia left-turn control expert system are described. The design process is shown schematically in Figure 1.2. The first step is to write the SPSS and PDC PROLOG program, then construct and verify all database files for intersections and midblock locations from years 1989 through 1994. These database files are used by the geographic information system, route guidance system, quality control chart of traffic accidents and multimedia left-turn control expert system (the details will be explained in section 3.2). The second step is to write the PDC PROLOG program so that the user can select any specified points directly from the map (the details will be explained in section 3.3). The third step is to write the PDC PROLOG program to develop the route guidance system so that the user can specify two points on the map and obtain the safest path between two points (the details will be explained in section 3.4). The fourth step is to write the PDC PROLOG program to develop the quality control chart of traffic accidents so that the user can identify high accident locations (the details will be explained in section 3.5). The

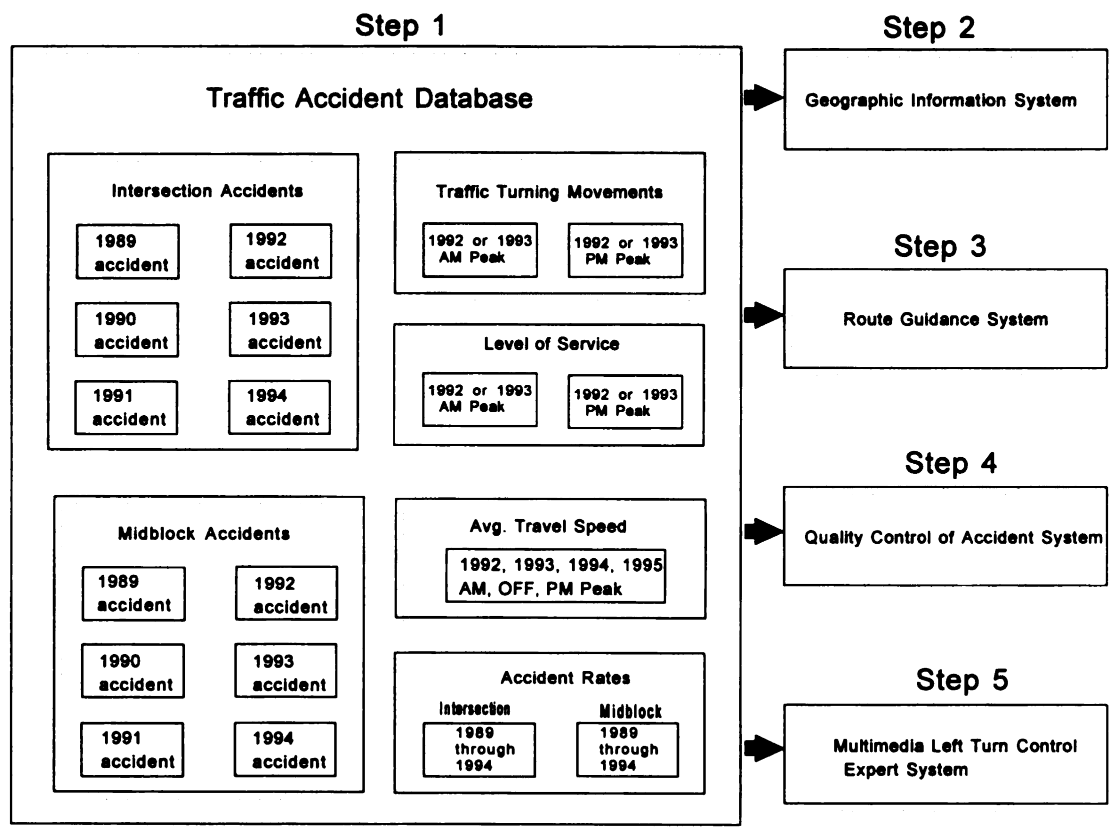

Figure 1.2 The Design Processes of the ITAGI System and the Multimedia Left-Turn Control Expert System

final step is to build the multimedia left-turn control expert system (the details will be explained in chapter 4).

1.4 ORDER OF PRESENTATION

The order of presentation in this paper is as follows:

Chapter 1 Introduction

Chapter 2 Literature Review

Chapter 3 Development of the Interactive Traffic Accident Geographic Information (ITAGI) System

Chapter 4 Development of the Multimedia Left-Turn Control Strategies Expert System

Chapter 5 Summary

CHAPTER 2 LITERATURE REVIEW

Left-turn control strategies have significant impacts on intersection capacity, traffic operations, and safety of signalized intersections. Selecting the proper left-turn signal phasing can improve the level of service (or decrease intersection delay) and reduce left-turn-related accidents. One of the objectives in this study was to provide assistance in making the trade-off between left-turn efficiency and safety among three left-turn treatments, permissive, protected, and prohibiting left turns. Often traffic engineers rely on experience or trial-and-error until a suitable solution is found. From the literature review, it was determined that most of the left-turn treatment guidelines were developed by either before-and-after studies that compared a change from one type of phasing to another or computer methods that optimize/simulate the network signal timing for different left-turn treatments. Only a limited number of articles dealt with the selection of a left-turn control strategy by expert systems, and none of the previous studies discussed guidelines for selecting permissive, protected, and prohibiting left turn control. In this chapter, the literature on the types of left-turn control, expert systems applications to transportation engineering, and expert systems applications to left-turn control treatments will be reviewed.

2.1 LEFT-TURN CONTROL GUIDELINES

2.1.1 TYPE OF CONTROL

A detailed review of previous research on the types of left-turn control and the guidelines for the selection of left-turn phasing and indication sequences was undertaken. Most of the guidelines were based on either a before-and-after study (Agent [1987], Stonex et al. [1987], Asante et al. [1993], Warren [1985], Cottrell [1986], Upchurch [1986, 1991], Greiwe [1986], Lalani et al. [1986], Shebeeb [1995], Florida ITE [1982]) or simulation/optimization methods (Rouphail et al. [1994], Chang et al. [1988], Cohen et al. [1985], Hummer et al. [1991]). In this section, the **left-turn phasing patterns** and **guidelines** will be introduced, then the **left-turn indication sequences** and **guidelines** will be presented.

2.1.2 LEFT-TURN PHASING PATTERNS

According to the 1988 Manual of Uniform Traffic Control Devices (MUTCD), there are three left-turn signal phasing patterns which are commonly used at signalized intersections. These are the permissive (or permitted), protected (or exclusive), and protected/permitted (or exclusive/permissive) phases. Permissive left turn means vehicles are allowed to make a turn on a circular green indication but must yield to opposing traffic. Protected left turn means vehicles are allowed to make a turn only on a green arrow indication and have the right of way while the green arrow is displayed. Protected/permissive means vehicles are allowed to make a turn either on a green arrow indication or on the circular green after yielding to oncoming traffic.

2.1.3 GUIDELINES FOR LEFT-TURN PHASING

Upchurch [1986], through an analysis of time-lapse film at six intersections, developed guidelines for selecting left-turn phasing based on the following decision variables: cycle length, available sight distance, product of left-turn and opposing volumes (a volume cross product), speed of opposing traffic, number of opposing lanes, and left-turn accidents. This study concluded that protected left-turn phasing should be provided when the left-turn volume during the peak hour is more than two vehicles per cycle and the volume cross product is greater than 100,000 $(vph)^2$ and 144,000 $(vph)^2$ for two and three opposing lanes, respectively. A combination of protected/permissive phasing is recommended unless the opposing speed is greater than 45 mph, there are three or more opposing lanes, sight distance is restricted, or a severe accident problem exists. However, in Upchurch's study, the definition of a severe accident problem is not clear and there are no general guidelines for the prohibiting left-turn treatment.

Cottrell [1986] also developed guidelines for the use of protected/permissive left-turn phasing. Data were collected at 45 sites in Virginia, including 20 with protected/permissive lefts, 15 with protected-only lefts, and 10 with permissive-only lefts. Based on these field observations, specific guidelines for left-turn phasing were developed. He concluded that protected/permissive phasing should be used when the peak hour volume cross product is between 50,000 $(vph)^2$ and 200,000 $(vph)^2$ and the left turning volume exceeds two vehicles per cycle; average peak hour delay for left-turn

vehicles exceeds 35 sec/veh and the total peak hour left-turn delay exceeds two vehicle-hours (with permissive left-turn only); there are no more than two opposing lanes; good intersection geometrics and good access management exist; and annual protected/permissive delay is less than that of protected-only delay. In this study, prohibiting left-turn guidelines were not developed.

Another significant study in this field was undertaken by the Florida Section of ITE [1982]. Accident analyses were conducted at 17 approaches that were converted from protected-only to protected/permissive operation. They concluded that protected/permissive phasing should be provided for all intersection approaches for which protected lefts are provided unless there is a compelling reason for using protected-only phasing. Conditions where protected-only phasing was recommended include a double left-turn lane, restrictive intersection geometry requiring protected-only, restricted sight distance, the leading left of a lead/lag phasing sequence, speed limit of opposing traffic greater than 45 mph, three or more opposing lanes, and more than six left-turn accidents in one year on the approach with protected/permissive phasing. Once again the prohibiting left-turn guidelines were not developed.

Asante et al. [1993] also developed guidelines for permissive, permissive/protected, and protected left-turn treatments. He recommended protected or permissive/protected left-turn control should be implemented when the sight distance for the left-turning vehicle is restricted on the basis of the posted speed limit for the opposing traffic, or more than eight left-turn-related accidents have occurred within the last 3 years at any one approach with permissive left turn phasing, or more than 450 left-turn-related conflicts per million $(vph/lane)^2$ are observed at an approach with permissive left turn phasing, or the plotted point representing the peak-period volume in vehicles per hour (based on the peak 15 minutes) and the corresponding opposing-traffic speed limit. He suggested that the protected only left-turn control should be used under any of the following conditions:

- Approaches with restricted sight distance, as determined on the basis of posted speed limit on the approach opposing the left-turn traffic, or
- Approaches with four or more opposing lanes that must be crossed by the left-turning traffic; or
- if any two of the following conditions are met:
    - Peak-hour volume measured at 15-min intervals for the left-turning traffic is greater than 320 vph,
    - Peak-hour volume measured at 15-min intervals for the opposing traffic is greater than 1,100 vph,
    - The opposing speed limit is greater than or equal to 45 mph,
    - There are two or more left-turn lanes exist; or
- when one of the following conditions or combination of conditions exist:
    - Three opposing lanes and the opposing speed limit is greater than or equal to 45 mph,
    - Left-turn volume is greater than 320 vph and the percent of heavy vehicles in the left-turning traffic exceeds 2.5 percent,

- Opposing volume is greater than 1,100 vph and the percent of heavy vehicles in the left-turning traffic exceeds 2.5 percent,
- Seven or more left-turn-related conflicts per million $(vph/lane)^2$ are observed for a permissive/protected approach, or
- Average stopped delay for left-turning traffic is acceptable for protected only phasing and the traffic engineer judges that the use of permissive/protected phasing will result in a greater number of left-turn accidents.

The guidelines developed by the various before-and-after study are difficult to synthesize because not all of the tested intersections were similar during the before-and-after periods. The characteristics of the intersections used in the various studies were not specified in the reports. Differences in these characteristics such as type of phasing, number of opposing lanes, left-turn volume, opposing volume, and the existence of a separate left-turn lane could lead to different results.

2.1.4 LEFT-TURN INDICATION SEQUENCES

Three left-turn indication sequences have been discussed in previous studies; leading, lagging, or a leading/lagging sequence. Leading left turns are, from an efficiency standpoint, more desirable since they are associated with lower delays and increased intersection capacity. However, accidents were reported to be more frequent at intersections with a leading left turn. Lagging left turns, on the other hand, appear to be safer. Leading/lagging operation are often implemented for reasons other than the reduction in delay, such as for progression purposes on an arterial to get the maximum bandwidth in the time-space diagram..

The Dallas phasing is not commonly used, but can be found in the recent literature [Asante et al., 1993]. This is a modified leading/lagging, protected/permissive sequence. During the portion of the cycle when one of the left turns is protected and its adjacent through movements plus right turns are shown a circular green signal, the opposing left turn is permitted. Because the throughs and rights adjacent to the permitted left are shown a red signal (because the opposing left is protected), Dallas phasing leads to a unique display. Motorist surveys have indicated that drivers understand the Dallas phasing as well as or better than they understand other types of left-turn phasing [Asante et al., 1993].

2.1.5 GUIDELINES FOR LEFT-TURN INDICATION SEQUENCES

Hummer [1991] developed some guidelines, by using the NETSIM simulation program, for the use of leading and lagging phase sequences. He suggested that lagging instead of leading phase sequences should be used when serving heavy pedestrian traffic after checking for the possibility of trapping. Trapping will occur in intersections where one approach has a permissive left turn and the opposing approach has a lagging sequence. If trapping is possible, the phasing should be changed to eliminate that possibility by eliminating the permissive turn (making it protected-only or prohibiting the turn), by eliminating the lagging sequence, or by ensuring that the opposing approaches both have lagging sequences with left-turn phases that begin simultaneously.

In this study, many of the decision variables are binary (such as is there heavy pedestrian crossing volumes), but the paper does not specify how many pedestrians constitute a heavy crossing volume.

Upchurch [1991] also compared the left-turn accident rates for different types of left-turn phasing. A total 523 signalized intersections were included in developing the accident statistics. This study concluded that the left-turn phasing type at a signalized intersection affects the left-turn accident rate, with permissive left turn policies being the most hazardous, and leading protected being less hazardous than lagging protected. The accident rate is also influenced by the number of opposing lanes of traffic, left-turn volume, and the volume of opposing traffic.

After collecting data from 216 intersection approaches, Asante et al. [1993] used a before-and-after study method to construct the guidelines for the sequence of phasing (leading, lagging, or leading/lagging). He used 10 decision variables which affect the intersection performance. Those variables are left-turn volume, opposing volume, volume cross product, vehicle mix, ratio of green to cycle length for left turn, number of left-turn lanes, number of opposing lanes, volume-to-capacity ratio of the approach, speed of opposing traffic, and sight distance. He indicated that a lagging sequence is recommended when it is intended to improve the safety of an already installed leading sequence under which more than 190 left-turn conflicts per million (vehicles per hour per lane)^2 are observed, or the lagging left-turn sequence is necessary as part of an overall network progression scheme. A leading/lagging sequence is recommended for intersections when there is inadequate space within the intersection to safely accommodate a dual left-turn operation, or it is necessary for the progression scheme.

Chang et. al [1988] used the MAXBAND program for optimizing the left-turn phase sequence in multiarterial closed networks. In determining optimal signal timing plans for signalized networks, Chang et al. used four decision variables to optimize the signalized networks. They are offset, green phase time, cycle length, and left-turn phase sequence. This study included a comparison of MAXBAND-produced timing plans with and without phase sequence optimization and an analysis of the effects of using phase sequence patterns given by MAXBAND in the TRANSYT-7F program. In other words, first, the MAXBAND program was executed to provide timing plans for each of the 10 arterials in the network, then TRANSYT-7F was used to optimize the timing plan for the whole network, finally the NETSIM program was employed to simulate the network. However, the delay-based programs, such as TRANSYT-7F, and bandwidth-based programs, such as MAXBAND, measure the performance in terms of minimum delay and stops. The delay-based programs optimize green phase time, offset, and cycle length; and the bandwidth programs optimize offset, cycle length, and phase sequence. In fact, these programs did not consider the safety and efficiency factors as their performance index (PI). Often, the researchers just focus on minimizing the delay and stops, while safety is not taken into account.

The guidelines developed by the various authors cited in this review are based on many common variables, including:

- the product of left turning and opposing volumes,

. speed of opposing traffic,

. left turn related accidents,

. number of opposing lanes and

. available sight distance.

In addition, Upchurch [1986] included cycle length as a variable. Cottrell [1986] included the left turning volume and delay as important variables. The Florida ITE guidelines added dual left turn lanes as an additional variable to be included. Asante et al. [1993] also listed delay and left turning volumes as important variables. All of these variables, with the level-of-service serving as a surrogate for delay, are included in the expert system developed in this study. Some of the variables are used as conditions (adequate sight distance), as they are seldom an issue in an urban setting, and there are no intersections in the City of Troy that have restricted sight distance. A limitation of each of the cited studies is that they do not provide guidelines for determining when left turns should be prohibited, as well as how the choice between protected and permissive should be made. The expert system developed in this study addressing this deficiency.

2.2 EXPERT SYSTEMS AND TRANSPORTATION ENGINEERING

Expert systems are computer programs that consist of a collection of heuristic rules and domain facts used by human experts in solving complex problems. The development of knowledge-based expert systems (KBES) is one of the most significant accomplishments in the field of artificial intelligence (AI). Since its initiation, the KBES technology has drawn much interest because of its problem-solving capability.

Many prototype expert systems have been developed in a number of disciplines, including agriculture, chemistry, computer systems, electronics, engineering, geology, information management, law, manufacturing, mathematics, medicine, meteorology, military science, physics, process control, and space technology.

The use of knowledge-based expert systems in transportation engineering has also been increasing. For example, TREMEX is an expert system which offers advice to the officer in charge of an incident, before the arrival of the expert [Lycett et al., 1989]. SRM (rollover threshold), YAWROLL (steering maneuver without braking), and PHASE4 (steering and braking maneuver) are integrated as an expert system for conducting stability analysis of heavy vehicles [Sankar et al.,1991]. There is also a knowledge-based geographic information system for safety analysis at rail/highway grade crossing [Panchanathan et al., 1995] and a system to address various aspects of heavy truck size and weight impacts on pavements, bridges, truck safety, and economics [Robinson, 1990]. In the field of traffic engineering, ISMIS is an intersection safety management information expert system. This system provides users with measures available for remedying a particular intersection safety problem. It permits the user to perform an analysis of cost-effectiveness based on statistical decision theory to determine the best alternative remedy [Seneviratne, 1989]. Other examples include expert systems for roadside safety [Zhou et al., 1991], for design of highway safety structures [Roschke, 1991], for highway safety[Sayed, 1994], for acoustic design of highway noise barriers, CHINA [Harris et al., 1985] and for selecting traffic analysis software [Chang, 1987]. Although much work has been done, only one expert system application to the left-turn control treatments was found (Chang [1987]).

2.3 EXPERT SYSTEMS AND LEFT-TURN TREATMENTS

Several research studies on combinations of left-turn signal phase patterns and indication sequences have been discussed. However, none of the previous study considered the choice of permissive, protected and prohibiting left-turn control. One of the purposes of this study was to develop an expert system that can assist the engineer in making this three way choice. In this section, literature discussing the trade-off between left-turn efficiency and safety will be presented, then the value of a left-turn control expert system will be addressed, then an example (literature) dealing with an expert system application to the left-turn treatment will be introduced, and finally the unique features of this study (the ITAGI system and left-turn control expert system) will be explained.

2.3.1 TRADE-OFF BETWEEN LEFT-TURN EFFICIENCY AND SAFETY

Shebeed [1995] and Warren [1985] studied the trade-off between left-turn efficiency and safety. A total of 54 intersections comprising 179 approaches were studied by Shebeed [1995]. The traffic volume counts, signal timing data, and left-turn accidents were collected to calculate the accident rate and stopped delay. The stopped delay for the left-turn group for each approach was calculated from the Highway Capacity Software (HCS). Seven patterns for left-turn phasing were considered: 1) permissive only, 2) lead-protected only, 3) lag-protected only, 4) lead-protected permissive, 5) lag-protected permissive, 6) lead Dallas, and 7) lag Dallas. The results show that a definite trade-off exists between left-turn accident rates and delay. The protected approaches are less efficient; however, they offer a higher level of safety than other phasing types. He concluded that protected phasing should be applied as a means of enhancing left-turn safety when the expected delay is acceptable, based on the desired level of service. Protected/permissive approaches are more efficient but less safe than protected-only and Dallas approaches. Permissive-only approaches are associated with the best efficiency but the highest accident rates. There is no significant difference in efficiency and safety between lead and lag left-turn sequences.

Warren [1985] also concluded a study of the accident experience as a function of the left turn phasing. He found that at the intersections that were converted from protected to protected/permissive phasing, rearend and total accidents decreased, while left turn accidents increased dramatically. From the survey result, he reported that motorists overwhelmingly favor protected/permissive left turn phasing and want additional protected-only signals converted to protected/permissive phasing. This means that motorists are willing to accept the additional risk of protected/permissive left turns in exchange for increased driving freedom, delay savings, and reduced driver frustration from not having to wait at traffic lights for no apparent reason.

2.3.2 THE VALUE OF A LEFT-TURN CONTROL EXPERT SYSTEM

Expert system technology is a new approach to problem solving. It is designed to provide the level of performance of a human expert in a specific professional domain and enable a computer to assist people in analyzing specific problems using that expertise [Waterman, 1986]. Because of the trade-off among the safety, efficiency, and delay in left-turn control decision making, a prototype knowledge-based expert system has been developed to address this problem.

The value of a left turn control expert system is based on the following conclusion derived from the literature review.

1) Currently, there is no uniform and consistent guideline to assist traffic engineers in selecting the appropriate phasing type. Engineers often rely on experience or trial-and-error until a suitable pattern is found. Building an expert system can accelerate the problem solving and decision making. The reasons for using expert systems in transportation engineering are the same as for using any type of automation: the use of less skilled personnel, quicker solutions, and more reliable solutions. An expert system does not replace the human being, and it merely assists the human being solve a problem quickly and efficiently.

2) There exists potential trade-offs between left-turn efficiency and safety. Because of the trade-offs existing in the left-turn control treatments, an expert systems can speed up the problem-solving .

3) There are many decision variables that need to be considered in selecting left-turn treatments, such as sight distance, number of opposing lanes, traffic volumes, delay and traffic accidents. Expert systems can help process the data and express procedures in understandable rules because the expert system can store past decisions as symbolic rules, search the symbolic rules and use these symbolic rules to assist the

engineer in making decisions.

2.3.3 THE EXPERT SYSTEM APPLICATION TO THE LEFT-TURN TREATMENTS

Only one previous study of the use of an expert system to select left-turn control treatments was done. Chang [1987] used TURBO PROLOG, PD PROLOG, and INSIGHT 1 programs to construct an expert system to select left-turn control strategies. He used six major decision variables in his expert system. The decision variables were derived from Upchurch's study as explained in section 2.1. They are common traffic input information: the left-turn demand, number of opposing through lanes, volume cross-product of the conflicting left-turn and through movement pairs, opposing travel speed, sight distance restrictions, and history of severe left-turn accidents. The factors used in his expert system were binary choices, such as: is the left-turn demand greater than or less than two per cycle; is the number of opposing lanes equal to two or three; is the opposing speed greater than or less than 45 mph; is the sight distance adequate or not; and is there a history of severe left-turn accidents.

To clarify the basic relationships among the outcomes of different data input, three different left-turn control treatments were combined with 15 different possible situations. In Table 2.1, the first horizontal row lists the options considered in this expert system (i.e., permissive phase, exclusive phase, and exclusive/permissive phase). The second horizontal row lists the 15 possible conditions ranging from Conditions “A”,”B”,”C” through “P” (refer to the second row in Table 2.1). In each column, X

Table 2.1 The Decision Table for Left-Turn Control Strategies

Left Turn Signal Treatments	Permissive						Exclusive				Phase				E/P
Conditions	**A**	**O**	**P**	**C**	**D**	**E**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**B**	**F**
Left turn Demand															
Demand > 2		x	x	x	x	x	x	x	x	x	x	x	x		x
Demand <= 2	x													x	
Opposing through Lanes															
Opposing Lanes = 2		x		x	x	x	x	x	x						x
Opposing Lanes = 3			x							x	x	x	x		
Volume Cross Product															
> 144,000				x	x	x									x
<= 144,000		x					x	x	x						
> 100,000													x		
<= 100,000			x							x	x	x			
Opposing Speed															
> 45				x			x			x					
<= 45		x	x		x	x		x	x		x	x			x
Sight Distance															
W/Restriction					x			x			x				
No Restriction		x	x			x			x			x			x
Severe Left Accident															
Could Be Corrected															
by Exclusive Phase						x			x			x		x	
Could Not Be Corrected															
by Exclusive Phase	x	x	x												x

Source: [Chang, 1987]

represents the requirements for fulfilling a certain decision criterion. For example, in Condition M under the exclusive phase, there are three Xs, one representing left-turn demand > 2 , the other standing for opposing lanes =3 and another the volume cross product > 100,000. The existence of these three conditions causes the exclusive left-turn phase treatment to be recommended.

2.3.4 WHAT'S NEW IN THE ITAGI & MULTIMEDIA LEFT-TURN CONTROL EXPERT SYSTEM?

The factors used by Chang were based on Upchurch's guidelines [1986] for the choice between permissive and protected left turn treatments. The intent of this study (the ITAGI system and multimedia left-turn control expert system) was to expand on Chang's expert system to include the choice of prohibiting left turns and to develop the ITAGI system as a multimedia expert system which makes the knowledge presentation more vivid and effective than the traditional plain text.

In addition, the binary choice used by Chang was improved by categorizing several variables into different levels according to real traffic conditions found in the City of Troy. All the knowledge was acquired from traffic experts by questionnaires, and an ID3 inductive tool was employed to develop the rules and facts for selecting the left-turn control treatments. The ID3 is a machine learning tool used to express the decision tree (or decision table) with the minimum nodes and links. The ID3 methodology will be explained in chapter 4.

CHAPTER 3 DEVELOPMENT OF THE INTERACTIVE TRAFFIC ACCIDENT GEOGRAPHIC INFORMATION SYSTEM

As outlined in chapter one, the ITAGI system has been integrated with the multimedia left-turn control expert system. With the push of a button, the user can switch between the ITAGI system and the multimedia left-turn control expert system. The ITAGI system was designed to provide the user quick access to the traffic characteristics database. This information, such as the number and type of accidents, link speed, level of service, and traffic volume are important variables used to determine the appropriate left-turn control strategy.

In this chapter, the ITAGI system and its application in Troy will be introduced. The multimedia left-turn control expert system will be presented in chapter 4. There are four components of the ITAGI system: The traffic characteristics database, the geographic information system, the route guidance system, and the accident quality control chart.

The traffic characteristics database provides the user with information on historical and current records of traffic accidents, volume, level of service at the intersections, and average speed on selected corridors. The user can access relevant data from the database by making selections from a menu.

The use of a geographic information system (GIS) will permit the user to select data for any specified location within the city. Via GIS, information on the types of traffic accidents at any specified intersections or midblocks (individual site or group of

locations) can be displayed.

At the request of the user, the route guidance system will search for and display the safest path through the network. The ITAGI system permits the user to input two desired points (origin and destination) and obtains a display of the safest path on the screen.

The quality control chart algorithm was used to identify the locations where the average accident rate was higher than the statistically defined level of confidence over the past six years (1989--1994). The Monte Carlo simulation method was used in this analysis. The use of this algorithm can be used to identify high accident locations for the Highway Safety Improvement Program (HSIP).

3.1 THE ITAGI SYSTEM TOOL

As described in the above section, the ITAGI system was designed as a tool to assist the decision maker (traffic engineer) in retrieving and analyzing traffic characteristic data in text or graphic format. It consists of computer programs used to analyze and display traffic characteristics. The entire ITAGI system and multimedia left-turn control expert system executable files are stored on a single CD. Upon entering the ITAGI program, a logo will appear showing the title and the authors of the program. After pushing the "**right arrow**" button, the main menu of the system will be displayed. From this menu, the user can choose a desired item, and go directly to that specific topic.

In the main menu, there are five selections: "**Introduction**", "**How to Use the Program**", "**Purpose of the Program**", "**Interactive Geographic Information**", and

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“**Left-Turn Control Expert System**”. The “**Introduction**” section explains the objectives behind the program development; the “**How to Use the Program**” item tells the user how to access and utilize the program; the “**Purpose of the Program**” illustrates the objectives of the program; the “**Interactive Geographic Information**” item brings the user to the ITAGI GIS system; the “**Left-Turn Control Expert System**” item brings the user directly to the multimedia left-turn control expert system. The components of the ITAGI system are depicted in Figure 3.1. A flow chart for each component of the ITAGI system is shown in Figures 3.2 through 3.5. Figure 3.2 shows the flow chart of the traffic characteristics database. Figure 3.3 shows the flow chart of the geographic information system. Figure 3.4 shows the flow chart of the route guidance system. Figure 3.5 shows the flow chart of the quality control algorithm. The details on the use of the multimedia left-turn control expert system are described in chapter 4. This chapter will introduce the ITAGI system.

3.2 TRAFFIC CHARACTERISTICS DATABASE

The design process of the traffic characteristics database included writing the PDC PROLOG program, then constructing and verifying all database files. The database files include traffic accidents for intersections and midblock locations for years 1989 through 1994; traffic turning movements for selected intersections (AM & PM peak); the level of service for selected intersections (AM & PM peak); average travel speed for selected corridors (AM peak, Off-peak, and PM peak); and traffic accident rates for intersection & midblock segments.

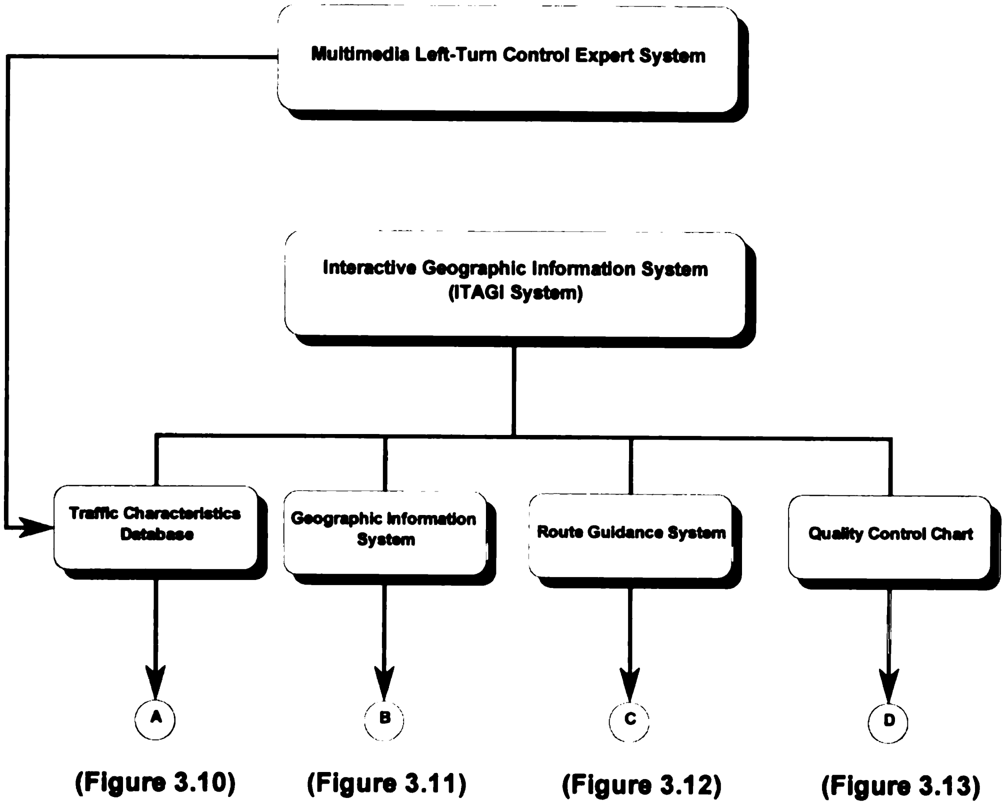

Figure 3.1 The Components of the ITAGI System

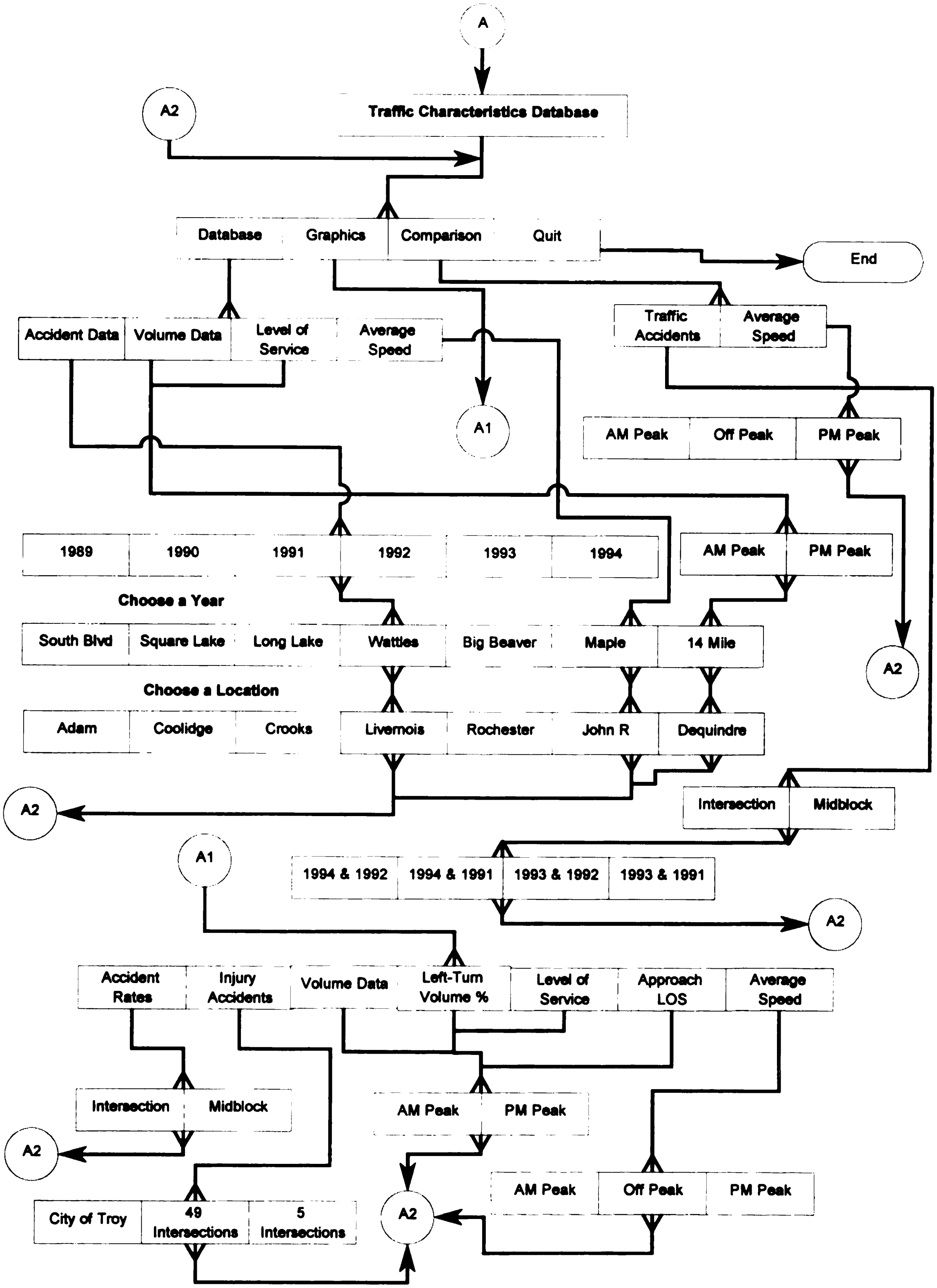

Figure 3.2 The Traffic Characteristics Database Flow Chart

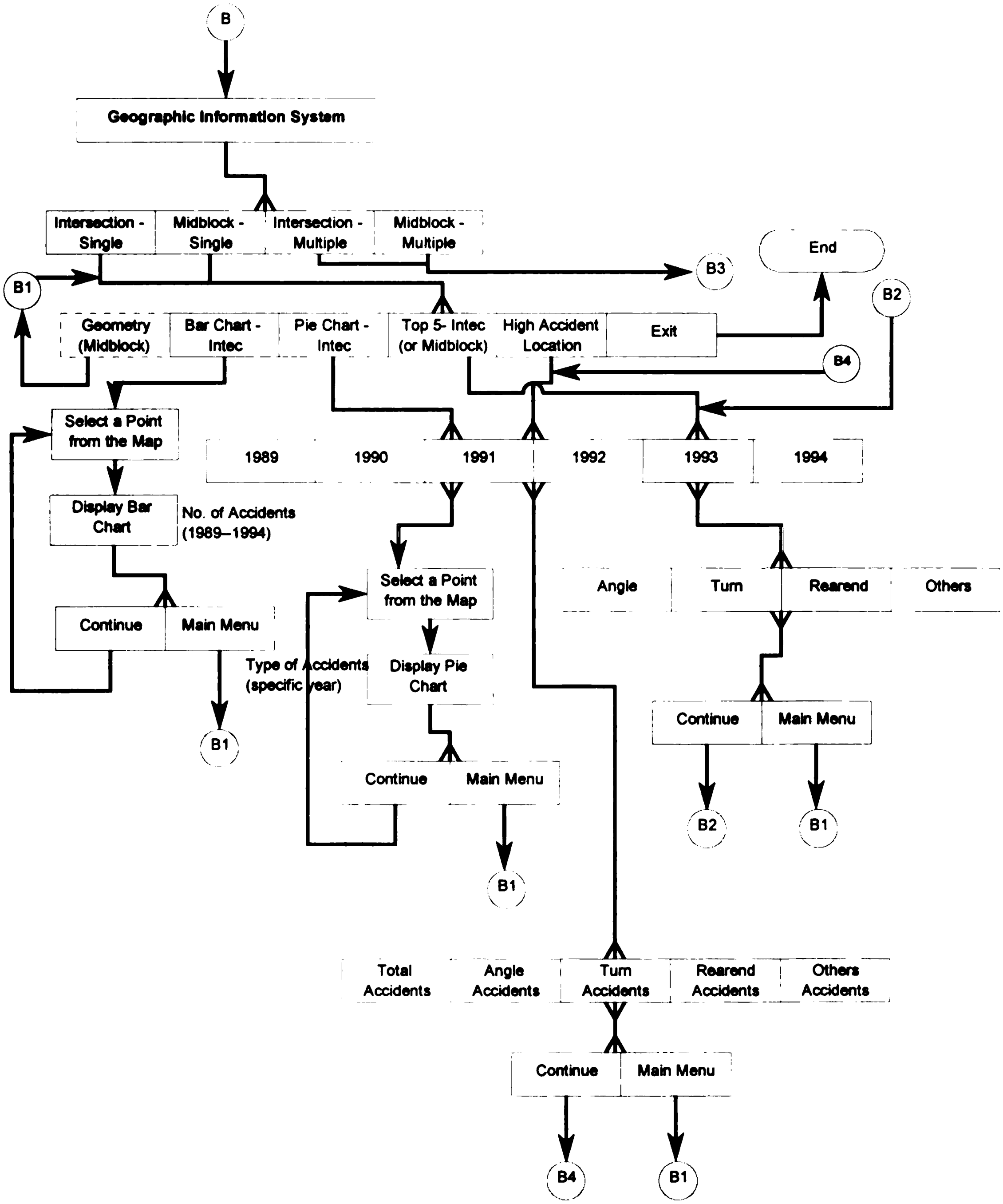

Figure 3.3 The Geographic Information System Flow Chart

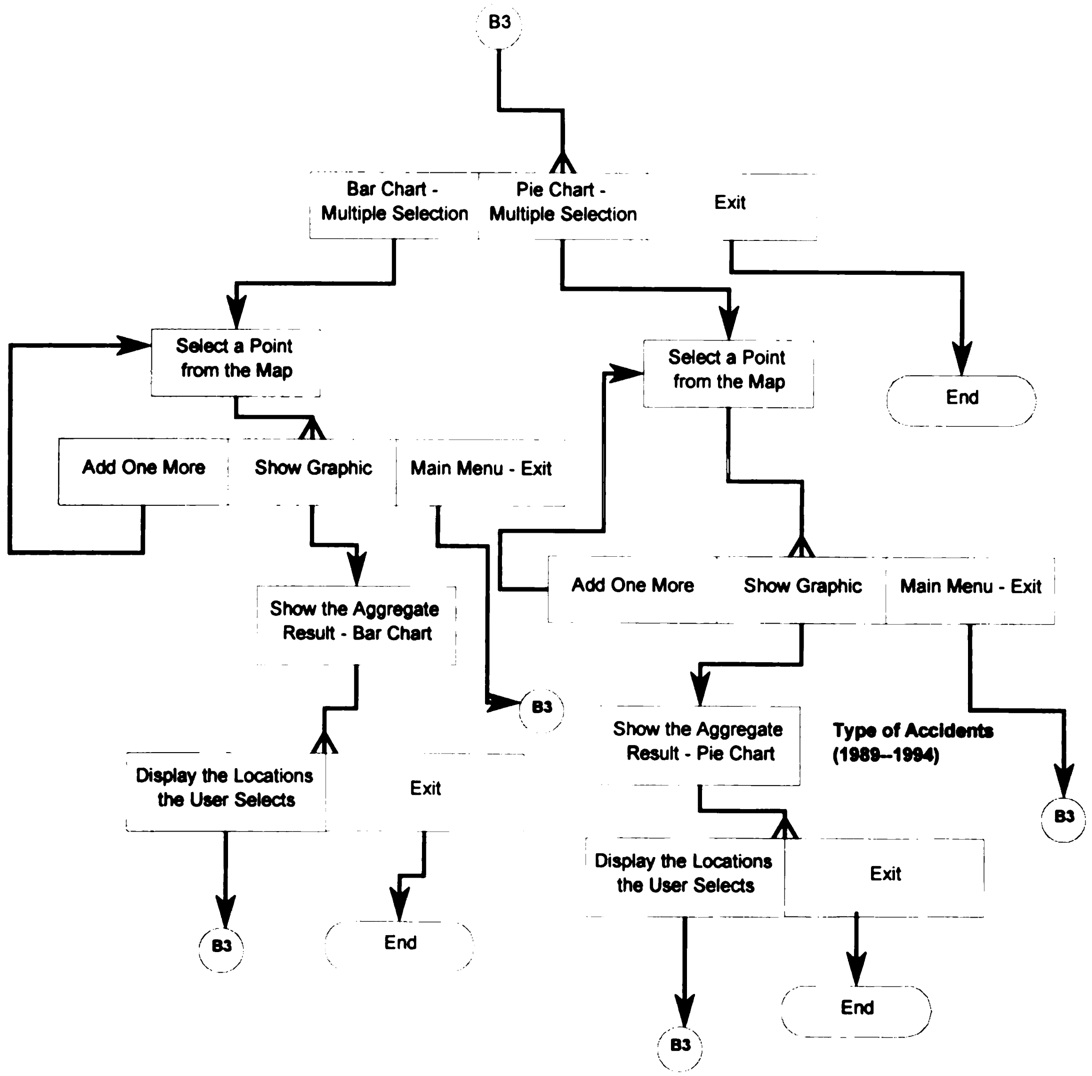

Figure 3.3 (cont'd)

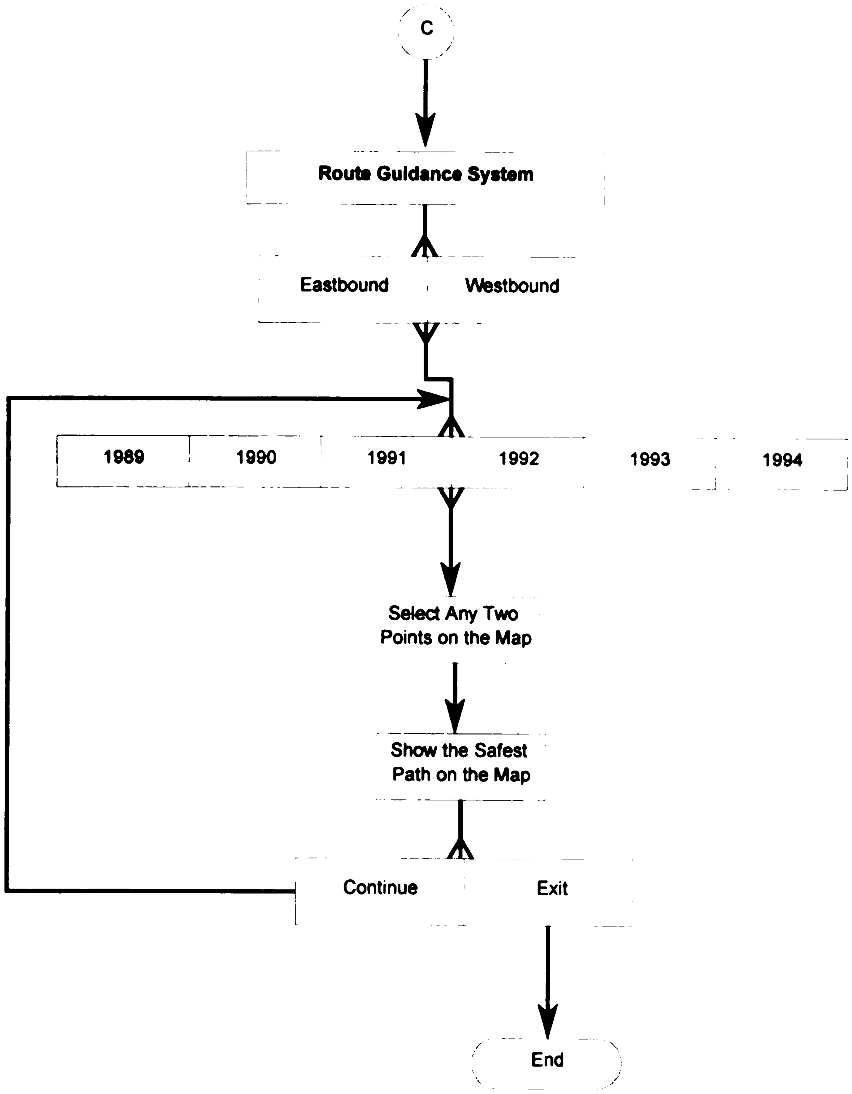

Figure 3.4 The Route Guidance System Flow Chart

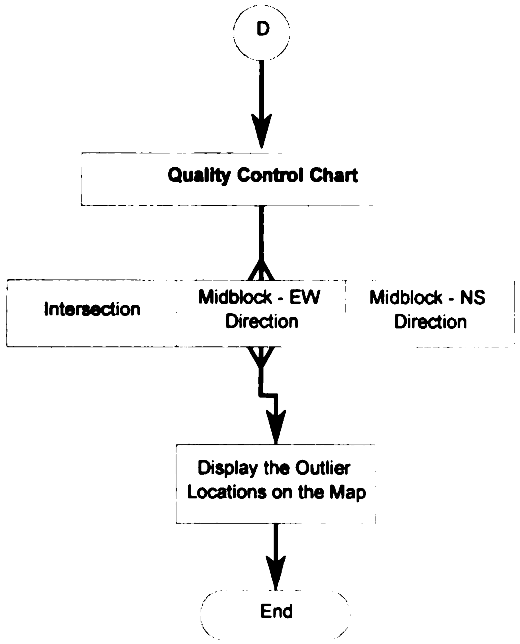

Figure 3.5 The Quality Control Flow Chart

3.2.1 TRAFFIC ACCIDENT DATABASE

The intersection accident database and the midblock accident database file names are listed in Table 3.1. The type and number of accidents were derived from the MDOT (Michigan Department of Transportation) master tape.

Table 3.1 The List of Intersection and Midblock Database File Names

Year	Intersection Database File	Midblock Database File
1989	acc89.dba	b89.dba
1990	acc90.dba	b90.dba
1991	acc91.dba	b91.dba
1992	acc92.dba	b92.dba
1993	acc93.dba	b93.dba
1994	acc94.dba	b94.dba

All directions and all types of traffic accidents are declared as an integer in the domain of the PDC PROLOG program. The definitions of angle, turn, rearend, and other traffic accidents as constructed from the Michigan State Police files are listed in Table 3.2.

When the "**Traffic Characteristics Database**" item is selected from the menu of the ITAGI system, a logo of the traffic characteristics database system will appear (see Figure 3.6), followed by an option menu. The user then selects the desired item from the menu (see Figure 3.7). After selecting the "**accident data**" item and the desired combination of attributes, the traffic accident output displays several items. They are the year of the data, the intersection selected and its ID number, and the number of angle, turn, rearend and other accidents. A map of the ID number for each intersection and

Table 3.2

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[illegible]
[illegible]

Source

Table 3.2 The Definition of Types of Traffic Accidents

Accident Type	Meaning	Angle	Turn	Rearend	Others
000	Miscellaneous Vehicle				X
010	Overturn				X
020	Hit Train				X
030	Hit Parked Vehicle				X
048	Backing				X
049	Parking				X
050	Pedestrian				X
060	Fixed Object				X
070	Other Object				X
080	Animal				X
090	Bicycle				X
141	Head-on				X
144	Angle Straight	X			
147	Rear-End			X	
244	Angle Turn		X		
342	Side Swipe Same				X
345	Rear End Left Turn		X		
346	Rear End Right Turn		X		
440	Other Drive				X
444	Angle Drive	X			
447	Rear-End Drive			X	
543	Side-Swipe Opposite				X
545	Head-On Left-Turn		X		
645	Dual Left-Turn		X		
646	Dual Right-Turn		X		

Source: MDOT Traffic Accident Tape Format

Figure

Traffic Characteristics Database

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Civil Engineering

Michigan State University

Dec. 13, 1994

Press any key to continue......

Figure 3.6 The Logo of Traffic Characteristics Database System

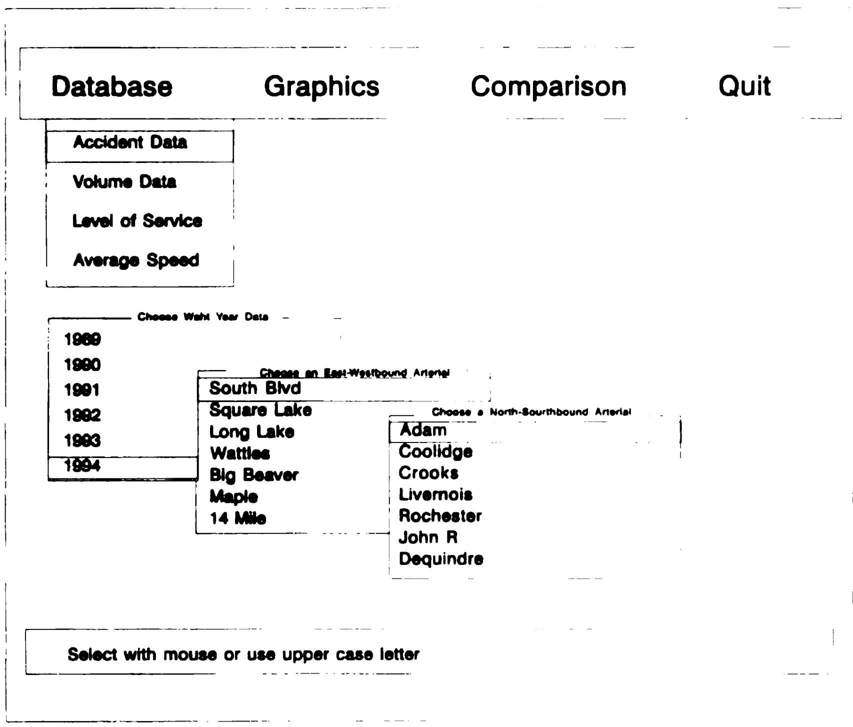

Figure 3.7 The Traffic Characteristics Database Menu Selection

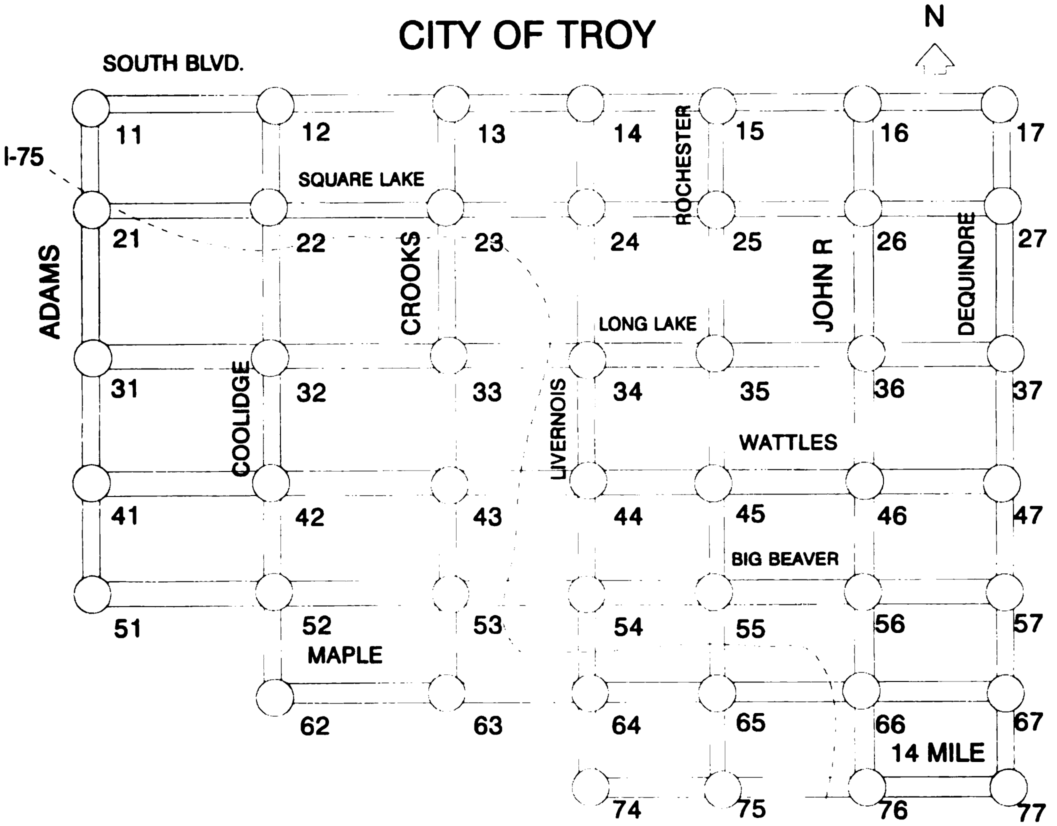

Figure 3.8 List of Intersection ID Numbers

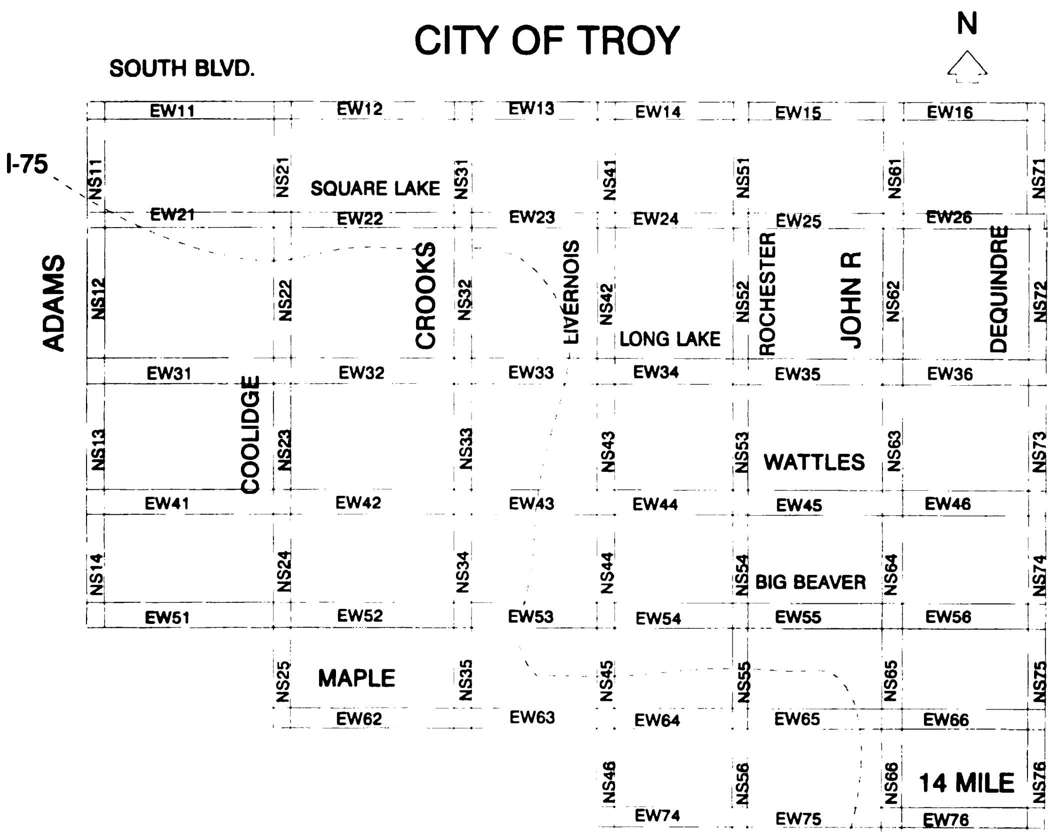

Figure 3.9 List of Midblock ID Numbers

midblock location is shown in Figure 3.8 (for each intersection) and Figure 3.9 (for each midblock location). The program automatically calculates the subtotal of each type of accident, and displays the total number of traffic accidents for a specific location and year.

3.2.2 TRAFFIC VOLUME DATABASE

The traffic turning movement database was constructed for each intersection in the City of Troy. The data were provided by Oakland County. When "**volume data**" is selected from the "**Traffic Characteristics Database**" item, and a specific intersection is selected, the traffic volume output displays several items. They are the ID number of the intersection, the name of the intersection, the year of the data, the time period of the data (AM peak or PM peak), total volume for all direction at the specified intersection, and the traffic volume and percentage of left-turn, through and right-turn movements in each direction.

3.2.3 LEVEL OF SERVICE DATABASE

When the "**level of service**" option is selected from the menu, and a specific intersection identified, the screen displays the ID number of the intersection, the name of the intersection, the year of the data (1989-1993), the time period of the data (AM peak or PM peak), overall level of service, overall delay (sec/veh), overall v/c, and level of service and v/c in each direction and for each movement (left-turn, through, and right-turn).

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The level of service data were derived from the Highway Capacity Software (HCS). Some of the intersections are not included in this database because of missing data. If one or more of the HCS input data items (geometry, volume, or timing plan) is missing or incomplete, the level of service can not be calculated by the HCS. The locations with missing data are listed in Table 3.3. Color codes are used to express different levels of service (LOS) at each intersection on the map. Both approach and intersection LOS can be displayed.

3.2.4 AVERAGE SPEED DATABASE

The average speed data were obtained from the average speed survey conducted by the research team from Michigan State University. When the "**average speed**" option is selected from the menu, the average speed database output shows several items. They are the ID number of the corridor, the name of the corridor, the year of the data (1993 except for the Big Beaver and Rochester corridors which are 1992 data), and the average speed and number of observations for each time period (AM peak, off peak, and PM peak). Only selected corridors are shown because the survey was limited to these locations.

3.2.5 THE TRAFFIC ACCIDENT RATE DATABASE

By combining the traffic accident database and the traffic volume database, the intersection (or midblock) accident rate can be calculated and displayed on the map. The definition of the intersection accident rate used in this study is:

Table 3.3 The List of Missing Data

Intersection Name (N-Sbound/E-Wbound)	Period of Time	Volume Data	Geometry Data	Timing Data
Adams/Big Beaver	16:00--18:00	x		
Coolidge/ Long Lake	16:00--18:00	x		
Coolidge//Big Beaver	16:00--18:00	x		
Coolidge/South Blvd.			x	x
Coolidge/Wattles	07:00--09:00	x		
Coolidge/Wattles	16:00--18:00	x		
Crooks/Big Beaver	16:00--18:00	x		
Crooks/Square Lake	16:00--18:00	x		
Crooks/Square Lake	07:00--09:00	x		
Dequindre/14 Mile			x	x
Dequindre/Big Beaver			x	x
Dequindre/Maple			x	x
Dequindre/Maple	07:00--09:00	x	x	x
Dequindre/South Blvd.	07:00--09:00	x		
Dequindre/Wattles	16:00--18:00	x		
John R/14 Mile			x	x
John R/Big Beaver	16:00--18:00	x		
John R/Square Lake				x
Livernois/Long Lake				x
Rochester/Big Beaver	16:00--18:00	x		x
Rochester/Long Lake	07:00--09:00	x		
Rochester/Long Lake	16:00--18:00	x		
Rochester/South Blvd.	07:00--09:00	x		
Rochester/Square Lake	07:00--09:00	x		
Stephenson/14 Mile			x	x
Stephenson/Rochester	16:00--18:00	x		
Troy Center/Big Beaver	16:00--18:00	x		
Troy Center/Big Beaver	07:00--09:00	x		

$$\textbf{ACC/MEV=}\ \frac{(annual \quad number \quad of \quad accidents \quad \times \quad 1000000)}{(annual \quad number \quad of \quad entering \quad vehicles)}$$

Where ACC/MEV: accidents per million vehicles entering the intersection

The definition of the midblock accident rate used in this study is:

$$\textbf{ACC/MVM=}\frac{(annual \quad number \quad of \quad accidents \quad \times \quad 1000000)}{(annual \quad vehicle-miles \quad of \quad travel)}$$

Where ACC/MVM: accidents per million vehicle-miles of travel

Note that the mileage in each road segment has been calculated and depicted on the map (see Figure 3.10 for details).

3.3 GEOGRAPHIC INFORMATION SYSTEM

The design process of the geographic information system involved developing a geographic information system which allows the user to select data from any specified location(s) from a map. There were three activities used to develop the geographic information system as shown in Figure 3.11.

The first was programming the computer to select any specified points(s) or location(s) on the map. Second, the PDC PROLOG was programmed to display these locations(s) on a map. Third, a method of summing the intersection(s) or midblock(s) traffic accidents for multiple locations was developed.

3.3.1 SINGLE INTERSECTION SELECTION

In this section, the program (**Map7.exe**) for single intersection selection will be

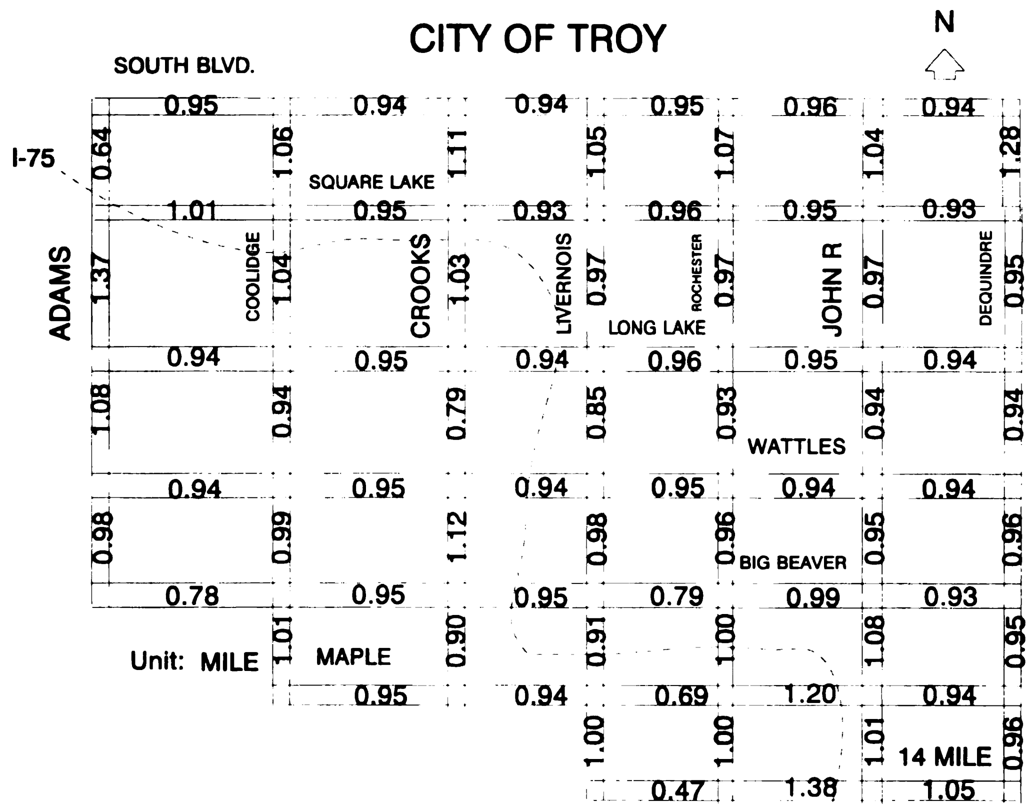

Figure 3.10 The Midblock Mileage List

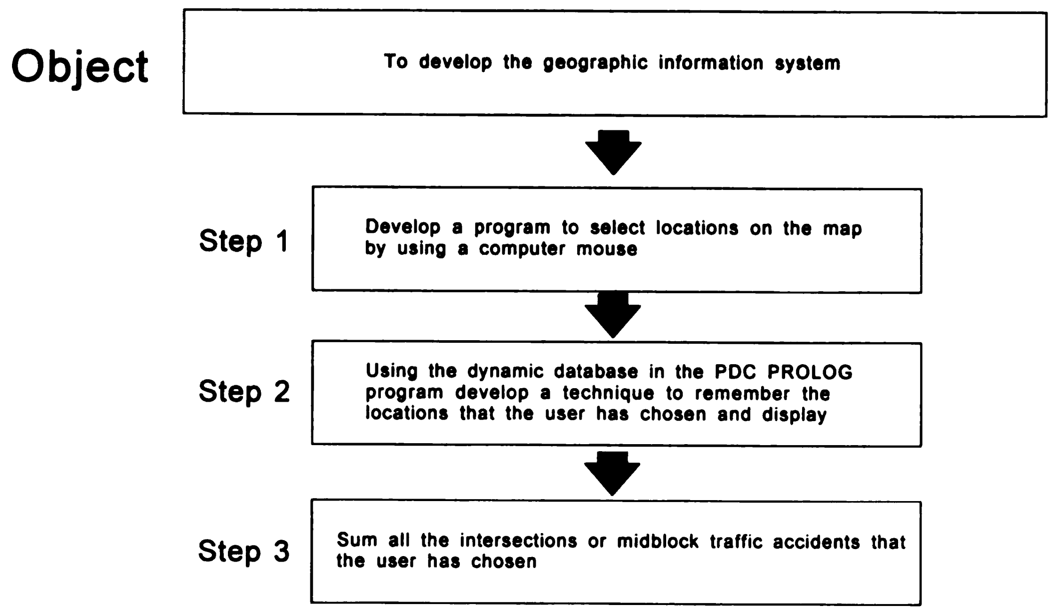

Figure 3.11 The Steps in Developing the Geographic Information System

introduced and explained. When the "**Single Intersection**" item is selected from the menu of the ITAGI system, there are five major selections available in this program. They are "**Bar Chart-Intersection**", "**Pie Chart-Intersection**", "**Top 5-Intersection**", "**High Accident Location-Intersection**", and "**Exit-Intersection**".

This first item in the menu is "**Bar Chart-Intersection**". When the user selects this item, a map of the City of Troy will appear and wait for the user to select an intersection. After the user selects an intersection, a bar chart showing the number of traffic accidents for the years 1989 to 1994 at the selected intersection will be displayed.

The second item in the menu is "**Pie Chart-Intersection**". When the user selects this item, a menu selection showing "**1989**", "**1990**", "**1991**", "**1992**", "**1993**", and "**1994**" will appear. After the user selects a year, a map of the City of Troy will be displayed. When the user selects an intersection, a pie chart will appear showing the percentage of accident types at the intersection.

The third item in the menu is "**Top 5-Intersection**". When the user selects this item, a menu selection showing "**1989**", "**1990**", "**1991**", "**1992**", "**1993**", and "**1994**" will appear. After the user selects a year, another menu selection showing "**Angle**", "**Turn**", "**Rearend**", and "**Others**" will appear. When the user selects the type of traffic accident, the five intersections with the highest frequency of the selected type of accident will appear on the map.

The fourth item in the menu is "**High Accident Locations-Intersection**". When the user selects this item, a menu selection showing "**1989**", "**1990**", "**1991**", "**1992**", "**1993**", and "**1994**" will appear. After the user selects a year, another menu selection

showing "**Total Accidents**", "**Angle Accidents**", "**Turn Accidents**", "**Rearend Accidents**", and "**Other Accidents**" will appear.

If the user chooses "**Total Accidents**", the screen will display the total traffic accidents at each intersection, stratified by three selected frequency levels. If the user chooses "**Angle Accidents**", "**Turn Accidents**", "**Rearend Accidents**", or "**Other Accidents**", the screen will display the data for the selected accident type.

The fifth item in the menu is "**Exit-Intersection**". The user can exit the program by selecting this item.

3.3.2 MULTIPLE INTERSECTION SELECTION

In the above section, a program called **Map7.exe** used to analyze a single intersection was introduced and explained. If the user wants to analyze a set of several intersections, a program called **Map77.exe** was designed for this purpose.

This type of analysis can be performed using the PDC PROLOG dynamic database function. With PDC PROLOG, dynamic databases are stored entirely in the computer's memory. Special standard predicates are used to add new facts to the database or remove facts from the database: asserta(fact), assertz(fact), and retract(fact). The asserta(fact) predicate inserts facts at the beginning of a database, while the assertz(fact) inserts facts into the end of the database. The entire dynamic database in the PDC PROLOG can be viewed as a push-down stack and the new fact can be placed either on the top of the database or at the end of the database depending on what the user needs. This function is an important feature for developing the expert system. Since the rules and ha

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and facts stored in the computer memory can be retracted or added as the rules and facts are obsolete or new rules are learned from the traffic experts. In the **Map77.exe** program, the dynamic database function in the PDC PROLOG program was used to memorize the locations that the user has chosen, and to make the corresponding calculation.

When the "**Multiple Intersections**" item is selected from the menu of the ITAGI system, a menu will show three items to be selected: "**Bar Chart-Multiple Intersection**", "**Pie Chart-Multiple Intersection**", and "**Exit-Multiple Intersection**".

If the user chooses the "**Bar Chart-Multiple Intersection**", a map of the City of Troy will appear and wait for the user to select an intersection. After the user selects a location from the map, the next menu will display three items: "**Add One More**", "**Show Graphic**", and "**Main Menu-Exit**". If the user wants the computer to display the bar chart of the current selected intersection, the "**Show Graphic**" item is selected from the menu. If the user wants to add one more intersection and analyze the sum of the accidents at the first two selected intersections, the user selects the "**Add One More**" menu item. Note that this program has a special feature to prevent the user from selecting the same intersection twice. For example, if the user initially chooses the Adams/Long Lake intersection, this intersection will be displayed in red to indicate that this intersection is already in the selected data set. The user can continually select intersections until the computer memory is exhausted.

The same operating procedure applies for the "**Pie Chart-Multiple Intersection**". The "**Pie Chart-Multiple Intersection**" item can display six years of pie charts of the types and percentage of accidents. The user can choose as many locations as desired until the computer memory is exhausted.

The third item in the menu is "**Exit-Multiple Intersection**". The user can exit the program by selecting this item.

3.3.3 SINGLE MIDBLOCK SELECTION

In the above section, two programs called **Map7.exe** and **Map77.exe** used to analyze a single intersection or multiple intersections were introduced and explained. If the user wants to analyze a singe midblock location, the program called **Map71.exe** was designed for this purpose. When the "**Single Midblock**" item is selected from the menu, there are six major selections available. They are "**Geometry-Midblock**", "**Bar Chart-Midblock**", "**Pie Chart-Midblock**", "**Top 5 - Midblock**", "**High Accident Locations-Midblock**", and "**Exit-Midblock**".

The first item in the menu is "**Geometry-Midblock**". When the user selects this item, a map of the City of Troy showing the number of traffic lanes on each road segment will appear. On the map, color codes are used to express different numbers of traffic lanes. This can be used to study the relationship between the number of traffic accidents and the number of traffic lanes.

The second item in the menu is "**Bar Chart-Midblock**". Again, like the "**Bar Chart-Intersection**" selection described in the preceding section, when the user selects this item, a map of the City of Troy will appear and wait for the user to specify a midblock location on the map. After the user chooses a midblock location, a bar chart showing the number of traffic accidents over the past 6 years (1989-1994) will be displayed. Note that the midblock number is the ID number which was shown in Figure 3.9.

The third item in the menu is "**Pie Chart-Midblock**". When the user selects this item, a menu selection showing "**1989**", "**1990**", "**1991**", "**1992**", "**1993**", and "**1994**" will appear. After the user selects a year, a map of the City of Troy will appear and wait for the user to specify a location. The pie chart will then display the types of accidents and the percentage of accidents (by type) at the specific midblock location.

The fourth item in the menu is "**Top 5-Midblock**". When the user selects this item, a menu selection will display "**1989**", "**1990**", "**1991**", "**1992**", "**1993**", and "**1994**". After the user selects a year, another menu selection showing "**Angle**", "**Turn**", "**Rearend**", and "**Others**" will appear. Again, after the user selects the type of traffic accident, a map showing the top five midblock accident locations will appear.

The fifth item in the menu is "**High Accident Locations-Midblock**". When the user selects this item, a menu selection showing "**1989**", "**1990**", "**1991**", "**1992**", "**1993**", and "**1994**" will appear. After the user selects a year, another menu selection showing "**Total Accidents**", "**Angle Accidents**", "**Turn Accidents**", "**Rearend Accidents**", and "**Other Accidents**" will appear.

If the user selects "**Total Accidents**", the screen will show the specific year and total midblock accidents broken down into three pre-selected categories. If the user selects "**Angle Accidents**", "**Turn Accidents**", "**Rearend Accidents**", or "**Other Accidents**", it will show the selected accident type in the specific year.

The sixth (last) item in the menu is "**Exit-Midblock**". The user can exit the program by selecting this item.

3.3.4 MULTIPLE MIDBLOCK SELECTION

As described under the section on intersections, it is often desirable for the user to analyze multiple midblock locations. The ITAGI system provides a mechanism for conducting this type of analysis.

When the "**Multiple Midblock**" item is selected from the menu of the ITAGI system, there are three major selections available. They are "**Bar Chart-Multiple Midblock**", "**Pie Chart-Multiple Midblock**", "**Exit-Multiple Midblock**".

If the user chooses the "**Bar Chart-Multiple Midblock**" item, a map of the City of Troy will appear and wait for the user to select a location. After the user selects a midblock location from the map, the next menu will display three items: "**Add One More**", "**Show Graphic**", and "**Main Menu-Exit**". If the user wants the computer to display an accident bar chart of the current selected midblock, they can select the "**Show Graphic**" item from the menu. If the user wants to add one more location and look at the sum of the traffic accidents of the first two selected midblock locations, the user selects "**Add One More**" item. The user can continually select midblock locations until running out of computer memory. The midblock locations that have been chosen will be displayed on the map.

The same operating procedure is used for the "**Pie Chart-Multiple Midblock**" selection. The "**Pie Chart-Multiple Midblock**" can display six years of pie charts of the type of accident and accident percentage.

The user can click the "**Exit-Multiple Midblock**" item from the menu to exit the **Map777.exe** program.

3.4 ROUTE GUIDANCE SYSTEM

As an example of an Advanced Traveler Information System (ATIS), the route guidance system in the ITAGI system was programmed to select the safest path. In the federal demonstration project in Troy, the Ali-Scout system has been selected to provide the road user with the shortest travel time route. The ITAGI system could be designed as a dynamic route guidance system like Ali-Scout if the travel time on all arterials were available in a real time. The ITAGI system offers the ability to search for the safest (shortest) path through the network. It provides a convenient device for the user to input two desired points (origin and destination), by simply selecting two desired points on the map, and the user can immediately obtain the safest (shortest) path.

In this section, the design process, the safest path probability theory and the two programs (**Shortew2.exe** and **Shortwe2.exe**) are explained and demonstrated. With these two programs, the safest (shortest) path between any two specified points can be found.

The route guidance system was designed so the user can input the origin and destination and obtain the safest (shortest) path displayed on a map. There were three activities required to develop the route guidance system as shown in Figure 3.12.

The first task was collecting the intersection (accident rate) data from the database for each intersection. Second, a distance (traffic accident rate) database file which contained the traffic accident rate between nodes was constructed. Third, a PDC

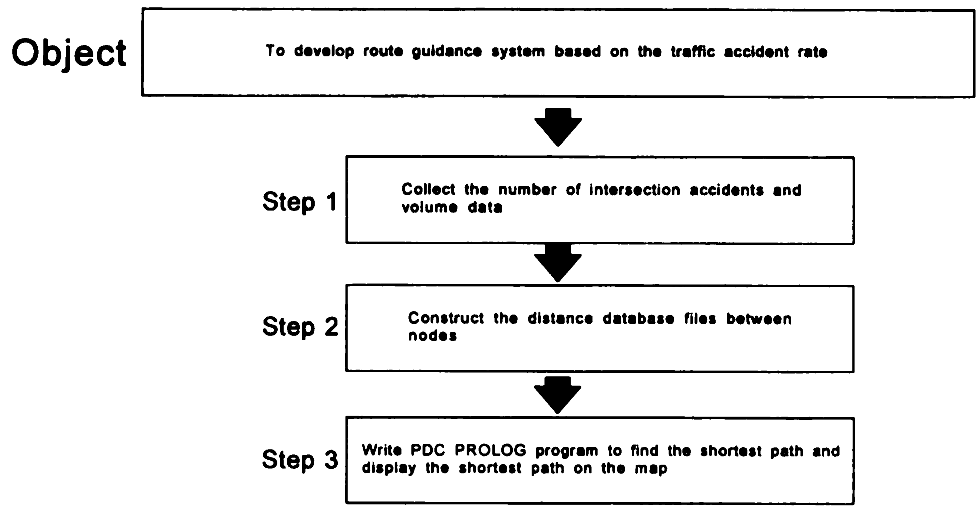

Figure 3.12 The Steps in Developing the Route Guidance System

PROLOG program was written to find the safest (shortest) path and display the path on the map.

3.4.1 SAFEST PATH PROBABILITY THEORY

If $P_{i,j}$ denotes the probability of an accident happening when traveling from node *i* to node j, then $1-P_{i,j}$ represents the probability of not having an accident which traveling from node *i* to node j. Assume at each link, the probability of an accident happening is independent. Then the probability of an accident happening along the path from node *i* to node z is:

$$1-[(1-P_{i,j})(1-P_{j,k})(1-P_{k,l})\ldots\ldots(1-P_{x,y})(1-P_{y,z})]$$

$$= 1-[1-(P_{i,j}+P_{j,k}+P_{k,l}+\ldots\ldots P_{y,z}) + (P_{i,j}P_{j,k}+P_{j,k}P_{k,l}+P_{i,j}+P_{k,l}+\ldots\ldots+P_{x,y}P_{y,z})$$

$$-(P_{i,j}P_{j,k}P_{k,l}\ldots\ldots\ldots\ldots P_{x,y}P_{y,z})]$$

$$\because\ (P_{i,j}P_{j,k}+P_{j,k}P_{k,l}+P_{i,j}+P_{k,l}+\ldots\ldots+P_{x,y}P_{y,z}) \cong 0 \text{ and } (P_{i,j}P_{j,k}P_{k,l}\ldots\ldots\ldots\ldots P_{x,y}P_{y,z}) \cong 0$$

$$\cong 1-[1-(P_{i,j}+P_{j,k}+P_{k,l}+\ldots\ldots\ldots+P_{y,z})]$$

$$= P_{i,j}+P_{j,k}+P_{k,l}+\ldots\ldots\ldots\ldots\ldots+P_{y,z}$$

Therefore, the cost from node *i* to node z can be defined as

$$P_{i,j}+P_{j,k}+P_{k,l}+\ldots\ldots\ldots\ldots\ldots+P_{y,z}$$

The cost is enlarged 1,000,000 times for analysis convenience

as : $1{,}000{,}000\,(P_{i,j}+P_{j,k}+P_{k,l}+\ldots\ldots\ldots\ldots\ldots+P_{y,z})$

Therefore, the final cost from node *i* to node z can be defined as:

$$1{,}000{,}000\,(P_{i,j}+P_{j,k}+P_{k,l}+\ldots\ldots\ldots\ldots\ldots+P_{y,z})$$

which is equal to $(R_{i,j}+R_{j,k}+\ldots\ldots\ldots\ldots+R_{y,z})$

where $R_{\alpha,\beta}$ is the accident rate per million vehicles from node α to node β

Therefore, from the probability standpoint, the cost should be defined as an accident rate between two nodes. To demonstrate this program, the route that minimizes the probability of vehicle collisions will be found and displayed using the accident rate between two nodes (intersections) as a measure of distance or cost from node (intersection) A to node (intersection) B.

3.4.2 DEMONSTRATION OF THE USE OF THE SAFEST PATH PROGRAM

There are two programs for the safest path: one is for the safest path from east to west (from north to south or from south to north included) called **Shortew2.exe**, while the other is for the safest path from west to east (from north to south or from south to north included) called **Shortwe2.exe**. When the "**Eastbound**" or "**Westbound**" item is selected from the menu of the ITAGI system, a map of the City of Troy will appear. The user then specifies any two points on the map. Note that the input direction must follow from east(origin) to west (destination) in the **Shortew2.exe** program, and from west (origin) to east (destination) in the **Shortwe2.exe** program. A mistake in specifying an origin and a destination will cause the program to fail.

3.5 QUALITY CONTROL CHARTS FOR TRAFFIC ACCIDENTS

The purpose of using the quality control chart in this study is to determine the high accident locations and road segments (outliers) necessary for a Highway Safety Improvement Program (HSIP) based on accident rates and changes in accident rates.

Safety improvement programs require an effective means for identifying hazardous or potentially hazardous intersection or midblock locations. Hazardous locations are those at which accidents happened at an abnormal rate when compared with similar locations elsewhere. The accident rate is a good index to use in quality control analyses because the traffic volumes are already taken into account in this measure. In this study, a statistical method known as the Monte Carlo method was used to decide the critical high accident locations.

The four activities used to develop the quality control chart of traffic accidents is shown in Figure 3.13.

First, the traffic accident rate data was obtained from the traffic accident database and geographic information system for intersections and midblock locations. Second, the MATHEMATICA program was used to perform the Monte Carlo simulation for 1000 iterations to get the 1000th sample. Third, the top five high accident locations were embedded in the PDC PROLOG program. The final step was developing a program to display the intersection and midblock quality control charts.

3.5.1 DEFINITION OF QUALITY CONTROL

According to the Branverman [1981] definition, quality control is that set of function and activities whose purpose is to assure the achievement of established standards of quality. These functions and activities can involve both qualitative and quantitative factors. In the ITAGI system, the traffic accident rate is a quantitative factor. Therefore, the scope of this study is quality control using a quantitative measurement.

The primary objective of process quality control is to achieve and maintain an

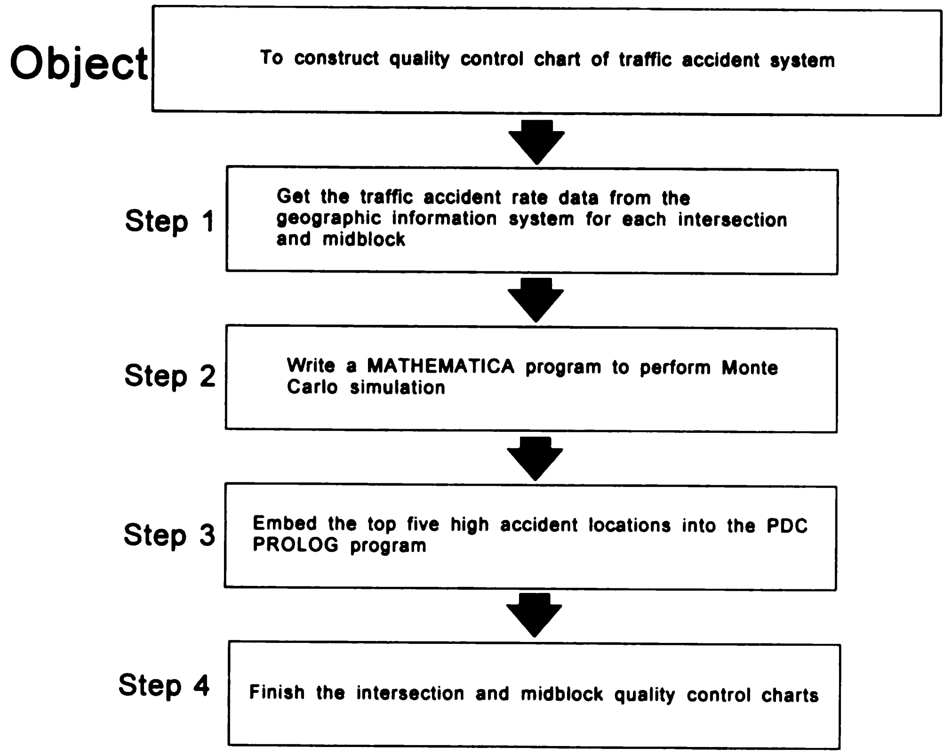

Figure 3.13 The Steps in Developing the Quality Control Chart of Traffic Accident system

acceptable and stable level of some process quality parameter. The principal statistical tool used for this purpose is the control chart. A control chart is simply a graph designed to present information. This information is obtained from a series of samples, called subgroups, drawn periodically from the process output.

A control chart is simply a device for testing a hypothesis about the state of a process on a continuing basis. There are two hypotheses displayed on a quality control chart, the null hypothesis is that the process is in control. The alternative hypothesis is that the process is out of control. The control limit can not be calculated directly by the traditional quality control method because the intersections selected for accident analysis will not be randomly selected (do not meet the requirement of the Central Limit Theory). In addition, each intersection has its own distribution over the six year time period. Therefore, it is not reasonable to treat the 45 intersections as if they were random samples drawn from the same population. Instead, the Monte Carlo simulation algorithm was used to construct the top 5 accident locations.

3.5.2 MONTE CARLO ALGORITHM

In statistical data analysis, the classical approach requires a strict distributional assumption. If this distributional assumptions can not be met, the classical analysis can not be performed. Modern electronic computation has enabled the analyst to use other statistical methods, such as the Monte Carlo algorithm, that require fewer assumptions than their predecessors (classical statistics), and can be applied to more complicated statistical estimators. Monte Carlo sampling is very straightforward, yet it provides

sampling distributions for a given parameter. Monte Carlo sampling does require a population distribution. One knows the population distribution so it is easy to simulate sampling from it.

In building the $\bar{x}$ quality control chart, the six year average accident rates at each intersection $(\bar{x}_1, \bar{x}_2, \bar{x}_3, \ldots\ldots\ldots \bar{x}_{45})$ were not treated as random samples (variables) drawn from the same population. Each individual intersection was assumed to have its own distribution(Poisson distribution). Therefore, the critical accident locations were formed by using the Monte Carlo algorithm rather than the traditional statistics method. The critical accident locations were determined by the following steps:

Step 1:

Combining accident counts and traffic volumes over six years (1989--1994) for each intersection produced observed accident counts n(i), traffic volumes v(i), and accident rates r(i) for intersections, i =1,2,...45.

Step 2:

Ranking intersections according to accident rates. The accident rate r(i) obtained from the traffic volumes v(i) and observed accident counts n(i) for intersections i=1,2,,.....45 were ranked from 1(highest) to 45(lowest).

Step 3:

For each intersection i independently, generate a random sample n*(i) from the Poisson distribution having mean n(i). Using these n(i) and v(i) re-rank intersections according to accident rates, obtaining ranks*(i) for intersections, i=1,2,....45.

Step 4:

Repeat **step 1** to **step 3** 1000 times.

Step 5:

Find the top 5 intersections from 1000 rank*(i) observations.

The major purpose of performing the above steps is to see if the intersections ranked in the top five are due to "chance". That is to see if rank*(i) varies with "replication". After performing the Monte Carlo simulation through 1000 iterations, those intersections ranking in the top five are assumed to be high accident locations. To perform the above procedures, the MATHEMATICA program was employed. The result is shown in Table 3.4. The location of the top five high accident intersections is shown in Figure 3.14. These results were then built into the PDC PROLOG program as the top 5 critical accident locations for intersection traffic accidents. Steps 1 to 5 were repeated to get the top 5 critical midblock traffic accident locations. The result is shown in Table 3.5. The top five midblock locations are shown in Figure 3.15.

3.6 THE ITAGI SYSTEM USED IN THE CITY OF TROY

The ITAGI system was designed as a tool to graphically display the current traffic characteristics data and to be used in the evaluation of new traffic control systems. In this study, two such systems changes was evaluated. The first was the implementation of SCATS, and the second was the change in the left-turn control strategy from permissive to protected, or from protected to prohibited, implemented at specific locations in the City of Troy. Several examples are provided to compare before-and-after data where these

Table 3.4 A Comparison between Original Rank(i) and Monte Carlo Rank*(i) (Intersection Locations)

Intersec. ID No.	Rank(i) 6-year average	Rank*(i)	95% CI for Rank*(i)
55	1	1	[1,2]
36	2	2	[1,5]
66	3	3	[2,6]
45	4	4	[2,6]
35	5	5	[2,6]
34	6	6	[3,7]
53	7	9	[6,11]
46	8	10	[7,15]
63	9	7	[7,13]
24	10	12	[7,16]
56	11	16	[8,16]
44	12	11	[9,21]
65	13	22	[10,21]
37	14	15	[10,23]
43	15	17	[10,23]
67	16	13	[10,22]
15	17	14	[10,24]
17	18	8	[9,26]
25	19	20	[12,24]
62	20	19	[12,25]
64	21	18	[14,24]
51	22	27	[14,27]
26	23	23	[14,28]
77	24	25	[17,28]
42	25	21	[18,31]
54	26	26	[22,29]
21	27	24	[21,35]
76	28	28	[24,33]
52	29	31	[27,35]
47	30	33	[26,36]
32	31	30	[26,37]
23	32	35	[27,38]
12	33	29	[24,39]
33	34	37	[28,38]
16	35	32	[26,39]
22	36	34	[27,39]
57	37	36	[31,38]
27	38	38	[31,40]
31	39	41	[36,41]
14	40	39	[36,41]
13	41	40	[40,42]
11	42	42	[41,43]
41	43	43	[42,44]
74	44	44	[43,44]
75	45	45	[45,45]

Note: Monte Carlo Rank*(i) was derived from the Mathematica simulation results (1000 iterations)
1=highest accident rate; 45=lowest accident rate

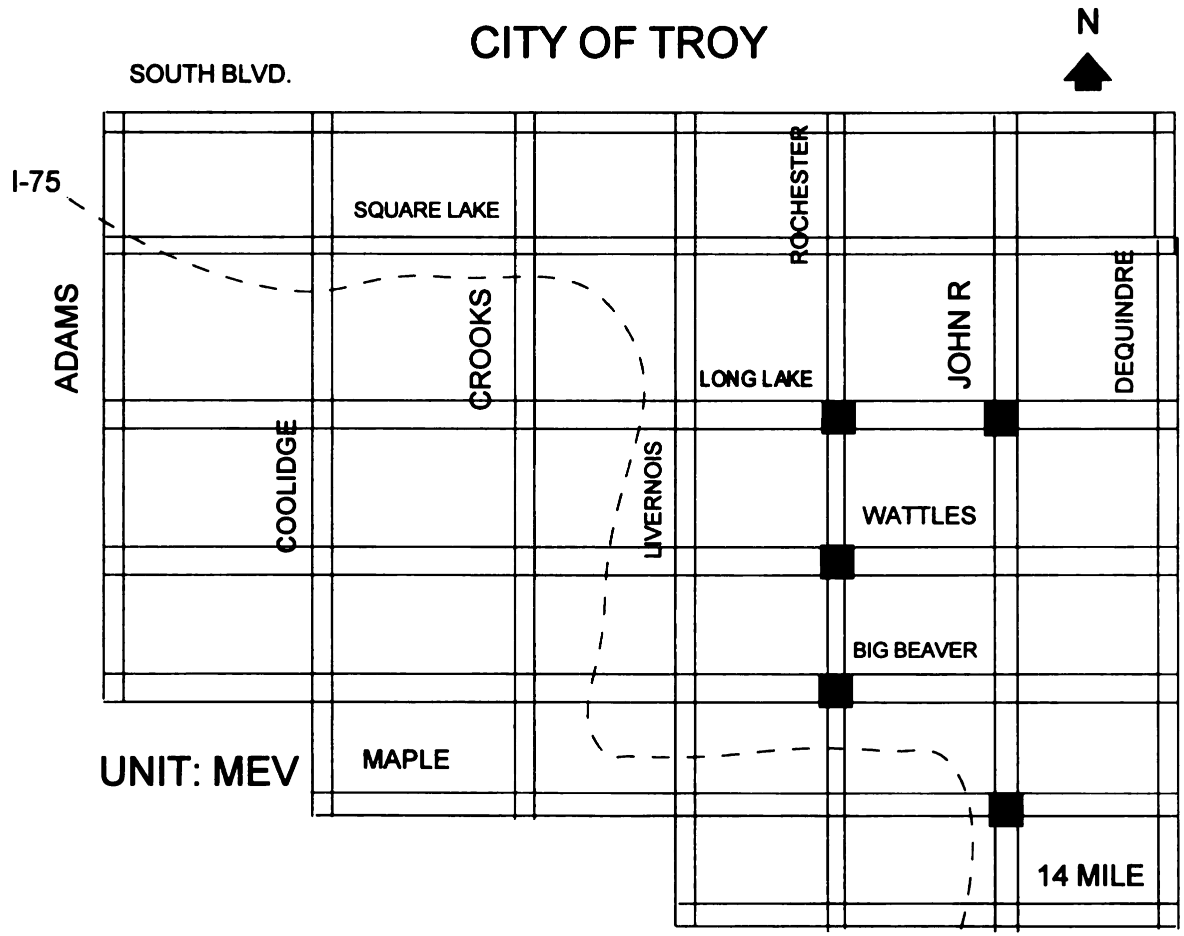

Figure 3.14 The Top Five High Intersection Accident Rate Areas

Table 3.5 A Comparison between Original Rank(i) and Monte Carlo Rank*(i) (Midblock Locations)

Midblock ID No.	Rank(i) 6-year average	Rank*(i)	95% CI for Rank*(i)
NS55	1	1	[1,1]
EW53	2	3	[3,3]
NS54	3	4	[4,4]
EW75	4	2	[2,2]
EW52	5	5	[5,8]
NS35	6	7	[6,10]
NS66	7	9	[7,10]
NS32	8	8	[5,10]
EW65	9	6	[5,8]
NS45	10	12	[10,14]
EW51	11	14	[12,22]
EW54	12	15	[13,22]
EW33	13	10	[10,16]
NS63	14	16	[11,21]
EW62	15	18	[13,24]
EW64	16	44	[33,44]
EW34	17	19	[14,31]
EW36	18	24	[16,32]
NS53	19	21	[19,31]
EW63	20	23	[19,32]
EW32	21	22	[17,33]
EW35	22	34	[19,35]
EW55	23	30	[20,32]
NS64	24	28	[20,36]
NS76	25	13	[13,26]
NS62	26	26	[21,37]
NS65	27	25	[18,33]
NS44	28	27	[14,30]
NS41	29	29	[20,38]
NS43	30	31	[30,44]
NS42	31	39	[25,41]
EW23	32	33	[25,44]
NS56	33	20	[12,26]
NS34	34	35	[32,45]
EW41	35	32	[21,49]
NS22	36	11	[5,12]
EW76	37	50	[42,52]
NS25	38	41	[33,46]

Note: Monte Carlo Rank*(i) was derived from the Mathematica simulation results (1000 iterations)
1=highest accident rate; 45=lowest accident rate

Table 3.5 (cont'd)

Midblock ID No.	Rank(I) 6-year average	Rank*(I)	95% CI for Rank*(I)
NS61	39	17	[11,28]
EW56	40	49	[49,57]
EW24	41	40	[33,54]
NS52	42	36	[35,46]
EW31	43	45	[37,55]
EW43	44	51	[36,55]
EW44	45	52	[34,52]
NS51	46	38	[[35,47]
EW66	47	47	[41,53]
EW46	48	48	[42,57]
EW45	49	53	[39,55]
NS31	50	37	[23,39]
NS75	51	46	[46,56]
EW42	52	43	[36,56]
NS11	53	56	[56,67]
NS24	54	54	[43,56]
EW25	55	42	[38,57]
NS46	56	58	[49,59]
NS72	57	55	[50,60]
EW26	58	57	[50,66]
EW16	59	65	[55,67]
EW21	60	67	[51,67]
EW11	61	60	[52,68]
NS74	62	61	[57,64]
EW13	63	59	[56,70]
NS23	64	68	[[58,69]
NS14	65	64	[60,70]
NS21	66	69	[58,74]
NS73	67	70	[64,72]
EW22	68	63	[61,74]
NS33	69	73	[68,75]
NS71	70	66	[60,70]
EW15	71	71	[66,75]
NS13	72	62	[65,74]
EW14	73	74	[[67,75]
EW12	74	75	[69,75]
NS12	75	72	[67,75]
EW74	76	76	[76,76]

Note: Monte Carlo Rank*(i) was derived from the Mathematica simulation results (1000 iterations)
1=highest accident rate; 45=lowest accident rate

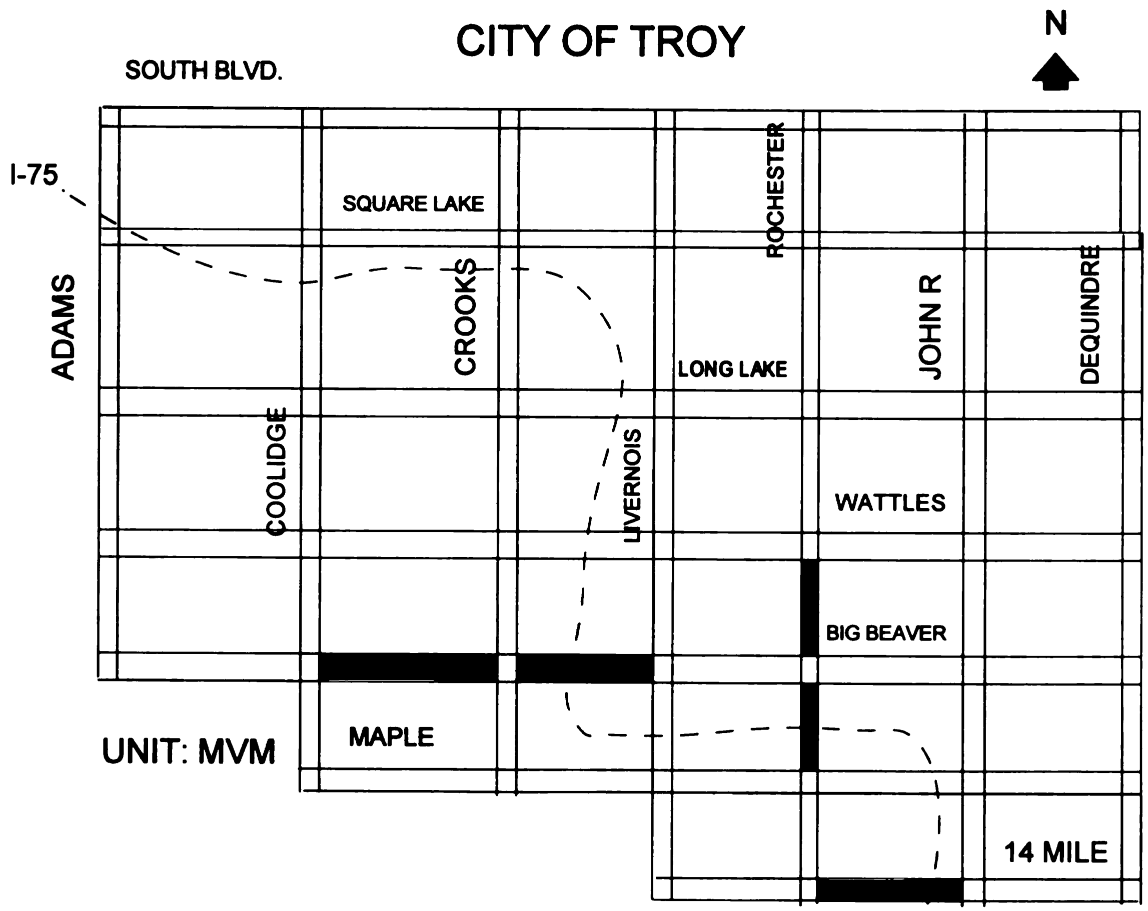

Figure 3.15 The Top Five High Midblock Accident Rate Areas

system changes were implemented. The data analyses include the aggregate decrease or increase in the total number of accidents, and the percentage of type of accidents. Statistical tests were conducted externally to determine if the expected number of accidents were different than the actual number of accidents after implementing SCATS or a new left-turn control strategy.

3.6.1 THE CURRENT AND HISTORICAL TRAFFIC CHARACTERISTICS DATA DISPLAY

As described in a previous section, the current and historical traffic characteristics data can be displayed to the decision maker (traffic engineer) in text or graphic format (such as bar chart or pie chart). In addition, by identifying high, middle and low accident locations, the ITAGI system can assist the analyst in identifying roadway deficiencies or areas needing improvement. To demonstrate the use of the ITAGI system, selected examples using each component were conducted.

3.6.2 TRAFFIC VOLUME DISPLAY

With the ITAGI system, the traffic volumes at intersections can be presented on a map. Figure 3.16 and Figure 3.17 show the total traffic volumes at intersections for AM peak and PM peak hours, respectively. From these two graphics, it is clear that during peak hours, Big Beaver and Maple, and John R Road near I-75 have high traffic volumes, while Adams Road has a lower traffic volume than the other roads in the city. This information can be used to identify links with unused capacity.

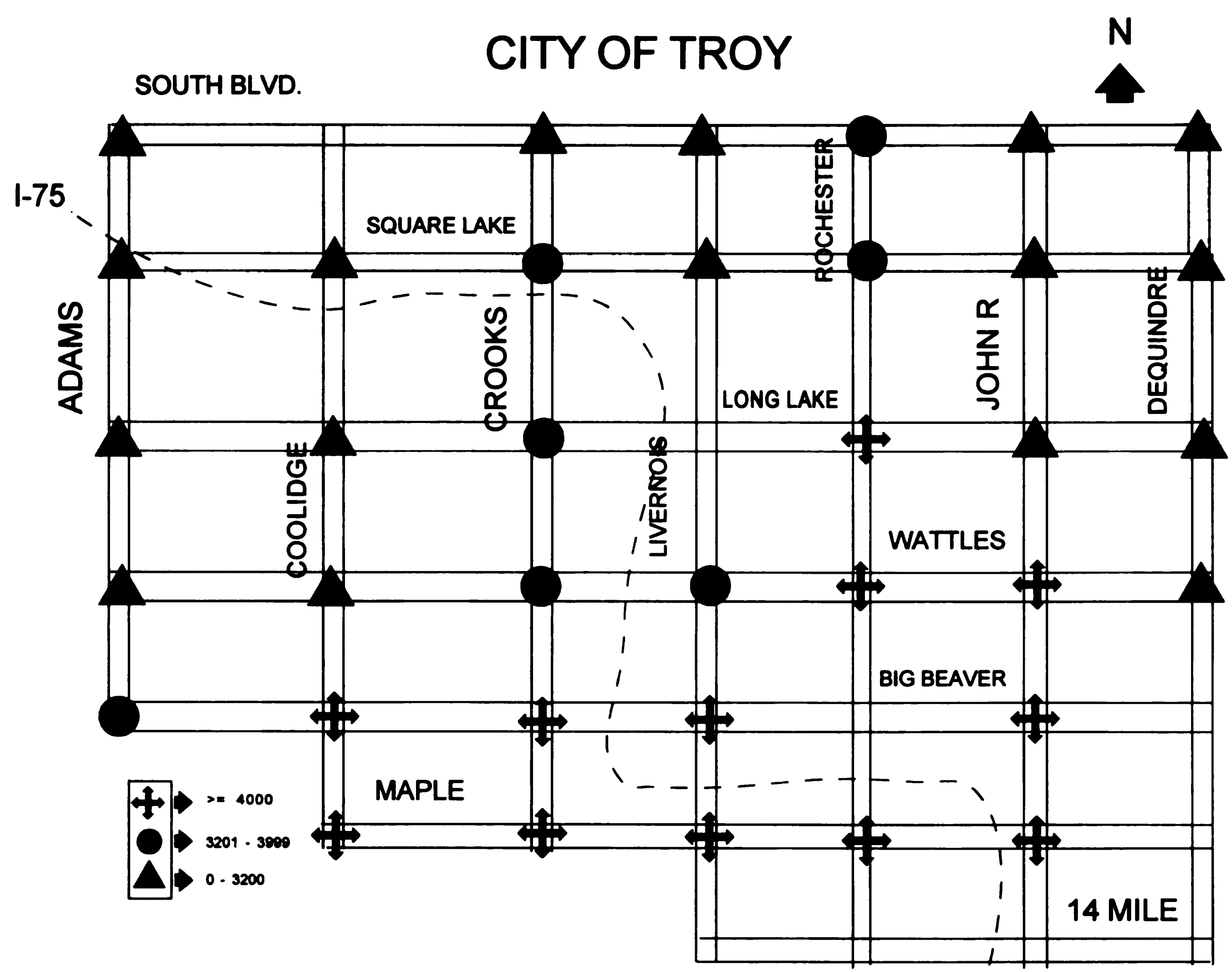

Figure 3.16 The AM Peak Total Traffic Volumes (Veh/Hour)

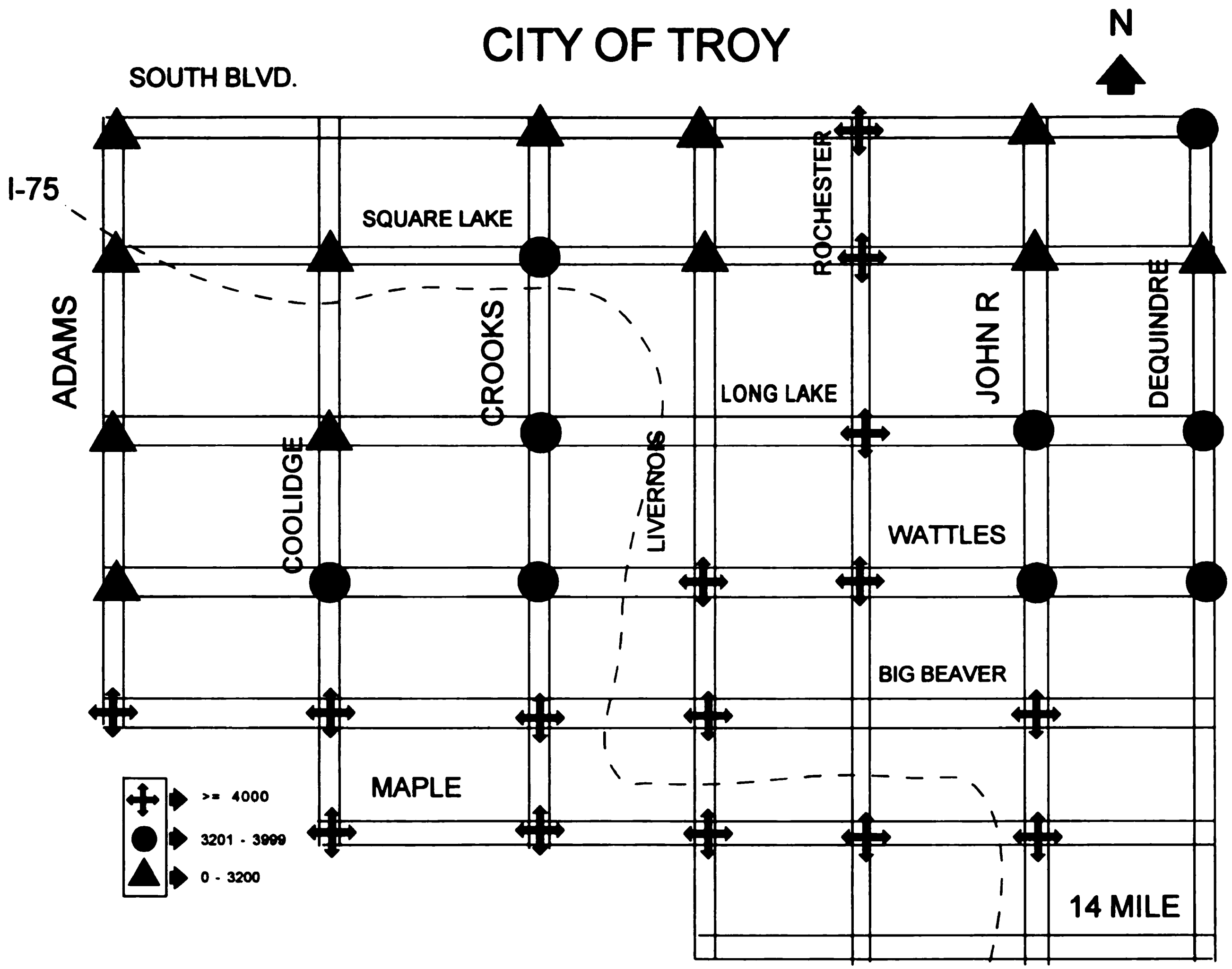

Figure 3.17 The PM Peak Total Traffic Volumes (Veh/Hour)

3.6.3 LEVEL OF SERVICE DISPLAY

With the ITAGI system, the level of service can also be depicted on the map. Figure 3.18 and Figure 3.19 show the level of service for AM and PM peak hours. As shown in these two graphics, nearly all the intersections have LOS F or worse during the peak hours. The intersections with no symbols represent missing data.

3.6.4 TRAFFIC ACCIDENT RATE DISPLAY

The 1994 intersection accident rates are shown in Figure 3.20. The intersection accident rates for other years are contained in the ITAGI system. As with the accident frequency data, the ITAGI system provides a method of displaying the intersection accident rate for each intersection on a map. From Figure 3.20, it can be seen that the high accident rate locations are concentrated on Big Beaver, Rochester, and John R Road.

The 1994 midblock accident rates are shown in Figure 3.21. The midblock accident rates for other years are contained in the ITAGI system. Figure 3.21 shows that the high midblock accident locations are also concentrated on Big Beaver and Rochester Road. Big Beaver, Crooks and 14 Mile Road all have interchanges with I-75. Thus, the midblock accident rate is high for these segments because all the ramp terminal accidents are attributed to these links. This menu item in ITAGI can be used to determine the high accident locations and road segments necessary for the Highway Safety Improvement Program (HSIP) required of all cities.

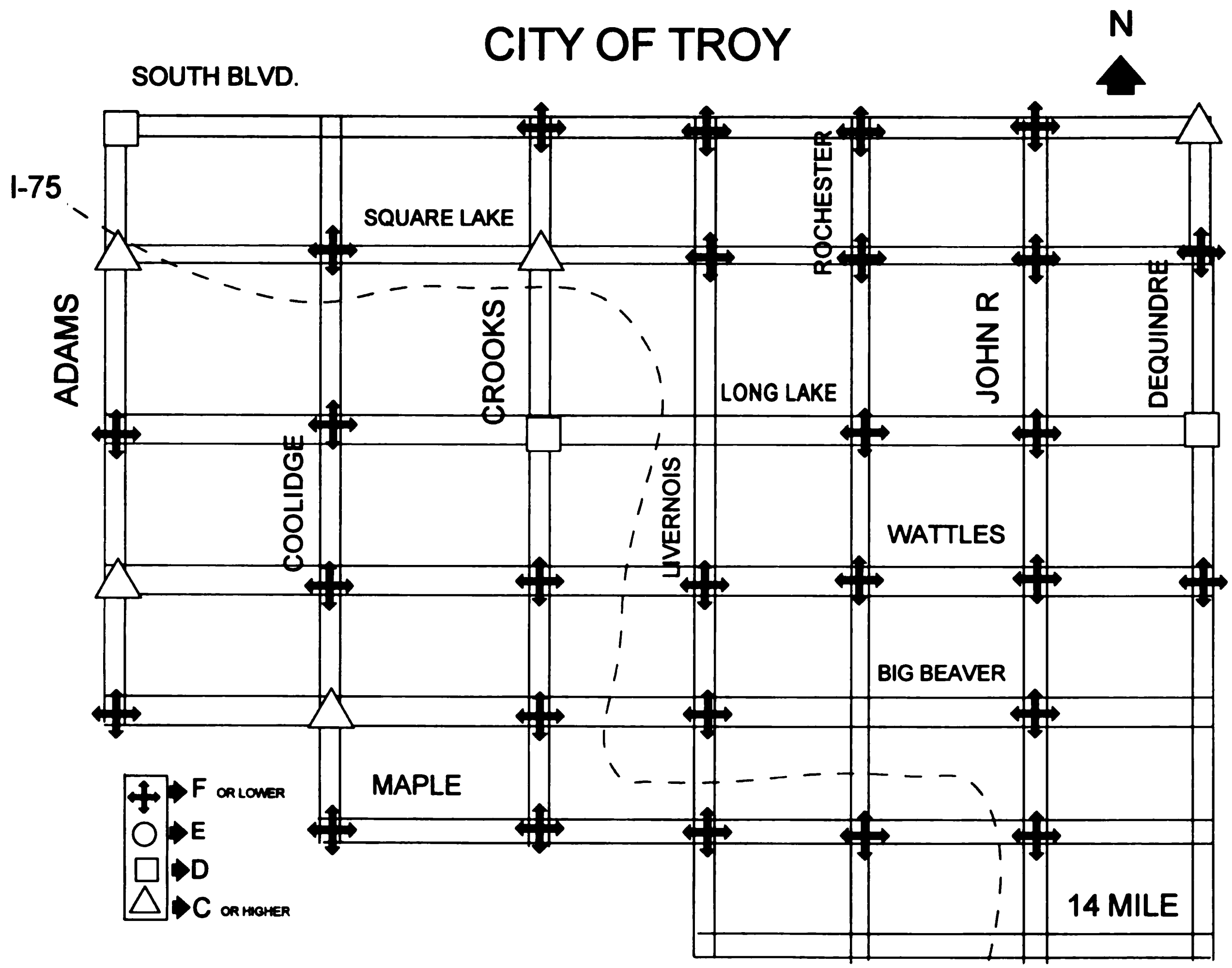

Figure 3.18 The AM Peak LOS at the Intersections

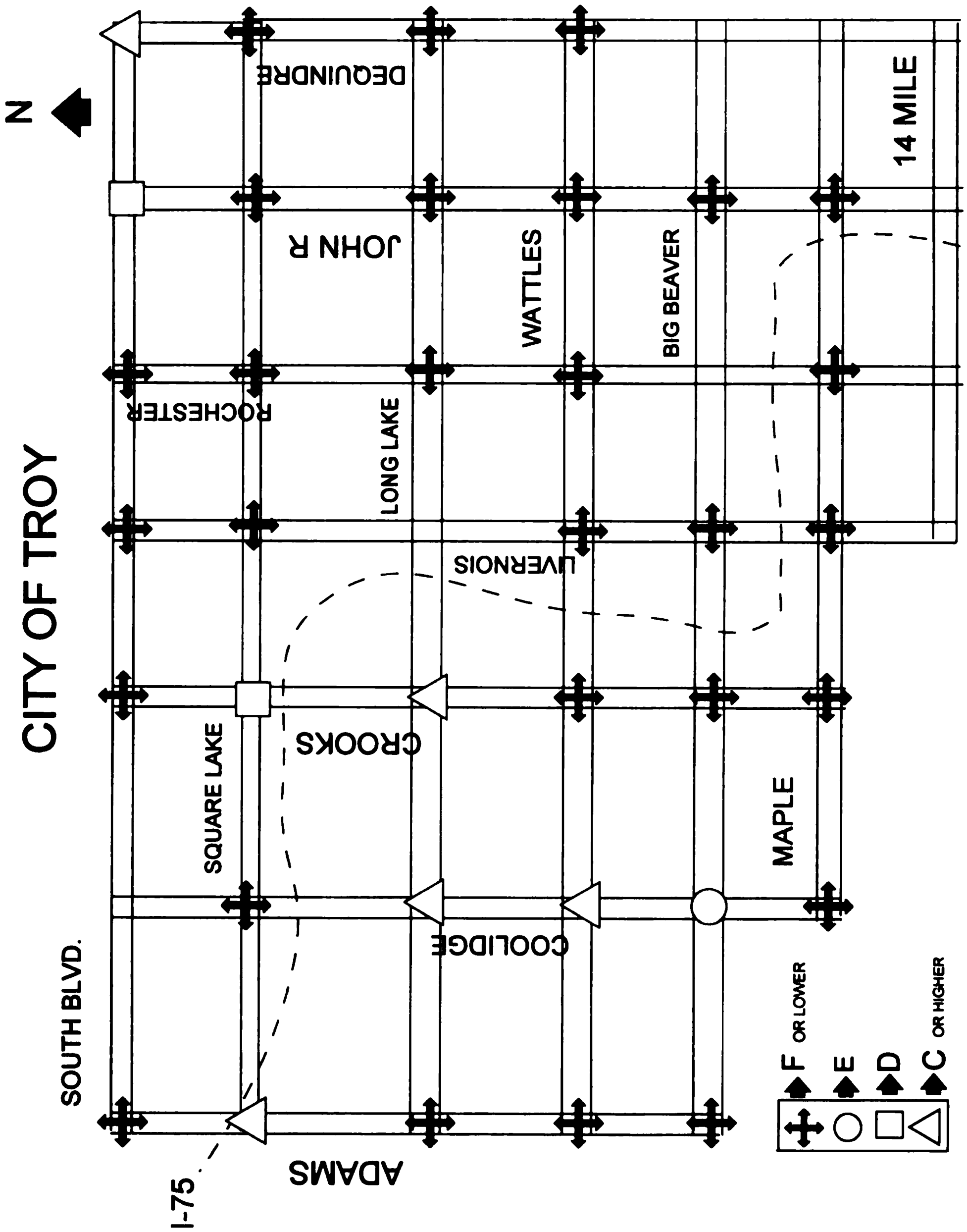

Figure 3.19 The PM Peak LOS at the Intersections

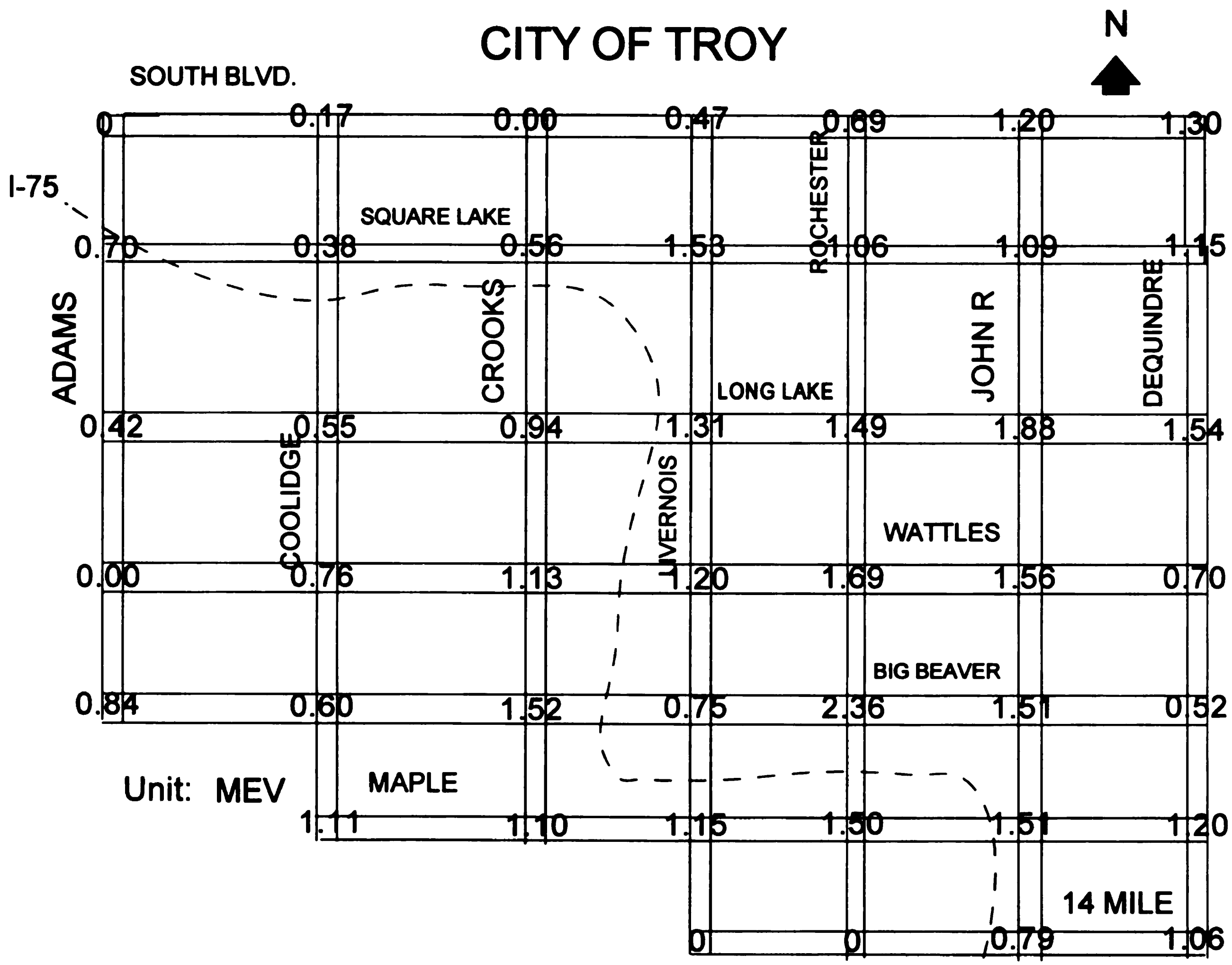

Figure 3.20 The Intersection Accident Rate in 1994

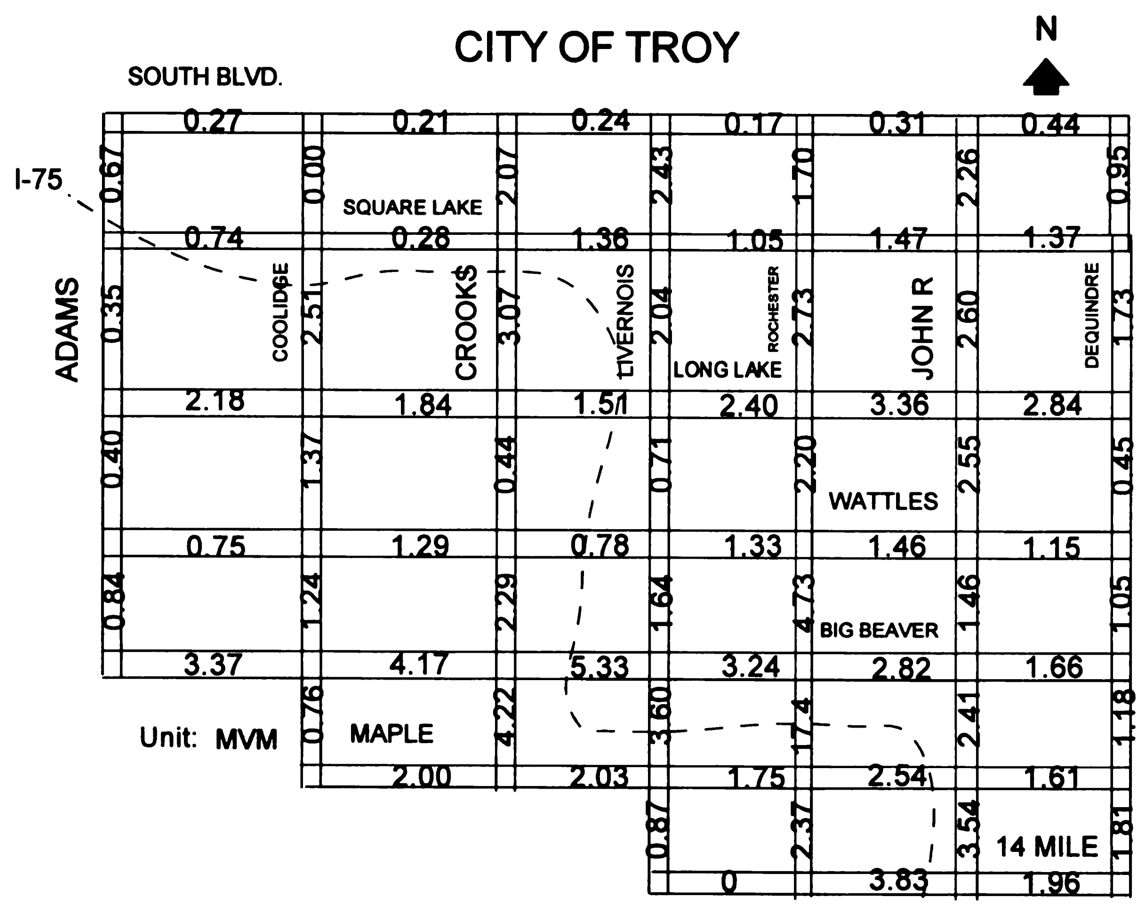

Figure 3.21 The Midblock Accident Rate in 1994

3.6.5 SINGLE INTERSECTION SELECTION

The 1994 top five angle accident intersections are shown in Figure 3.22. In addition, the 1994 total intersection accidents is shown in Figure 3.23. The other years and accident type data are contained in the ITAGI system. The other years total intersection accident data are contained in the ITAGI system.

3.6.6 SINGLE MIDBLOCK SELECTION

The top 5 locations based on angle midblock accidents in 1994 is shown in Figure 3.24, and the 1994 total midblock accidents is shown in Figure 3.25. Detailed information about the top 5 locations for each year (1989--1994) and each type of traffic accident is contained in the ITAGI system. The other years total midblock accidents are contained in the ITAGI system.

3.6.7 MULTIPLE MIDBLOCK SELECTION

An example of the potential use of this program would be to determine the relationship between the number of traffic lanes and midblock traffic accidents. For example, if the traffic engineer wants to examine the number of accidents occurring on 2-lane roads, 5-lane roads, and boulevards, it is easy to obtain these results. Five road segments on Wattles Road were selected as a 2-lane road sample, five road segments on Maple Road as a 5-lane road sample, and five road segments on Big Beaver as a boulevard sample. The results show that:

1. The boulevard segments had the highest number of traffic accidents, followed

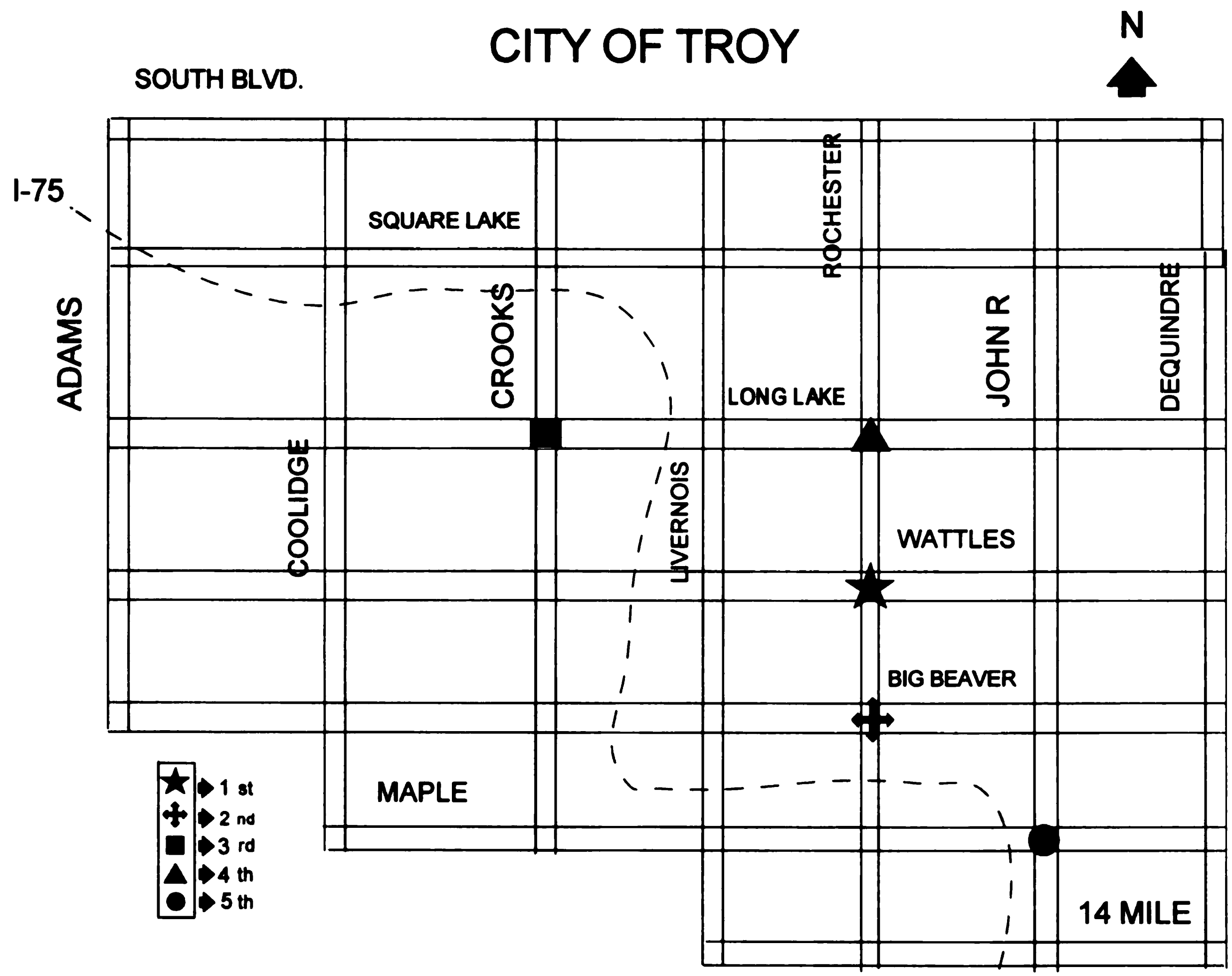

Figure 3.22 The 1994 Top Five Angle Accident Intersections

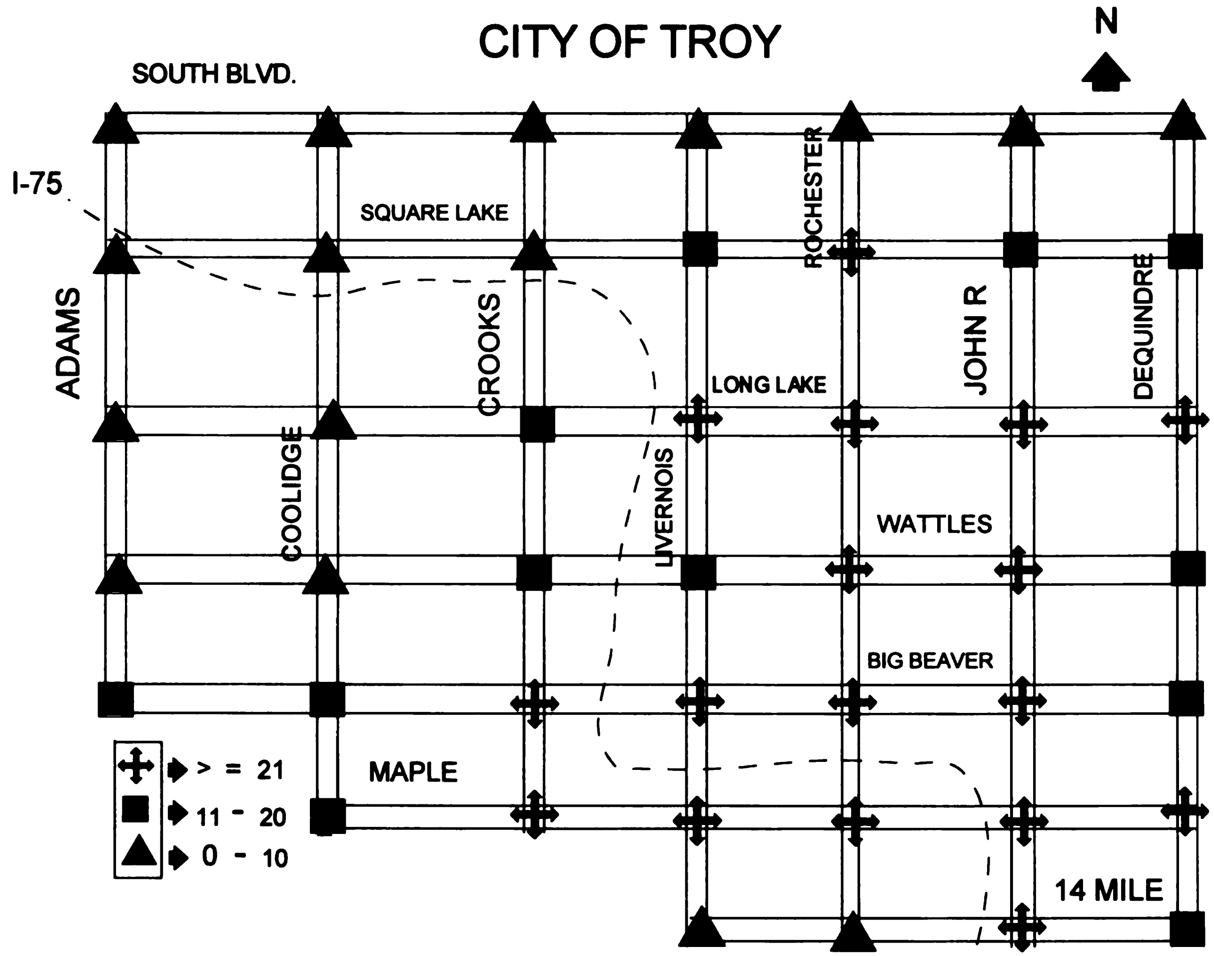

Figure 3.23 The 1994 Total Intersection Accidents

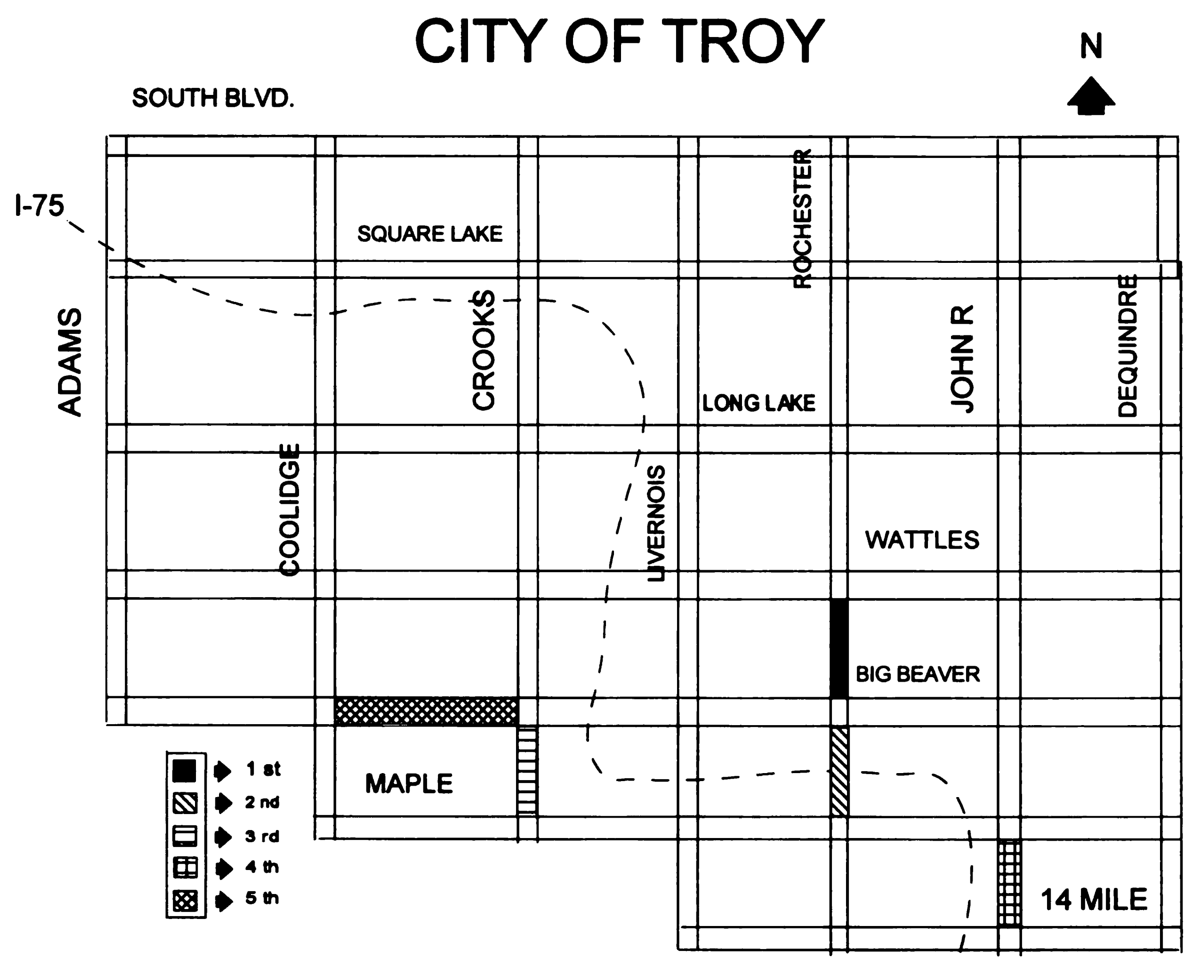

Figure 3.24 The 1994 Top Five Angle Accidents Midblocks

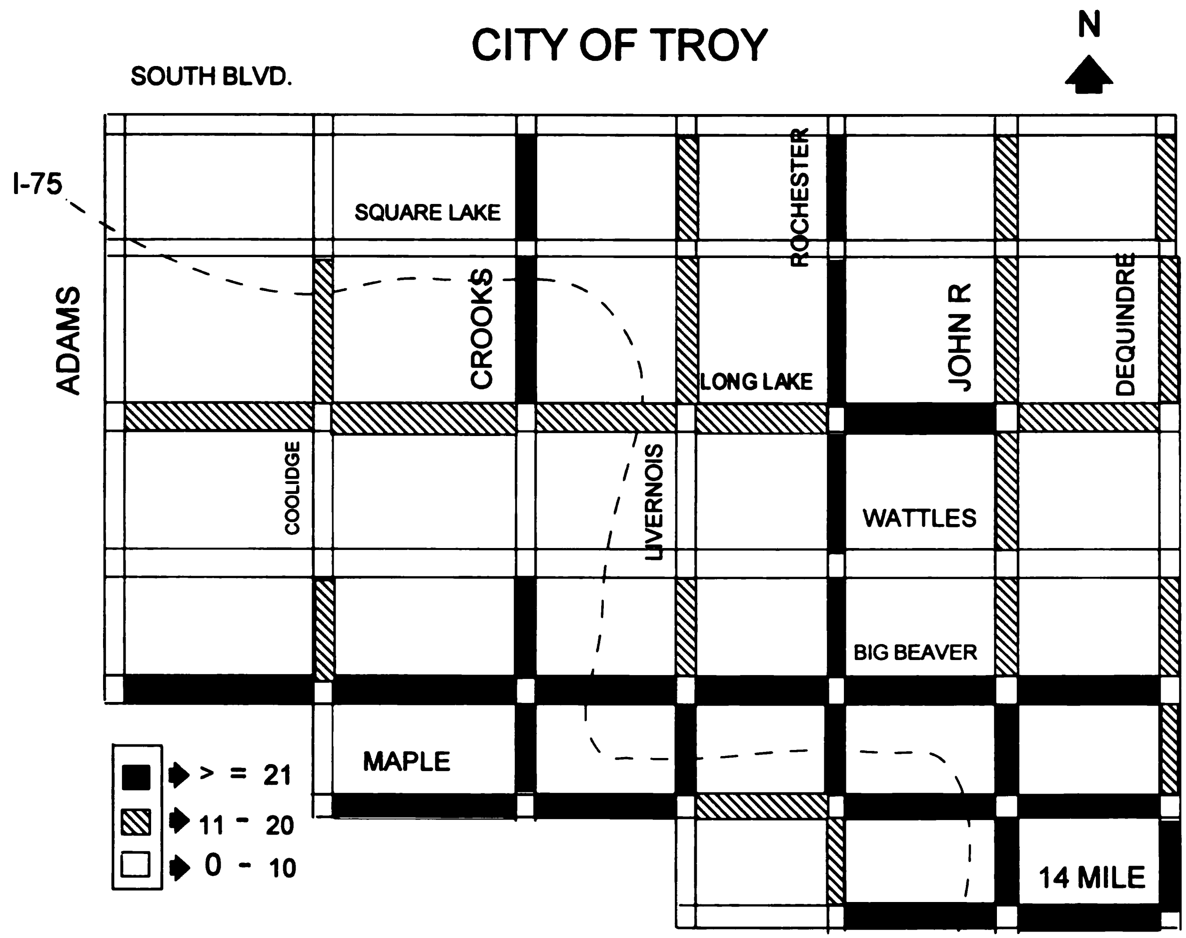

Figure 3.25 The 1994 Total Midblock Accidents

by 5-lane roads, and then 2-lane roads;

2. 5-lane roads have the highest percentage of angle accidents, then 2-lane roads, and then boulevards;
3. After implementing SCATS in 1993, the 2-lane roads showed a significant increase in the percentage of rearend accidents. The change on the boulevard and 5-lane road segments were not significant; and
4. After implementing SCATS, the percentage of angle accidents on 2-lane roads decreased from 20% (1992) to 18% (1993), to 9% (1994), while the percentage of angle accidents on 5-lane roads increased slightly from 21% (1992) to 27% (1993), to 23% (1994). On boulevards, the angle accidents increased from 7% (1992) to 8% (1993), to 9% (1994).

3.6.8 ROUTE GUIDANCE SYSTEM

The ITAGI system can be used to determine if the safest path changes from year to year. This type of information would be useful in tracking trends in accident rates as a city or region develops, or to evaluate the effect of spot improvements.

3.7 ACCIDENT REDUCTION BEFORE-AND-AFTER SCATS

Data necessary to develop the trend of all accidents occurring in the City of Troy is contained in the ITAGI system. SCATS control was initiated in a part of the city in June 1992 and in the remainder of the city in November 1993. The trend analysis was constructed to differentiate these areas, and to consider total accidents and injury accidents separately.

Figure 3.26, Figure 3.27 and Figure 3.28 display the results of this analysis. Figure 3.26 displays all accidents in the City of Troy. This accident summary includes intersection accidents and non-intersection accidents in the six mile by six mile area of the city. Figure 3.26 shows that the total number of accidents in the city was higher in 1994 (after SCATS installation), than in the three prior years, including the year of installation. The number of accidents in the last six months of 1994 was less than the number in the first six months. These same observations are true of injury accidents as well.

Figure 3.27 presents a similar analysis for the five intersections where SCATS was installed in June 1992. At these intersections, total accidents were lower in the three six-month intervals following installation than in the six month period which included the installation. However, in the first six months of 1994 the accidents increased significantly and then declined again in the last six months of the year. Injury accidents were higher in each of the after period six-month intervals except the last six months of 1994.

Figure 3.28 depicts the accident history for the entire 49 major intersections in the city. The same phenomenon is present as was observed in the first two figures. That is, a large increase in both total and injury accidents in the first six months of 1994 followed by a decrease in the last six months of the year.

Another example of how the ITAGI system can be used to assist the analyst is in identifying locations where the change in accident frequency between the before period (1991) and the after period (1994) at an intersection or midblock location was large. The

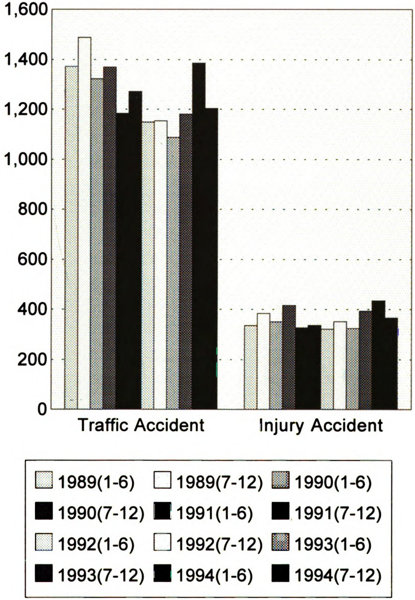

Figure 3.26 The Number of Traffic Accidents & Injury Accidents (1989--1994) (The City of Troy -- 7x7 Major Arterials)

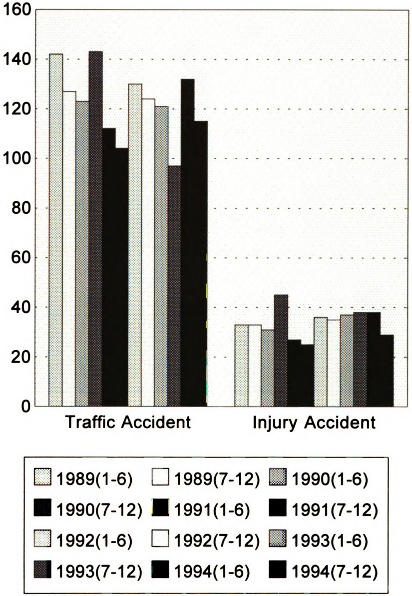

Figure 3.27 The Number of Traffic Accidents & Injury Accidents (1989--1994) (5 intersections in the City of Troy)

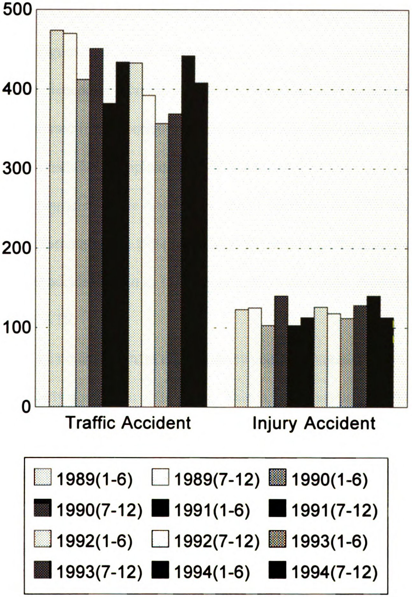

Figure 3.28 The Number of Traffic Accidents & Injury Accidents (1989--1994)
(49 Intersections in the City of Troy)

ITAGI system has the ability to display intersection and midblock comparisons for 1991& 1993, 1992 & 1993, 1991 & 1994, and 1992 & 1994. For demonstration purposes, the intersection and midblock comparisons for 1991 and 1994 are shown in Figure 3.29 and Figure 3.30. From Figure 3.29, it is clear that the majority of the intersections experienced an increase in traffic accidents in 1994 compared to 1991. Almost all the intersections experienced more accidents in 1994 (after SCATS). This was not the expected result when implementing SCATS.

Similar comparison were made for midblock locations for 1994 and 1991 (refer to Figure 3.30). Unfortunately, in 1994 (after SCATS) almost all the midblock locations experienced more accidents than in 1991. Again, this was not the expected result when implementing SCATS.

It should be noted that there are frequency comparisons and do not necessarily represent statistically significant differences. That is, there can be no before-and-after statistical analysis because the data is not controlled for the effect of extraneous factors, such as changes in geometry, changes in control strategy, changes in signal phasing, changes in volume, changes in weather, changes in the enforcement level, changes in the economy of the region, changes in driver performance and vehicle design, and changes in reporting and coding of accident data. These are all known to affect accident data. It is difficult to attribute changes in accidents over time to a single factor, and at this level of analysis, it is not possible to determine which of the changes caused any recorded effect.

3.8 TRAVEL TIME SAVING BEFORE-AND-AFTER SCATS

The average speed data were obtained from the survey conducted by the research

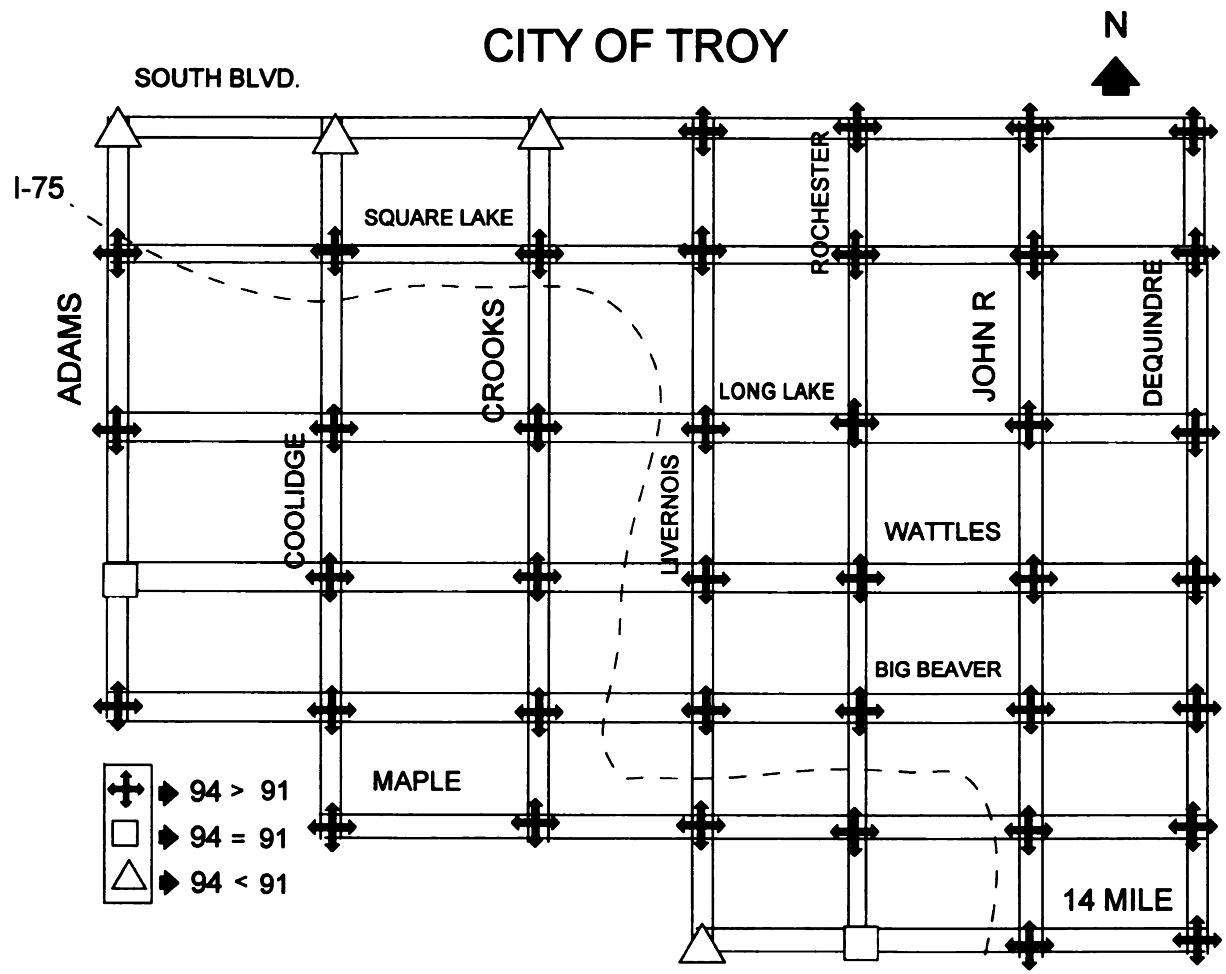

Figure 3.29 The Comparison of Intersection Accidents between 1991 and 1994

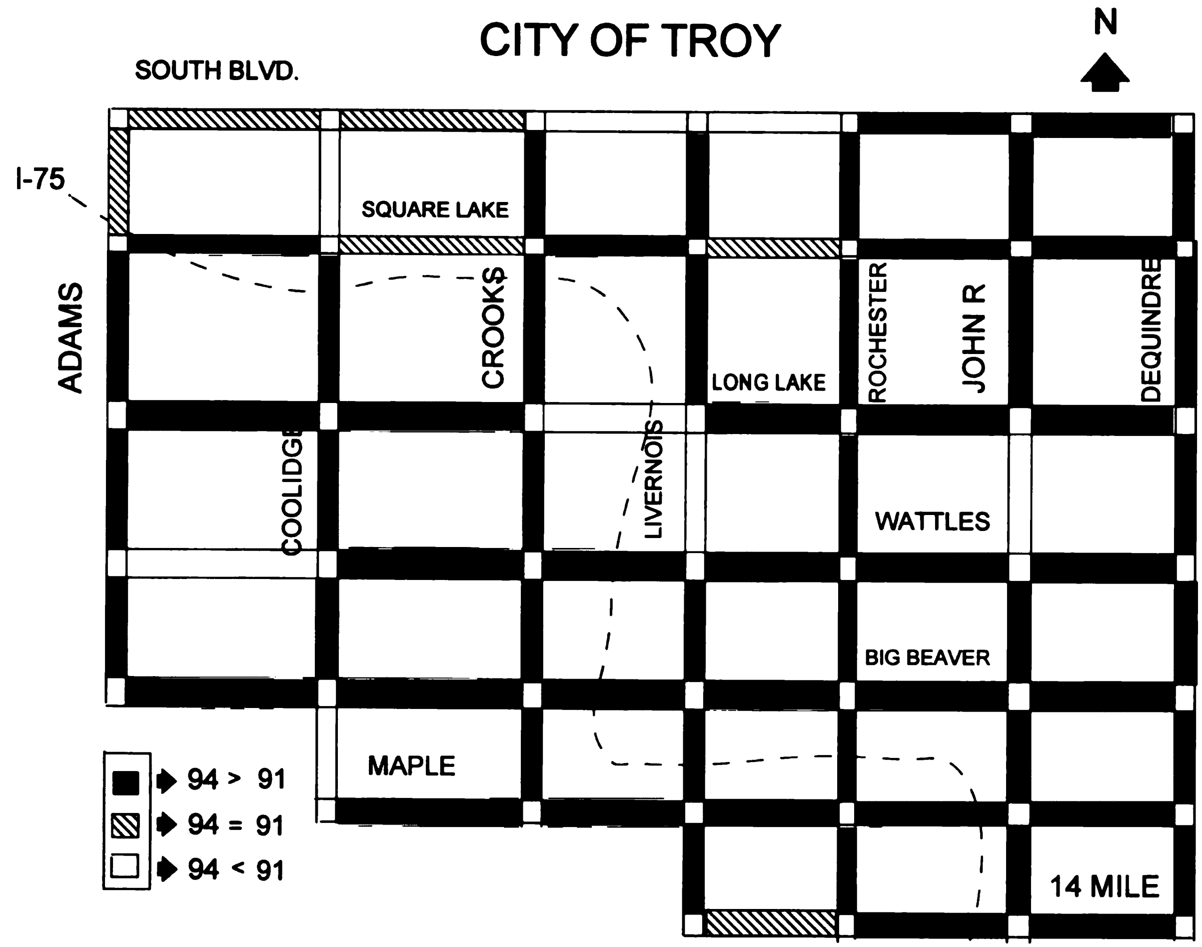

Figure 3.30 The Comparison of Midblock Accidents between 1991 and 1994

team from Michigan State University. After data reduction, the average speeds are summarized in Table 3.6 and Table 3.7. These two tables show the average speed on the Rochester and John R corridors before and after SCATS. The before SCATS data was collected in 1992 or 1993, and the after data was collected in 1994 or 1995. With the ITAGI system, the effect of SCATS on travel time can be displayed on the map. As shown in Figure 3.31, Figure 3.32 and Figure 3.33, during the AM peak, southbound Rochester road and northbound John R road show an increase in average speed after SCATS, while northbound Rochester and southbound John R show a negative effect after SCATS. During off-peak, southbound John R road shows a negative effect after SCATS. During the PM peak, only northbound John R has a better average speed after SCATS. Note that only selected corridors are shown because the survey was limited to these locations.

3.9 ACCIDENT REDUCTION BEFORE-AND-AFTER PROHIBITING LEFT-TURNS

This section compares the accident frequency before-and-after prohibiting left-turns. In Troy, left-turns were prohibited at several intersections in 1992 (refer to Table 3.8). With the multiple intersection selection function in the ITAGI system (as described in section 3.3.2), the aggregate results were obtained to determine whether there was an increase or decrease in the number or type of accidents. The results show that the percentage of turn accidents at these locations increased from 4% in 1991 to 7% in 1993, then decreased to 4% in 1994. However, the total number of accidents increased from 110 in 1991, to 137 in 1993, and to 151 in 1994.

Table 3.6 The Average Speed on Rochester Corridor Before and After SCATS

Rochester Road		1992 (before)		1995 (after)	
		Avg. Speed	No. of Obs.	Avg. Speed	No. of Obs.
NB	AM Peak	30.60	7	15.80	47
	Off Peak	29.90	17	N/A	N/A
	PM Peak	20.20	12	15.90	51
SB	AM Peak	30.80	5	33.36	67
	Off Peak	35.30	14	14.84	51
	PM Peak	32.30	9	23.42	44

Unit: mph

Table 3.7 The Average Speed on John R Corridor Before and After SCATS

John R Road		1993 (before)		1994 (after)	
		Avg. Speed	No. of Obs.	Avg. Speed	No. of Obs.
NB	AM Peak	31.90	148	32.56	204
	Off Peak	42.20	117	N/A	N/A
	PM Peak	28.80	238	29.78	161
SB	AM Peak	36.70	349	31.19	189
	Off Peak	35.60	131	N/A	N/A
	PM Peak	31.40	49	22.49	27

Unit: mph

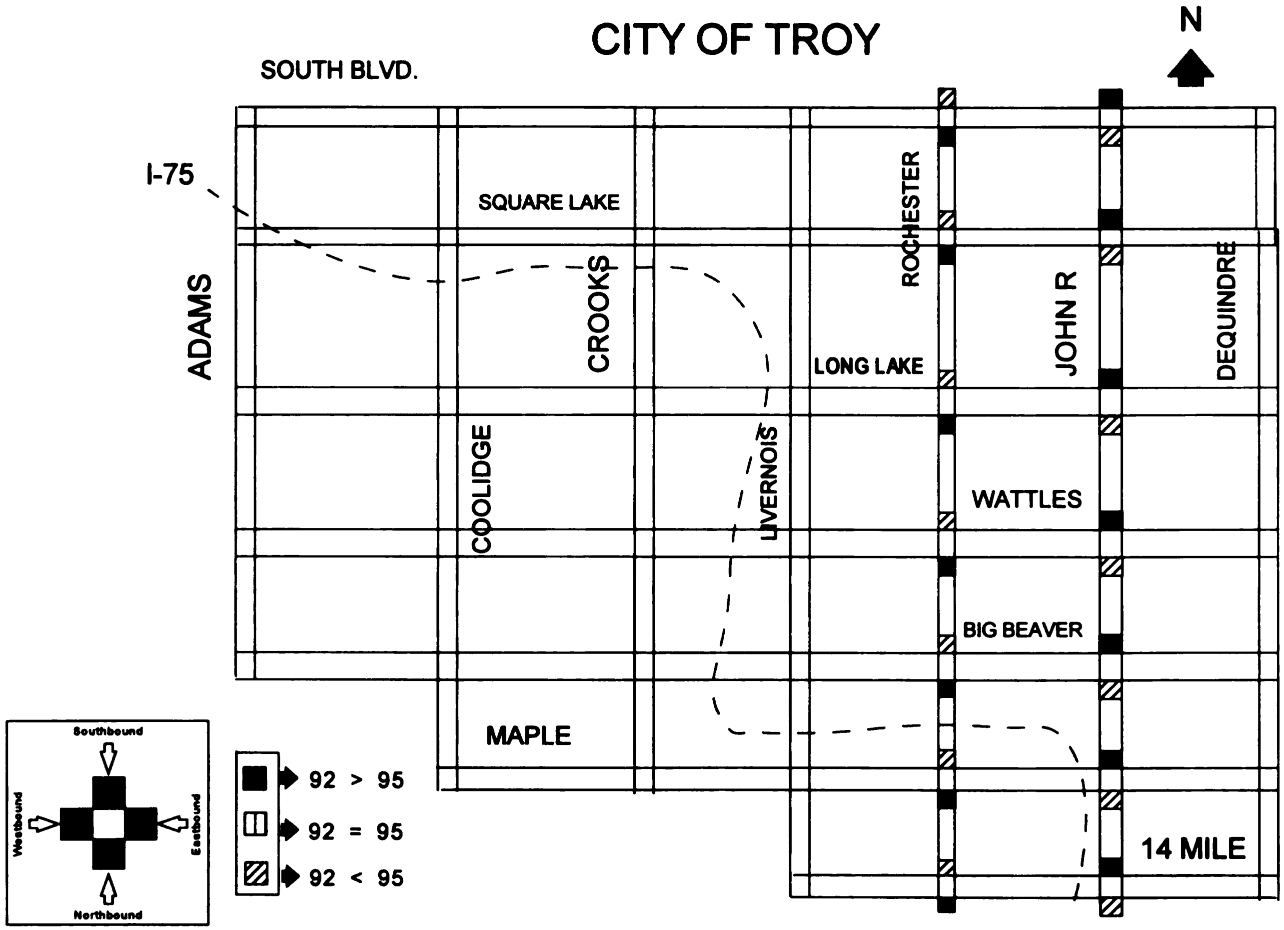

Figure 3.31 Comparison of AM Peak Average Speed on Rochester & John R Road between 1992 and 1995

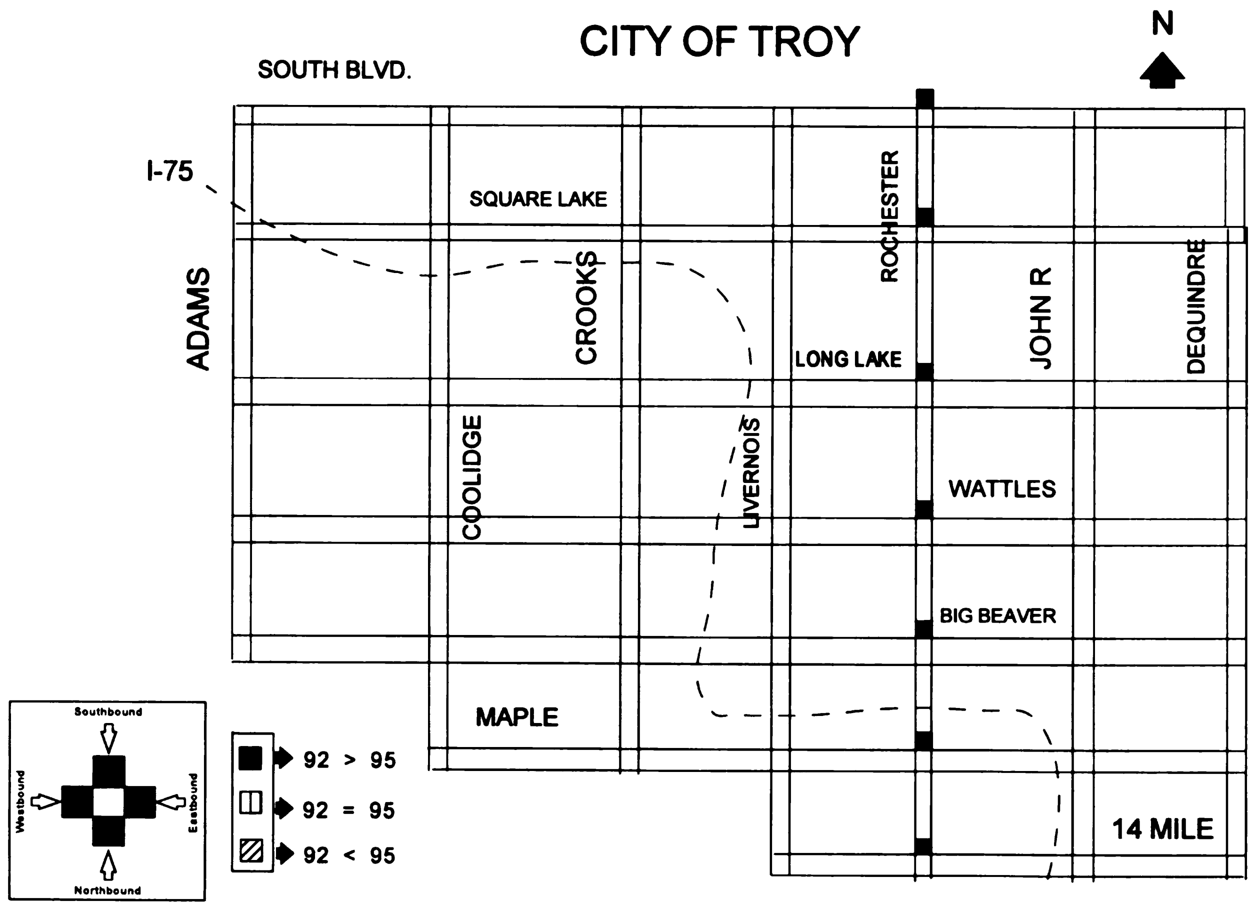

Figure 3.32 Comparison of Off Peak Average Speed on Rochester Road between 1992 and 1995

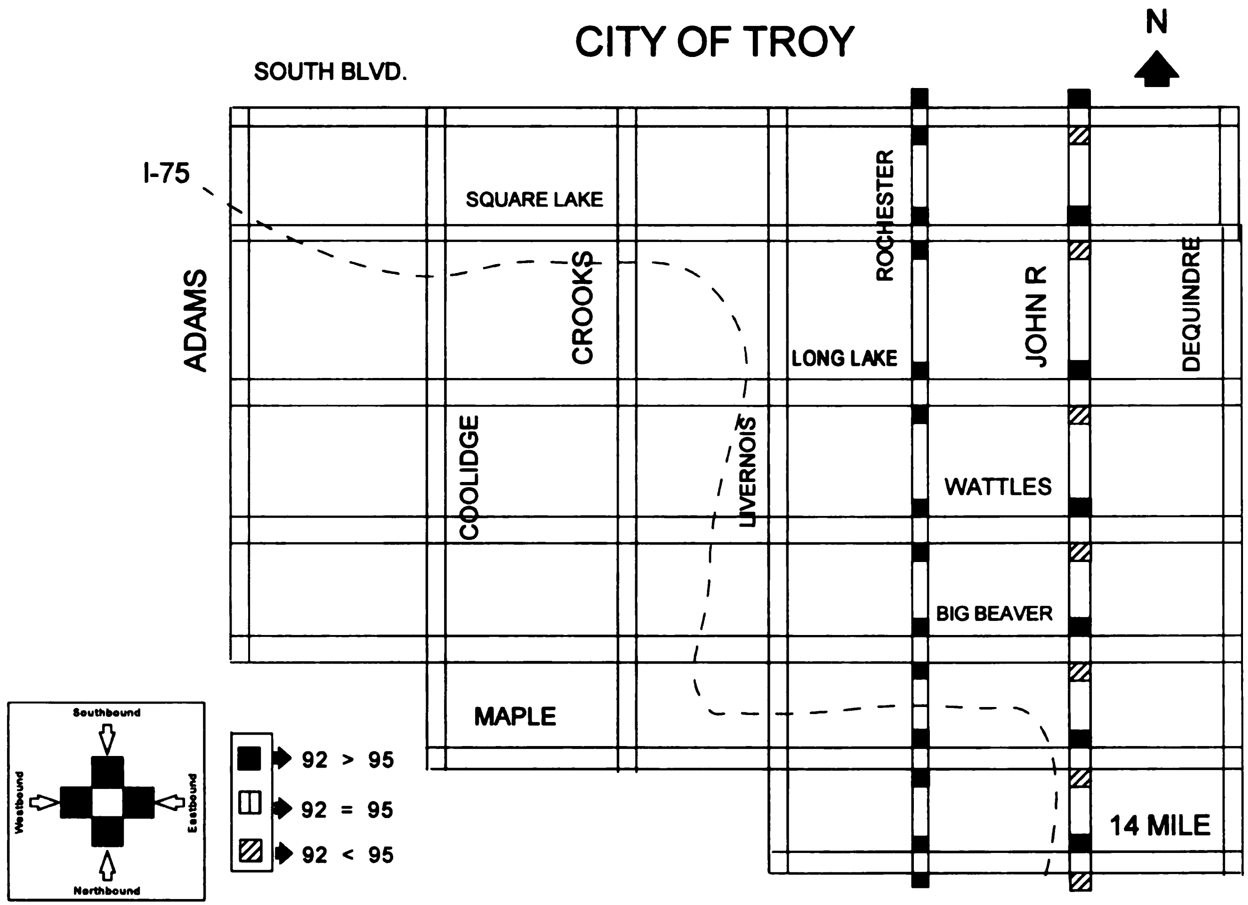

Figure 3.33 Comparison of PM Peak Average Speed on Rochester & John R Road between 1992 and 1995

Table 3.8 Intersections Implementing Prohibited Left-Turn Control in 1992

Intersection Name	1991		1993	
	Total Acc.	Turn Acc.	Total Acc.	Turn Acc.
Big Beaver & Crooks	37	4	41	3
Big Beaver & Livernois	23	2	23	2
Big Beaver & Rochester	50	4	73	4
Total Accidents	110	10	137	9

A statistical test was conducted to determine if the prohibition of left turns resulted in more accidents in 1993 than in 1991.

Suppose $A_{i,j}$ denotes the number of accidents for all independent intersections *i* and independent years j, $N_{i,j}$ denotes the yearly traffic volumes for these same intersections and years and $P_{i,j}$ denotes the probability of an accident happening for the same i,j. Assume there are $N_{i,j}$ Bernoulli trials with accident probability $P_{i,j}$, and the number of accidents $A_{i,j}$ is approximately binomially distributed. If $N_{i,j}$ is large and $P_{i,j}$ is small, the number of accidents $A_{i,j}$ is approximately Poisson distributed with mean $N_{i,j}$ $P_{i,j}$ and variance $N_{i,j} P_{i,j}$. If $N_{i,j} P_{i,j} \geq 5$, the number of accidents $A_{i,j}$ is approximately normally distributed with mean $N_{i,j} P_{i,j}$ and variance $N_{i,j} P_{i,j}$. The formula can be written as described above in the following:

$$A_{i,j} \cong \text{Binomial}\,(N_{i,j}, P_{i,j})$$

$$\cong \text{Poisson}\,(N_{i,j}, P_{i,j}),\ \text{if } N_{i,j} \approx \infty \text{ and } P_{i,j} \approx 0$$

$$\cong \text{Normal}\,(N_{i,j} P_{i,j}, N_{i,j} P_{i,j}),\ \text{if } N_{i,j} P_{i,j} \geq 5$$

$\forall$ independent intersection *i* and independent year j

In 1991, the distribution of the total number of accidents is :

$$\sum_{i=1}^{3} Normal(N_{i,91}P_{i,91}, N_{i,91}P_{i,91}) \approx Normal(\sum_{i=1}^{3} N_{i,91}P_{i,91}, \sum_{i=1}^{3} N_{i,91}P_{i,91})$$

In 1993, the distribution of the total number of accidents is :

$$\sum_{i=1}^{3} Normal(N_{i,93}P_{i,93}, N_{i,93}P_{i,93}) \approx Normal(\sum_{i=1}^{3} N_{i,93}P_{i,93}, \sum_{i=1}^{3} N_{i,93}P_{i,93})$$

Therefore, the distribution of the difference in the total number of accidents between 1991 and 1993 is:

$$Normal(\sum_{i=1}^{3} N_{i,93}P_{i,93} - \sum_{i=1}^{3} N_{i,91}P_{i,91}, \sum_{i=1}^{3} N_{i,93}P_{i,93} + \sum_{i=1}^{3} N_{i,91}P_{i,91})$$

Where the $\sum_{i=1}^{3} N_{i,93}P_{i,93} - \sum_{i=1}^{3} N_{i,91}P_{i,91}$ and $\sum_{i=1}^{3} N_{i,93}P_{i,93} + \sum_{i=1}^{3} N_{i,91}P_{i,91}$ are unknown.

For the purpose of setting confidence limits on the difference in the expected total number of accidents in 1993 and the expected total number of accidents in 1991, $\mu_{93} - \mu_{91}$ can be estimated by observing the total number of accidents ($\sum X_{i,93} - \sum X_{i,91}$) for all intersections for both years combined where:

$X_{i,j}$ denotes the number of accidents at intersection i, in year j , $\forall\ i=1,2,3$

$\mu_{i,j}$ denotes the expected total number of accidents ($\Sigma X_{i,j}$) at intersection i, in year j , $\forall\ i=1,2,3$

The value of ($\sum X_{i,93} - \sum X_{i,91}$) may or may not be a good estimator for the $\mu_{93} - \mu_{91}$. If $x1 = \sum X_{i,93}$, $x2 = \sum X_{i,91}$, $\mu_1 = \mu_{93}$, and $\mu_2 = \mu_{91}$, a test of whether x1 and x2 are good estimators for μ_1 and μ_2 is to determine whether R is a standard normal distribution of the form $\mu_1 - \mu_2$, where

$$R = \frac{(x1-\mu_1)-(x2-\mu_2)}{\sqrt{(x1+x2)}}, x1 \approx N(\mu_1,\mu_1), x2 \approx N(\mu_2,\mu_2)$$

Note that with very small probability x1+x2 is not positive and so $\sqrt{(x1+x2)}$ will be imaginary or zero. This simply means there is a very small probability that the ratio R upon which the confidence interval is constructed is not well defined, but the probability is very small and causes no problem. Based upon independent N(0,1) random variables Z and Z',

we take a $=\sqrt{\mu_1}$, A = μ_1, b = $\sqrt{\mu_2}$, and B = μ_2. Hence, R can be expressed as:

$$R = \frac{(A + aZ - A - B - bZ' + B)}{\sqrt{(aZ + A + bZ' + B)}}$$

$$\Rightarrow R = \frac{(aZ - bZ')}{\sqrt{(aZ + A + bZ' + B)}}$$

Define the normal random variables:

U = a Z - b Z'

V= a Z + A + b Z' + B

then

Var(U) = Var(a Z - b Z') = a^2 Var(Z) + b^2 Var(Z') = $a^2 + b^2$ = A+B.

Var (V) = Var(a Z + A + b Z' + B) = a^2 Var(Z) + b^2 Var(Z') = $a^2 + b^2$ = A + B.

$\therefore$ Var(U) = Var(V) = A+ B.

Cov(U,V) = E(UV) - E(U) E(V)

= E([a^2Z^2 + AaZ + abZZ' + aBZ - abZZ'- AbZ' - b^2Z^{2}' - BbZ']) - E(aZ-bZ')E(aZ + A + bZ' + B)

$\therefore$ Cov(U,V) = a^2 E(Z^2) - b^2 E(Z^{2}') = a^2 - b^2 = A - B.

$$\therefore \text{Corr(U,V)} = \frac{Cov(U,V)}{\sqrt{Var(U)}\ \sqrt{Var(V)}} = \frac{(A-B)}{(A+B)}.$$

In terms of a standard normal random variable W, U can be expressed as:

U= c W, where c= $\sqrt{(A+B)}$,

$$\text{So,}\quad R = \frac{U}{V} = \frac{c\ W}{c\sqrt{1 + \frac{(a\ Z\ +\ b\ Z')}{C}}} = \frac{W}{\sqrt{1 + \frac{(a\ Z\ +\ b\ Z')}{C}}}$$

where C= A+B.

The normal random variable W and (a Z + b Z') have correlation equal to the correlation between (a Z - b Z') and (a Z + b Z'). This correlation is equal to $\frac{(A-B)}{(A+B)}$. The random variable W' is standard normal too, where

$$W' = \frac{(a\ Z\ +\ b\ Z')}{c}$$

Therefore, R= $\frac{W}{\sqrt{(1 + \frac{W'}{c})}}$, where W, W' are each standard normal with correlation (W, W')= $\frac{(A-B)}{(A+B)}$. For large c, R is approximately standard normal. The correlation really does not matter, since the important thing is that $\frac{W'}{c}$ is small.

Therefore, the 95% confidence interval for the **expected total number of accidents** for year 1993 minus the year 1991 ($\mu_{i,93} - \mu_{i,91}$) is:

$$(\sum X_{i,93} - \sum X_{i,91}) \pm\ 1.96 \times \sqrt{(\sum X_{i,93} + \sum X_{i,91})}\ ,\ \forall\ i=1,2,3$$

$$= (137\text{-}110) \pm (1.96 \times \sqrt{(110+137)})$$

$$= 27 \pm (1.96 \times 15.72)$$

$$= [-3.81, 57.81]$$

The 95% confidence interval for the **expected total turn accidents** for year 1993 minus the expected total turn accidents for year 1991 ($\mu_{i,93} - \mu_{i,91}$) is:

$$(\sum X_{i,93} - \sum X_{i,91}) \pm\ 1.96 \times \sqrt{(\sum X_{i,93} + \sum X_{i,91})}\ ,\ \forall\ i=1,2,3$$

$$= (9\text{-}10) \pm (1.96 \times \sqrt{(9+10)})$$

$$= -1 \pm (1.96 \times 4.36)$$

$$= [-9.54, 7.54]$$

where the total number of accidents in 1993 $\sum X_{i,93}$ is approximately normal with

unknown mean and unknown variance, and

the total number of accidents in 1991 $\sum X_{i,91}$ is approximately normal with

unknown mean and unknown variance.

Hypothesis

$H_0 : \theta_{i,93} - \theta_{i,91} = 0$ (null hypothesis)
$H_1 : \theta_{i,93} - \theta_{i,91} \neq 0$ (alternative hypothesis)

If you accept H_0, there is no significant evidence to say the expected total number of accidents and the expected total turn accidents in 1993 is lesser or greater than 1991.

Since 0 is inside the 95% confidence interval [-3.81,57.81] and [-9.54,7.54], these data are sufficient to accept the null hypothesis. Therefore, the conclusion can be drawn that the process in 1993 did not produce a statistically significant change than the before year (1991) at significance level $\alpha = 0.05$ (two-tailed statistics test).

3.10 BEFORE-AND-AFTER PROTECTED LEFT-TURN CONTROL

In this section, an example to demonstrate the use of the ITAGI system in analyzing before-and-after protected left-turn control in accident reduction will be demonstrated and explained. For example, in the City of Troy, left-turns were protected at several intersections in 1992 (refer to Table 3.9). Table 3.9 shows the accident figures for the intersections of Maple/Livernois and Maple/Rochester where protected left-turn control was implemented in 1992. The performance after implementing this control strategy is that he percentage of turn accidents decreased from 13% in 1991 to 7% in 1993, and to 14% in 1994. However, while the total number of accidents decreased in 1993, they increased again in 1994.

Table 3.9 Intersections Implementing Protected Left-Turn Control in 1992

Intersection Name	1991		1993	
	Total Acc.	Turn Acc.	Total Acc.	Turn Acc.
Maple & Livernois	34	6	23	3
Maple & Rochester	28	5	22	0
Total Accidents	62	11	45	3

The 95% confidence interval for the **expected total number of accidents** for year 1993 minus the expected total number of accidents for year 1991 ($\mu_{i,93} - \mu_{i,91}$) is:

$$(\sum X_{i,93} - \sum X_{i,91}) \pm 1.96 \times \sqrt{(\sum X_{i,93} + \sum X_{i,91})}\ , \forall\ i=1,2$$

$$= (45\text{-}62) \pm (1.96 \times \sqrt{(45+62)})$$

$$= -17 \pm (1.96 \times 10.34)$$

$$= [-37.27\ , 3.27]$$

And the 95% confidence interval for the **expected total turn accidents** for year 1993 minus the expected total turn accidents for year 1991 ($\mu_{i,93} - \mu_{i,91}$) is:

$$(\sum X_{i,93} - \sum X_{i,91}) \pm 1.96 \times \sqrt{(\sum X_{i,93} + \sum X_{i,91})}\ , \forall\ i=1,2$$

$$= (3\text{-}11) \pm (1.96 \times \sqrt{(3+11)})$$

$$= -8 \pm (1.96 \times 3.74)$$

$$= [-15.33, -0.67]$$

where the total number of accidents in 1993 $\sum X_{i,93}$ is approximately normal with

unknown mean μ_{93} and unknown variance μ_{93}, and

the total number of accidents in 1991 $\sum X_{i,91}$ is approximately normal with

unknown mean and unknown variance

Hypothesis

$H_0 : \theta_{i,93} - \theta_{i,91} = 0$ (null hypothesis)
$H_1 : \theta_{i,93} - \theta_{i,91} \neq 0$ (alternative hypothesis)

If you accept H_0, there is no significant evidence to say the expected total number of accidents in 1993 is fewer than 1991. Since 0 is inside the 95% confidence interval [-37.27, 3.27] for total accidents, these data are sufficient to accept the null hypothesis. However, we must reject H_0 with respect to the expected turn accidents since 0 is outside the 95% confidence interval [-15.33, -0.67]. Therefore, the conclusion can be drawn that the process in the after year (1993) did not produce fewer total accidents than the before year (1991), but it did produce fewer turn accidents than the before year (1991) at significance level $\alpha = 0.05$ (two-tailed statistics test).

3.11 SUMMARY

3.11.1 GIS CAPABILITY FOR TROY

Geographic Information Systems (GIS) play an important role in Intelligent Transportation Systems (ITS). The term ITS, (previously known as IVHS), is composed of six major areas: Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Advanced Vehicle Control Systems (AVCS), Commercial Vehicle Operations (CVO), Advanced Public Transportation Systems (APTS), and Advanced Rural Transportation Systems (ARTS) [Euler, 1990]. The definition of GIS according to Simkowitz [1988] is a computerized database management system for the capture, storage, retrieval, analysis, and display of spatial (i.e., locationally defined) data. A GIS is a useful decision support tool for transportation applications because it provides a visual display of a transportation network and the associated spatial data. GIS has been used primarily for planning activities by transportation agencies. With the development and availability of larger and faster computers, GIS appears to have applications for traffic management operations in real time. In ATIS and ATMS, it would be desirable to capture real time traffic data and apply it to a GIS database to provide roadway information that the operator at the traffic operations center can use to make decisions. Most of the traffic characteristics data, such as traffic volume, travel speed and delay data can now be captured through detectors and transmitted on to a control center in real time. With a GIS, the operator in the traffic operations center could monitor the road conditions in real time. By adding a static accident database to the GIS, the operator could identify where high hazard locations are and can associate these locations with real time traffic characteristics data. GIS offers the decision maker information on which traffic control strategies can be based. The ITAGI system was developed as a GIS-based tool for use in the traffic operations center in Troy. The operator in the traffic operations center can monitor traffic data in real time, and with ITAGI examine the accident records over the past six years at specified locations, and make decisions based on real time data on traffic conditions combined with historical accident data.

The ITAGI system provides a convenient format for the user to obtain the specified information. More importantly, rather than being limited to textual queries, it is possible to perform geographic queries in the ITAGI system. The user simply selects the desired points on the computer screen, and acquires the desired information. This is an important feature of a GIS which is not included in a general spreadsheet program, such as Excel. Because transportation-related data usually have a spatial component, the most natural way to associate elements from different data sets is through a consistent spatial referencing system. The ITAGI system is capable of topological operations; that is, it understands how elements contained in the database are related to each other spatially and it can perform spatial manipulations on these elements. In other words, what distinguishes a GIS from a traditional database is that the attribute data are associated with a topologic object (point, line, or polygon) that has a position somewhere on the surface of the earth. Using the ITAGI system, easily understood data can be shown on a screen. A convenient graphic interface program provides quick access to traffic characteristics information and easily understood presentations, improved updating capabilities, and a more flexible and comprehensive source of information than general spreadsheet programs.

3.11.2 GRAPHIC INTERFACE CAPABILITY FOR THE CITY OF TROY

A major advantage of the ITAGI system is quick access. The ITAGI system has already embedded several hundred customized maps, easily-understood color-coded graphics and information associated with their locations in the system. The data includes lane configuration, traffic accident data stratified by high, medium and low levels, or as a display of the top five locations by number of angle, turn, rearend, or other accident types, and a comparison of specified differences in yearly accident frequencies. These and other data can be displayed on the screen at the request of the user. This is an important feature of the ITAGI system.

The second important feature of the ITAGI system is graphical presentation. Specifically, a graphic representation of the data can serve as an effective "filing system" because any specified location(s) in Troy can be instantly accessed by pointing to a map rather than by searching through records. With little computer knowledge, the user or traffic operator can easily get the information by simply selecting the desired location. This function can be very useful in ATIS when information is provided on an in-vehicle screen to the general road user via the traffic operations center. At this time, a quickly understood graphic presentation definitely is more useful than raw data.

The third important feature of the ITAGI system is the provision for possible modification. A GIS data storage system is able to respond to the changing needs of transportation agencies. The ITAGI system was designed for this purpose. The separation of the database and source program allows a more flexible data input and output process. The program codes need not be rewritten when the coded data are revised. Thus, the system is easily maintained. There are some exceptions, such as the aggregation and disaggregation of data, and the introduction of other types of accidents, or other variables. These limitations will be explained in the "limitations of ITAGI" section.

Finally, the ITAGI is a more flexible source of information than a general spreadsheet program. GIS can be formulated to meet the many objectives of the transportation agency. Inevitably, every transportation agency that implements a roadway information system (RIS) will have some GIS data requirements that will be unique to that agency. In this system, a traffic accident database, GIS capability of selecting and aggregating single or multiple intersections and midblock locations, the display of the safest path, quality control of traffic accidents, and a multimedia left-turn control expert system are integrated into a single system. The operator in the traffic operations center is not required to switch or retrieve files and perform routine calculations with the ITAGI system.

In summary, the ITAGI system provides quick access and response to traffic characteristics information, more easily understood presentations, improved updating capabilities, and a more flexible and comprehensive source of information than general spreadsheet programs.

3.11.3 DETERMINING MULTIPLE INTERSECTION OR MIDBLOCK CHARACTERISTICS

The ITAGI system has the ability to combine data from multiple intersections (or groups of intersections) or midblock locations. With mathematics-performing capability (note that currently, the program has aggregation ability only, but it can be rewritten to perform other mathematics-performing functions), the ITAGI system allows the user to do mathematics on the map. As described in section 3.3.2 and section 3.3.4, by combining traditional conditional query capabilities with spatial queries and adding mathematical manipulation, statistics, and charting, a full assessment of the road system is possible from within the ITAGI system. By using the "**add one more**" function, the user can exam accident records over the past six years and to incrementally add desired locations (intersection or midblock) and look at the incremental aggregate accident data for these locations. This capability is useful when a new traffic control strategy, such as a left-turn control strategy is implemented on specific locations. The ITAGI system allows the user to see the aggregate change in the total number of accidents, or the percentage of any specified type of accidents at these locations.

3.11.4 SAFEST (SHORTEST) PATH SEARCHING CAPABILITY

In the FAST-TRAC federal demonstration program, Ali-Scout has been selected as the route guidance and in-vehicle navigation system for improving travel efficiency based on finding the minimum travel time path between any two points in the network.

The ITAGI system has been constructed to find the minimum path between any two points based on other characteristics contained in the database. For example, if current data on the level-of-service (LOS) at each intersection approach were available, it would be possible to select the route between two points that maximizes the LOS, thus avoiding congested areas of the city.

To demonstrate this capability, the ITAGI system was programmed to select the route which passes through intersections that had the lowest accident rates in the most recent year for which accident data are available. This is named the safest route. The safest route is drawn on the screen and the analyst can see how the logic directs the route away from certain major intersections.

3.12 LIMITATIONS OF ITAGI

3.12.1 LACK OF DISAGGREGATE CAPABILITY

Like most analysis programs (not including general spreadsheet programs), aggregation and disaggregation problems also exist in the ITAGI system. When developing a program, a decision must be made on the number of years to use for a historical base and on how many variables to include in the system. The ITAGI system was designed primarily for the evaluation of SCATS since this evaluation was programmed to last three years, an annual database (rather than a daily or weekly database) was selected, and the prescribed graphical results are shown on a yearly basis before and after SCATS. Because of its intended use, certain types of accidents (angle, turn, and rearend) and limited variables (traffic accidents, traffic volumes, level of service, and average travel speed) that were necessary for the evaluation of SCATS were captured in the ITAGI system. These variables were selected in consultation with the Road Commission of Oakland County. While the system was not designed to test other types of accidents or to analyze changes occurring over a shorter period of time (less than one year), this is not a limitation of the ITAGI system as the source program could be rewritten for the user's specified purpose. However, it is a limitation on the application of the system as developed for this project. If a user wants to stratify accident data for a shorter period of time, such as a month or a day, or to use variables such as weather conditions (rain, clear, snow), road conditions (dry, wet, icy), or driver conditions (drinking), the database could be rewritten to include these variables. For example, if the user wanted to study the effect of converting traffic signals to flashing operation at night on alcohol involved accidents, the original database could be structured to include these variables. However, there is always a trade-off between the size of the database and the processing time for the program. The decision was made to include only these variables expected to be influenced by the SCATS system in the database.

3.12.2 DATA AVAILABILITY

Only selected intersections have turning movement volume data and only selected corridors have travel time data because the data were not available for other intersections and corridors. A study of the effect of geometric changes that occur in the system would how to be conducted external to the ITAGI system, as was done with the left turn control evaluation. The accident data is available in the ITAGI system, but the geometry could be coded to represent either the before condition or the after condition. Thus, the system is not designed to be used by an analyst not familiar with the network.

3.12.3 DATA ACCURACY

The traffic accident data were derived from the Michigan Department of Transportation master tape by writing SPSS program. Thus, any coding errors or location error included in the master tape will be carried forward into the ITAGI system. It is known that the 1992 master tape contains location errors, and these will be found in the ITAGI database. For this reason, comparisons were made for the years 1991 and 1993 or 1991 and 1994 in this study. The criteria used to separate the intersections from the midblock locations were the physical road (PR) number and mileage. The definition of the intersection used in the ITAGI system is the location of the intersection of the two centerlines plus 0.03 miles in each direction. This criteria may or may not be the same as other agency's definitions of an intersection.

CHAPTER 4 DEVELOPMENT OF THE MULTIMEDIA LEFT-TURN CONTROL EXPERT SYSTEM

This chapter describes how the multimedia left-turn control expert system was developed (knowledge acquisition and knowledge representation) and calibrated (model validation). This expert system provides knowledge-based and user-friendly information for the user. In addition, this expert system utilizes the computer multimedia technique to store video images, audio voices, pictures, and graphics for CD-ROM computer use.

4.1 KNOWLEDGE-BASED EXPERT SYSTEMS

Mishkoff [1985] defined expert systems or knowledge-based systems as computer programs that contain both declarative knowledge (facts about objects, events, and situations) and procedural knowledge (information about courses of action) to emulate the reasoning processes of human experts in a particular domain or area of expertise. Harmon and King [1985] also defined expert systems as artificial intelligence programs designed to represent human expertise in a specific domain. A knowledge-based expert system is a computer program that emulates human behavior in solving problems. It includes a separate mechanism that mimics the reasoning process of the human brain. Expert systems are composed of at least three basic entities: the knowledge base, inference engine, and a user interface.

The knowledge base contains rules expressing an expert's heuristics for the domain. The collection of facts, rules, and computational procedures that represent this domain is called its knowledge base; it is the power base of the expert system.

The inference engine is made up of rules that are used to control how the rules in the knowledge base are used or processed. Inference is the derivation of new facts from known facts. An inference engine is the processor of the known facts. The set of procedures for manipulating the information in the knowledge base to reach conclusions is called the inference engine. The objective of the inference engine is to find one or more solutions for the goal (or for a subgoal) of the consultation. It searches the facts and rules in the knowledge base and identifies and stores conclusions.

The user interface allows communication or interaction between the expert system and an end user. This can be textural, or the text can be augmented by visual or audible communication.

A knowledge-based expert system is one of the applications of artificial intelligence (AI) research to software programming. Artificial intelligence is a specialty area of computer science that attempts to make computers behave in a way that mimics logical human behavior [Ramamoorthy et al., 1987]. Robotics, image processing, and pattern recognition, as well as knowledge-based expert systems, are branches of artificial intelligence.

Expert systems provide advice for problem solving that is derived from the knowledge of experts. Expert systems typically make recommendations based on a knowledge base stored as a set of rules and facts. The objective of an expert system is to help the user choose a solution based on expert opinions.

As described above, the components of the expert system must contain at least three parts: the knowledge base, the inference engine, and a user interface. The knowledge base in the current application is composed of rules obtained from traffic experts responses to a questionnaire. The inference engine is the component that separates an expert system from a system using experts. If the knowledge base were stored in the computer without any inference mechanism and there was a good user interface to search the knowledge base, it could be considered a system using experts.

To construct a computerized expert system, the program must contain the knowledge base, the inference engine, and a user interface. It is possible to write an expert system in a computer language, such as C or FORTRAN. However, certain languages have been developed with features which make them particularly suitable for artificial intelligence work. PROLOG is a language which is designed for this purpose. The ITAGI system and multimedia left-turn control expert system were developed using an AI language PDC PROLOG, which stands for programming in logic. The reasons for selecting this particular language are its descriptive nature, ease in describing a relationship, and capability in symbolic processing.

By far, the most popular knowledge representation technique used in expert systems is rule-based. The production rule is simply a combination of **IF** and **THEN** as shown below:

Rule : IF Condition,
THEN Condition.

A rule-based system uses production rules to specify a set of conditions. The left-turn control expert system is a rule-based expert system. It uses **IF-THEN** statements to represent a production rule.

The PROLOG language provides a natural way to represent production rules. In addition, PROLOG's built-in pattern matching (unification) and backtracking facilities make it easy to implement a backward-chaining inference mechanism.

4.2 OBJECTIVES

As described in chapter 2, the purpose of a left turn control expert system is to expedite problem solving and decision making in the potential trade-offs between left-turn efficiency and safety, and express the rules and facts in understandable "English" rules. The objective of this study is to provide assistance in making the trade-off between left-turn efficiency and safety among the three left-turn treatments, permissive turns, protected turns, and no left turns. In this study, the object is divided into several subgoals listed below:

1. to expedite problem solving and decision making in the potential trade-offs between left-turn efficiency and safety,
2. to express the knowledge base (rules and facts) in understandable "English" rules,
3. to use multimedia techniques to demonstrate how a knowledge-based expert system (KBES) can be made more vivid and more effective than plain text, and
4. to demonstrate that the ITAGI system can be integrated with the expert system to form a decision support tool to assist the decision maker (traffic engineer) in retrieving and analyzing the available traffic characteristic data before determining the appropriate left-turn control treatment.

4.3 THE DESIGN PROCESS

There were seven activities used to develop the multimedia left-turn control expert system (Figure 4.1). These are: determining the variables for the left-turn control expert system; designing a questionnaire for acquiring knowledge from traffic specialists to build the knowledge base; video taping traffic experts and digitizing the video tape using Intel Video Recorder Pro; recompressing and editing the video file by Asymetrix Digital Video Producer; using the ID3 method to build decision trees and embedding rules and facts into the PDC PROLOG program; performing model verification and validation for the questionnaire rules and inductive rules; and finally employing Multimedia Toolbook 3.0 to integrate video, audio and picture files as a multimedia left-turn control expert system.

4.4 PURPOSE

The purpose of this part of the study was to select guidelines for determining whether permissive turns, protected turns or no left turn control should be used at an intersection using an expert system. As noted in the literature review, only a limited number of articles dealt with the selection of left-turn control by expert systems, and none of the previous studies contained guidelines for the option of no left turn control.

4.5 THE FACTORS USED IN DETERMINING THE APPROPRIATE LEFT-TURN CONTROL

As described in section 4.2, one of the subgoals for building a multimedia expert system was to demonstrate the integration of the ITAGI system as described in chapter 3

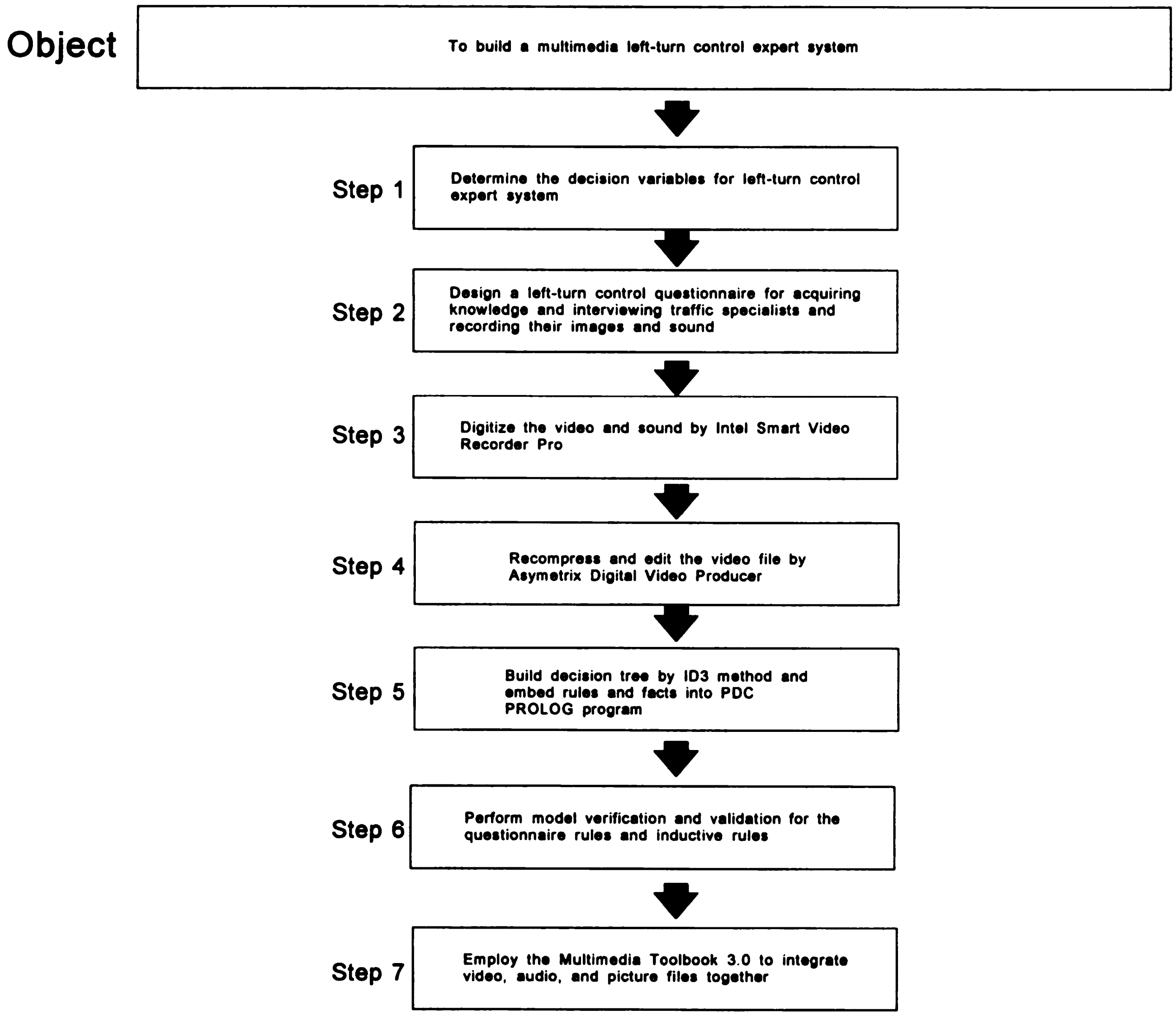

Figure 4.1 The Steps in Developing the Multimedia Left Turn Control Expert System

as a decision support tool to assist the decision maker (traffic engineer) in retrieving and analyzing traffic data necessary to determine the appropriate left-turn control treatment. Considering the decision variables used in the previous studies (literature) and the desire to integrate the ITAGI system in the selection process, the factors to be used in determining the left-turn control treatment were selected. They are:

1. overall level of service at the intersection,
2. left turn level of service at the intersection,
3. upstream and downstream intersection left turn level of service,
4. the frequency of left-turn accidents per year,
5. the left-turn volume (veh/hr),
6. the opposing through and right-turn volume (veh/hr),
7. the average speed in the driver's direction (mph), and
8. the average speed in the opposite direction (mph).

4.5.1 OVERALL LEVEL OF SERVICE AT THE INTERSECTION

The level of service (LOS) at the intersection is an important factor which will affect the choice of the left-turn control strategy. If the LOS at the intersection is too low, such as E or F, there is often insufficient time in the cycle for a protected left-turn phase. There may also be insufficient opportunities for a permissive left-turn movement. An option is to prohibit left turns for the approach. If the LOS is D, permissive left-turn control might be considered, while if the LOS is A, B, or C, with high left-turning volume the protected left-turn control becomes an option.

4.5.2 LEFT-TURN LEVEL OF SERVICE AT THE INTERSECTION

For the same reasons as above, the left-turn level of service at the intersection is an important variable. If the left-turn LOS is lower than the LOS of the other movements, protected left-turn control may be considered, depending on other factors.

4.5.3 UPSTREAM AND DOWNSTREAM INTERSECTION LEFT-TURN LEVEL OF SERVICE

If the upstream and downstream left-turn movements are already at LOS E or F, a protected or permissive left-turn control is desirable at the intersection, since there may not be acceptable alternatives for the driver if left turns are prohibited.

4.5.4 THE FREQUENCY OF LEFT-TURN ACCIDENTS PER YEAR

According to ITE Traffic Engineering Handbook [1991], protected left-turn control phasing should be considered when on any approach, there are four or more left-turn accidents within one year. Therefore, if the left-turn traffic accident frequency is high, protected left-turn control or prohibiting left turns should be considered.

4.5.5 THE LEFT-TURN VOLUME

The left-turn volume is also an important factor in selecting the appropriate left-turn control strategy. Historically, the product of left-turning volume and the opposing through and right-turning volume has been considered when deciding on a left-turn control strategy. If the demand for left-turning vehicles is high and the opposing through and right-turn volumes are high, permissive left-turn control will not function satisfactorily.

4.5.6 THE OPPOSING THROUGH AND RIGHT-TURN VOLUME

According to the Traffic Engineering Handbook [1991], protected left-turn control should be considered when the product of left-turning vehicles and opposing volumes during peak hours exceeds 100,000 on a four-lane street or 50,000 on a two-lane street, and the left-turn volume is greater than two vehicles per cycle with an average delay per left-turning vehicle of at least 35 seconds.

4.5.7 THE AVERAGE SPEED IN THE DRIVER'S DIRECTION (MPH)

Higher speed in the driver's direction increases a hazard for left-turning vehicles. The speed differential increases the risk of a collision between through traffic and traffic slowing to make a left turn. Therefore, prohibiting left turns should be considered on high speed roads.

4.5.8 THE AVERAGE SPEED IN THE OPPOSITE DIRECTION (MPH)

The speed of the traffic opposing the left-turning vehicles is an important factor in the safety of left-turns. As the speed of opposing traffic increases, it becomes more difficult for left-turning vehicles to judge the gap, and traffic accidents may increase. According to the Bottom et al. [1983] studies, most drivers underestimate time gaps at high speed. Therefore, high-speed opposing traffic argues against permissive left-turn control.

4.6 SAMPLE SIZE

The selection of the expert(s) is an important task in the development of an expert system. Unlike a general poll, or marketing survey, the appropriate sample size for building a knowledge-based expert system can not be easily determined by assuming (or testing for) a statistical distribution. The quality of the knowledge is much more important than the quantity of the knowledge. A large number of non-experts is worse than a few good experts who can contribute valuable knowledge to the expert system. None of previous studies reviewed for this study discussed the sample size needed in an expert system. However, Gonzalez and Dankel [1993] indicated the relationship between the size of an expert system and the number of experts interviewed. They assumed a direct relationship between the size of the knowledge-based system and its complexity. They concluded that small knowledge-based systems (containing less than approximately 200 rules) could be obtained from one expert or from the printed literature. Medium-sized knowledge-based systems (containing between 250 and 1,000 rules) are generally developed using specialized workstations or larger computers. The system may employ multiple experts in their development because of the need for multiple fields of expertise to build the system. The large expert systems (containing more than 1,000 rules) used to solve intricate and complex problems need multiple experts and a workstation or special purpose computer. These complex problems need multiple fields of expertise to build the system, and the problem itself can not be well defined.

The assumption about the size of the knowledge-based system and its complexity may not always be valid. In fact, the number of rules is not necessarily the only factor that should be used in deciding the number of experts. Other factors, such as the breadth of the knowledge based involved, the complexity of the rules (well or ill-defined), experts' competence and availability are also important factors for deciding the number of experts that should be involved.

In this study, the expert system is a small knowledge-based expert system containing less than 200 rules, and only one field of knowledge is involved (transportation engineering or traffic engineering). The rules used in this expert system were derived from a questionnaire, and the rules were well-defined (simple) and case by case (case-based) as shown in the questionnaire. The selected experts' competence were measured by a combinations of several factors. First, experts were selected from related organizations, such as Michigan State University (MSU), Michigan Department of Transportation (MDOT), and Oakland County Road Commission (OCRC). Second, years of employment in the field (transportation engineering or traffic engineering) were considered. The last factor was the experts' availability. The experts needed to be available and willing to participate throughout the expert systems development processes. After considering these factors, traffic experts for the first and second survey (model validation and consistency check) were selected (Table 4.1). In the first survey, six traffic experts were asked to complete the questionnaire. Among the traffic experts, three are professors, Dr. William Taylor, Dr. Richard Lyles, and Dr. Thomas Maleck from Michigan State University. The fourth expert from Michigan State University was Mr.

James Neve who served as a district traffic engineer for the Michigan Department of Transportation (MDOT) for many years. The other two experts were from the Oakland County Road Commission (OCRC), they are Mr. Mohammed Lutfi, a senior traffic engineer, and Mr. Dave Allyn, the director of traffic safety at OCRC. In the second survey, five traffic experts were asked to complete the questionnaire for model validation. Among the traffic experts, four out of five were the same experts as in the first survey. In addition, Mr. William Savage, who directed the traffic signal section of the Michigan Department of Transportation for many years, was invited to participate.

Table 4.1 The Interviewed Traffic Experts List

Expert's Name	Organization	Position	Years in the Trans.-related Field
Dr. William Taylor ***	Michigan State University	Professor	38
Dr. Richard Lyles ***	Michigan State University	Professor	29
Dr. Thomas Maleck ***	Michigan State University	Professor	31
Mr. James Neve *	Michigan State University	Senior Traffic Engineer	38
Mr. Mohammed Lutfi ***	Oakland County Road Commission	Senior Traffic Engineer	11
Mr. Dave Allyn *	Oakland County Road Commission	Director, Traffic Safety Department	21
Mr. William Savage **	Private Consultant (self-employed)	President	38

Note: * interviewed in the first survey

** interviewed in the second survey

*** interviewed expert in both surveys

4.7 KNOWLEDGE ACQUISITION AND REPRESENTATION

4.7.1 METHODOLOGY

A left-turn control questionnaire was designed for acquiring knowledge and for use in developing the inductive learning tool. Because not all combinations of all the variables were included in the questionnaire (by design), the knowledge-based expert system was forced to develop inductive rules. The definition of inductive reasoning, according to Webster's dictionary [Webster, 1960] is "reasoning from particular facts or individual cases to general conclusions". In artificial intelligence terms, inductive learning is performed by presenting to a machine a series of examples and the conclusions drawn from each example. The machine, through a set of redefined induction heuristics, analyzes each example and builds an internal representation of the domain characteristics that are present.

ID3 is an inductive reasoning tool used to develop rules and facts by learning from examples. ID3 was developed by Quinlan in the late 1970s to learn object classifications from labeled training examples (a machine learning method). This tool is very useful when a significant quantity of knowledge exists as examples or cases. The detailed computation of the ID3 algorithm can be found in most artificial intelligence (or expert system) books. The ID3 algorithm has the ability to derive a minimal classification tree from examples and to construct the necessary decision tree.

The major components of the ID3 algorithm are:

1. attributes,
2. decisions,
3. examples, and
4. inductive decision tree (or table)

There are two sets of rules imbedded in the left-turn control knowledge based expert system. First, all rules developed from the questionnaire. The second source is the inductive rules developed by the ID3 algorithm. The search logic for this program is shown in Figure 4.2. Given a set of input data, the search will first determine if an answer already has been derived by the traffic experts for an identical data set. If the identical data set does not exist, then the rules and facts created by the ID3 inductive machine learning tool are applied to the intersection. If neither of these sources produces a rule, the message "**Rules can't be found**" will be shown on the screen. If a rule can be found, it will immediately display the rule on the screen and explain what conditions that led to this conclusion.

To narrow the factors the users had to consider, some assumptions were made and presented to the experts when they were asked to complete the questionnaire:

1. the cycle length is equal to 80 seconds,
2. good intersection geometry,
3. there are no visual obstructions for drivers that want to make a left turn, and
4. only two opposing lanes must be crossed.

The questionnaire for the left-turn control expert system contains nine attributes, three decisions and twenty-one examples. The nine attributes are overall LOS, left-turn LOS, upstream left-turn LOS, downstream left-turn LOS, total left-turn related accidents at the intersection per year, left-turn volume (veh/hour), opposing through and right turn volume (veh/hour), average speed in the driver's direction (mph), and average speed in

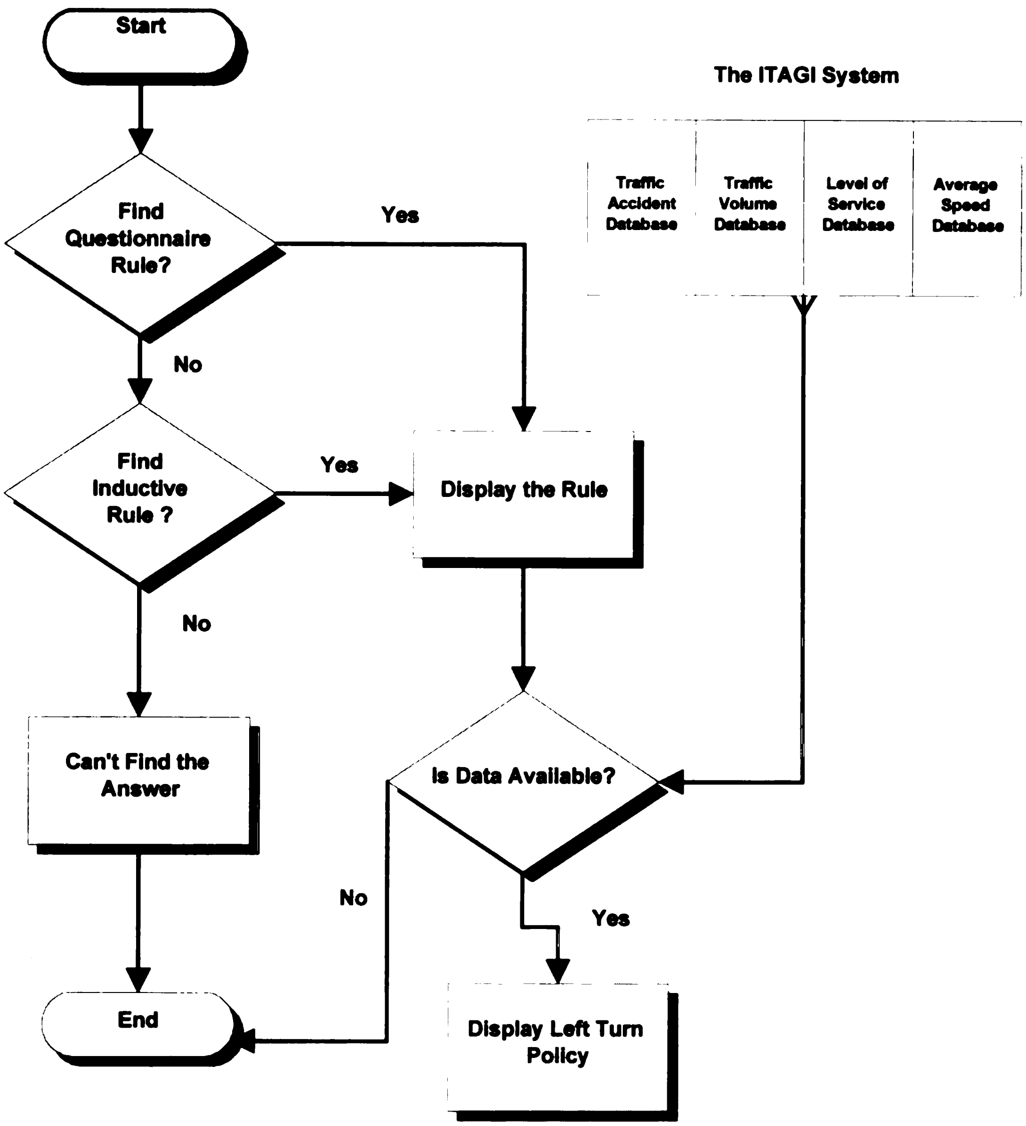

Figure 4.2 The Rule Search Logic Flow Chart for the Expert System

the opposing direction (mph). Each case presented in the questionnaire contained a different set of attribute values. For example, in the overall LOS attribute, there are three attribute values: C or better, D or E, and F or worse. The three decisions include permissive turns, protected turns, and no left-turn control. The 21 examples were developed using data from intersections in the City of Troy, Michigan. A copy of the questionnaire is shown in Appendix A (first survey) and Appendix B (second survey).

4.7.2 THE INITIAL SURVEY RESULT

The initial survey results were collected and prepared as input files for the ID3 program. The program then constructed the inductive decision tree (table) for the left-turn control expert system. The questionnaire based rules are shown as cases 1 through 21 in Table 4.2, Table 4.3 and Table 4.4. The inductive rules developed from the responses to the questionnaire are:

Inductive rule #1:

Implement permissive left-turn control

if left-turn LOS is C or better, and

if downstream left-turn LOS is C or better.

Inductive rule #2:

Implement permissive left-turn control

if left-turn LOS is C or better, and

if downstream left-turn LOS is D or E.

Table 4.2 The Percentage of the Traffic Experts Selecting Each Strategy (Case 1 - 8)

Condition and Case Number	1	2	3	4	5	6	7	8
LOS - Overall								
C or Better					X	X	X	X
D or E			X	X				
F or Worse	X	X						
LOS - Left Turn								
C or Better					X	X		X
D or E		X	X	X			X	
F or Worse	X							
No Left Turn								
LOS - Upstream Left Turn								
C or Better				X		X		
D or E	X	X			X			
F or Worse			X					
No Left Turn							X	X
LOS - Downstream Left Turn								
C or Better					X			
D or E	X		X	X		X		
F or Worse		X						
No Left Turn							X	X
The frequency of left-turn accidents per year								
0 -- 5	X	X	X	X	X	X	X	X
6 -- 10								
11 and above								
Left- Turn Volume (veh/hour)								
0 - 100		X		X	X	X		X
101 -- 150								
151 -- 200								
201 and above	X		X				X	
Opposing Thru + Right Volume (veh/hour)								
0 -- 600	X	X	X	X	X	X	X	
601 -- 800								
801 and above								X
Avg. Speed in the Driver's Direction (mph)								
15 -- 19.9								
20 -- 29.9	X		X		X	X	X	
30 and above		X		X				X
Avg. Speed in the Opposing Direction (mph)								
15 -- 19.9								
20 -- 29.9		X		X	X	X		X
30 and above	X		X				X	
The percentage of the strategy approval (%)								
Permissive	33	83	33	100	100	100	17	83
Protected	33	17	67	0	0	0	83	17
No Left Turn	33	0	0	0	0	0	0	0

Table 4.3 The Percentage of the Traffic Experts Selecting Each Strategy (Case 9 - 16)

Condition and Case Number	9	10	11	12	13	14	15	16
LOS - Overall								
C or Better								
D or E							X	X
F or Worse	X	X	X	X	X	X		
LOS - Left Turn								
C or Better			X		X			
D or E				X				
F or Worse	X	X				X		
No Left Turn							X	X
LOS - Upstream Left Turn								
C or Better								
D or E		X						
F or Worse	X		X	X		X	X	
No Left Turn					X			X
LOS - Downstream Left Turn								
C or Better	X		X		X			
D or E								
F or Worse		X		X				X
No Left Turn						X	X	
The frequency of left-turn accidents per year								
0 -- 5	X	X	X	X	X	X	X	X
6 -- 10								
11 and above								
Left- Turn Volume (veh/hour)								
0 -- 100				X			X	X
101 -- 150		X	X		X	X		
151 -- 200	X							
201 and above								
Opposing Thru + Right Volume (veh/hour)								
0 -- 600	X	X	X		X			
601 -- 800				X				
801 and above						X	X	X
Avg. Speed in the Driver's Direction (mph)								
15 -- 19.9								
20 -- 29.9	X	X	X	X	X		X	X
30 and above						X		
Avg. Speed in the Opposing Direction (mph)								
15 -- 19.9								
20 -- 29.9	X	X	X	X		X	X	X
30 and above					X			
The percentage of the strategy approval (%)								
Permissive	33	83	100	100	100	50	33	17
Protected	33	17	0	0	0	50	17	33
No Left Turn	33	0	0	0	0	0	50	50

Table 4.4 The Percentage of the Traffic Experts Selecting Each Strategy (Case 17 - 21)

Condition and Case Number	17	18	19	20	21
LOS - Overall					
C or Better					
D or E	X	X			
F or Worse			X	X	X
LOS - Left Turn					
C or Better					
D or E					
F or Worse					X
No Left Turn	X	X	X	X	
LOS - Upstream Left Turn					
C or Better		X			
D or E					
F or Worse	X		X	X	X
No Left Turn					
LOS - Downstream Left Turn					
C or Better			X		
D or E	X				
F or Worse		X		X	X
No Left Turn					
The frequency of left-turn accidents per year					
0 -- 5	X	X	X	X	X
6 -- 10					
11 and above					
Left- Turn Volume (veh/hour)					
0 -- 100	X	X	X	X	
101 -- 150					
151 -- 200					X
201 and above					
Opposing Thru + Right Volume (veh/hour)					
0 -- 600					
601 -- 800			X		
801 and above	X	X		X	X
Avg. Speed in the Driver's Direction (mph)					
15 -- 19.9					
20 -- 29.9	X		X		X
30 and above		X		X	
Avg. Speed in the Opposing Direction (mph)					
15 -- 19.9					
20 -- 29.9		X		X	X
30 and above	X		X		
The percentage of the strategy approval (%)					
Permissive	33	17	17	50	50
Protected	0	0	0	0	33
No Left Turn	66	83	83	50	17

<u>Inductive rule #3:</u>

Implement permissive left-turn control

if left-turn LOS is D or E,

if upstream left-turn LOS is C or better and

if left-turn volume is less than 100 (veh/hour).

<u>Inductive rule #4:</u>

Implement permissive left-turn control

if left-turn LOS is D or E,

if upstream left-turn LOS is F or worse and

if left-turn volume is less than 100 (veh/hour).

<u>Inductive rule #5:</u>

Implement protected left-turn control

if left-turn LOS is D or E,

if upstream left-turn is prohibited (no left turn) and

if left-turn volume is more than 201 (veh/hour).

<u>Inductive rule #6:</u>

Retain prohibited left-turn control

if overall LOS at the intersection is D or E,

if left-turn is prohibited (no left turn), if upstream left-turn is C or better and

if downstream left-turn LOS is F or worse.

Inductive rule #7:

Retain prohibited left-turn control

if overall LOS at the intersection is F or worse,

if left-turn is prohibited (no left turn),

if upstream left-turn is F or worse and

if downstream left-turn LOS is C or better.

The percentage of the experts selecting various left-turn control strategies is shown in Tables 4.2, 4.3 and 4.4. There was general agreement on the use of permissive left turns and the prohibition of left turns (cases 4, 5, 6, 11, 12, 13, 18 and 19), while the experts disagreed on the use of protected left turns (cases 1, 9, 15 and 16). The facts and rules from the survey results and from the ID3 inductive tool form the left-turn control knowledge base expert system.

4.8 MODEL VALIDATION

Because of the trade-off required in the left-turn control treatment decision, it was necessary to use traffic experts to build rules. Since each individual traffic expert may have a different concept of the most desirable trade-off between delay and safety, some variation in the response to the questionnaire was expected. To determine whether the inductive rules developed by the expert system were consistent with views of the experts when they were presented with new cases, a model validation procedure was developed. The model validation process is depicted in Figure 4.3. The overall purpose of model validation is to test if the expert system mimics the thought process of the experts. One form of validation is a check for consistency. The purpose of a consistency check is to determine whether the experts give the same answer to identical questions asked at different times. There were two consistency checks used in this study. First, two identical questions were included in the original questionnaire (first survey) to determine if the answer presented by each expert was the same. Second, after constructing the expert system, a second questionnaire was used in which several questions used in the first survey were presented to the same experts again to see if the results were consistent. Another type of validation was a check on the accuracy of the inductive rules developed by the ID3 algorithm. Banning [1984] reported that system validation is ideally accomplished by means of a Turing test (Figure 4.3) in which the same questions are presented to experts and the computer expert system. The expert system is validated if the results show no difference between the two sources. In the second questionnaire, some of the questions from the first survey and some new questions which required use of the inductive rules were mixed together. Six questions from the first questionnaire were repeated on the second questionnaire as a consistency check (two questions for each left-turn control strategy). Fifteen new scenarios selected to represent each of the inductive rules were used as the ID3 inductive rule check (refer to Table 4.5). The questions were mixed together and presented to five traffic experts including four experts who completed the first questionnaire. Please refer to Table 4.6 for rule numbers and

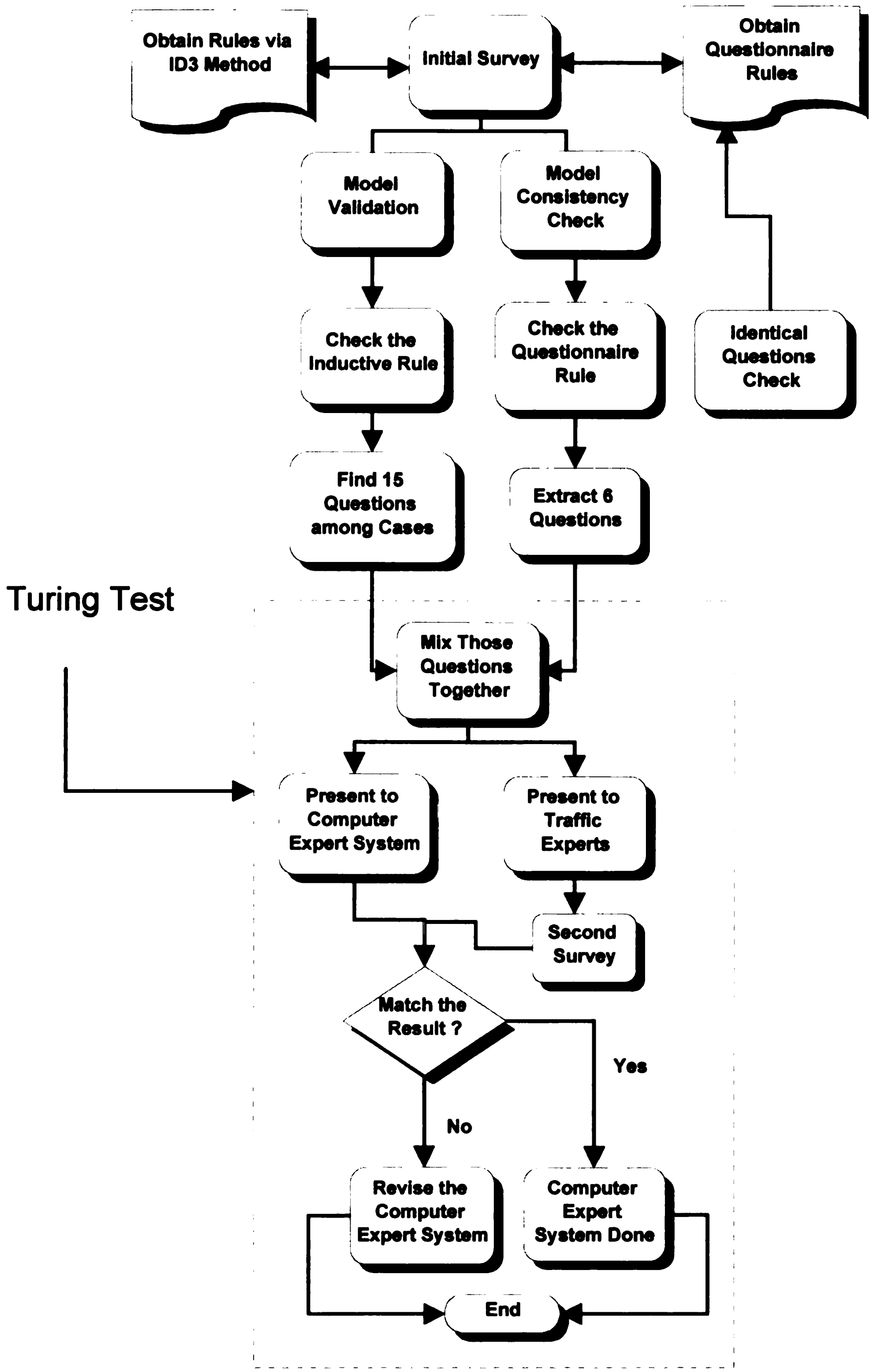

Figure 4.3 The Model Validation Process for the Expert System

Table 4.5 The Selected Testing Questions for the Inductive Rules

Rule No.	Ind.1	Ind.2	Ind. 3	Ind.4	Ind.5	Ind.6	Ind.7
LOS - Overall							
C or Better	x	x			**X**		
D or E	?		x			**X**	
F or Worse	x	?	?	x			**X**
LOS - Left Turn							
C or Better	**X**	**X**					
D or E			**X**	**X**	**X**		
F or Worse							
No Left Turn						**X**	**X**
LOS - Upstream Left Turn							
C or Better	?	x	**X**			**X**	
D or E	x						
F or Worse	x	?		**X**			**X**
No Left Turn	x	?			**X**		
LOS - Downstream Left Turn							
C or Better	**X**		?	?	?		**X**
D or E		**X**	x				
F or Worse			?	x	?	**X**	
No Left Turn			?	?			
The frequency of left-turn accidents per year							
0 – 5	x	x	x	x	x	x	x
6 – 10							
11 and above							
Left- Turn Volume (veh/hour)							
0 - 100	x	x	**X**	**X**		x	x
101 – 150	x						
151 – 200							
201 and above	?	?			**X**		
Opposing Thru + Right Volume (veh/hour)							
0 – 600	x	x	x	?	x	?	?
601 – 800				x			x
801 and above	?	?	?	?	?	x	?
Avg. Speed in the Driver's Direction (mph)							
15 – 19.9							
20 – 29.9	x	x		x	x	?	x
30 and above	?	?	x	?	?	x	?
Avg. Speed in the Opposing Direction (mph)							
15 – 19.9							
20 – 29.9	x	x	x	x	?	x	?
30 and above	x	?	?	?	x	?	x
Suggested Left-Turn Control Strategies							
Permissive	**X**	**X**	**X**	**X**			
Protected					**X**		
No Left Turn						**X**	**X**
Possible Paths							
Total: 15 paths	1	2	3	4	2	1	2

Note: **?** represents the selected testing questions for inductive rules in the second survey; x and **X** represent the questions which were asked in the first survey.

Table 4.6 The Model Validation Testing Rules for the Initial Survey

Rule No.	Q.3	Q.5	Q.6	Q.7	Q.18	Q.19	Ind.1	Ind.2	Ind. 3	Ind.4	Ind.5	Ind.6	Ind.7
LOS - Overall													
C or Better		X	X	X							X		
D or E	X				X							X	
F or Worse						X							X
LOS - Left Turn													
C or Better		X	X				X	X					
D or E	X			X					X	X	X		
F or Worse													
No Left Turn					X	X						X	X
LOS - Upstream Left Turn													
C or Better			X		X				X			X	
D or E		X											
F or Worse	X					X				X			X
No Left Turn				X							X		
LOS - Downstream Left Turn													
C or Better		X				X	X						X
D or E	X		X					X					
F or Worse					X							X	
No Left Turn				X									
The frequency of left-turn accidents per year													
0 -- 5	X	X	X	X	X	X							
6 -- 10													
11 and above													
Left- Turn Volume (veh/hour)													
0 - 100		X	X		X	X			X	X			
101 -- 150													
151 -- 200													
201 and above	X			X							X		
Opposing Thru + Right Volume (veh/hour)													
0 -- 600	X	X	X	X									
601 -- 800						X							
801 and above					X								
Avg. Speed in the Driver's Direction (mph)													
15 -- 19.9													
20 -- 29.9	X	X	X	X		X							
30 and above					X								
Avg. Speed in the Opposing Direction (mph)													
15 -- 19.9													
20 -- 29.9		X	X		X								
30 and above	X			X		X							
Suggested Left-Turn Control Strategies													
Permissive		X	X				X	X	X	X			
Protected	X			X							X		
No Left Turn					X	X						X	X

Note: Q.5 means questionnaire rule number 5 and Ind.3 means inductive rule number 3, etc.

Table 4.7 The Model Validation Results

Case No.	Expert #1 (First time)	Expert #2 (First time)	Expert #3 (First time)	Expert #4	Expert #5 (First time)	Rule Validation	Rule Consistent	Rule No.
1	1	2	2	1	2	2	x	Ind. 5
2	1	1	1	1	2	1	x	Ind. 2
3*	1 (1)	1 (1)	1 (1)	1	1 (1)	1	x	Q. 5
4**	1 (2)	2 (2)	1 (2)	1	1 (2)	2		Q. 3
5	3	3	3	3	1	3	x	Ind. 7
6	1	1	1	1	1	1	x	Ind. 3
7	1	1	1	1	1	1	x	Ind. 3
8*	1 (1)	1 (1)	1 (1)	1	1 (1)	1	x	Q. 6
9***	3 (3)	3 (3)	3 (3)	3	1 (1)	3	x	Q. 19
10	3	3	1	1	1	1	x	Ind. 4
11	1	1	1	1	1	1	x	Ind. 4
12	1	1	1	1	2	1	x	Ind. 2
13	1	1	1	1	1	1	x	Ind. 1
14	1	1	1	1	1	1	x	Ind. 4
15	1	1	1	1	1	1	x	Ind. 4
16	3	1	1	1	1	1	x	Ind. 3
17	3	3	3	3	2	3	x	Ind. 7
18	1	3	3	3	1	3	x	Ind. 6
19	2	1	2	1	2	2	x	Ind. 5
20***	1 (3)	3 (3)	1 (3)	3	2 (1)	3		Q.18
21**	2 (2)	1 (2)	2 (2)	1	1 (2)	2		Q.7

Second Time → (values in parentheses) First Time → (values outside parentheses)

See Table 4.6 for definitions (Rule No.)

Note: 1 represents permissive left-turn control
2 represents protected left-turn control
3 represents no left-turns
* represents permissive left-turn control consistency check
** represents protected left-turn control consistency check
***represents no left-turns consistency check

Table 4.7 for the model validation results.

4.8.1 CONSISTENCY CHECK RESULTS

In the first survey, one out of six interviewed experts failed to give the same answer when presented identical cases (case 10 and case 18 in Appendix A). From Table 4.7, the consistency check result shows that the experts did not always select the same strategy when the identical data set was presented in the first and second questionnaire. In the second survey, three cases (which then are treated as questionnaire rules) were answered differently by at least one expert. The logical reason for the traffic experts to change their mind is that the difference between the two strategies is small, and either of the strategies would be acceptable. For example, the choice between permissive and protected left-turn control must have been close for the questionnaire cases 3 and 7 because of the low number of left-turn accidents (0-5 per year), the high left-turn volume (201 and above), low opposing through and right-turn volume (0-600 veh/hour), high opposing speed (30 and above mph) and D or E left-turn level of service. From the safety and delay viewpoint, the low number of left-turn accidents per year and D or E left-turn level of service may cause the traffic experts to choose the permissive left-turn strategy. However, from the safety point of view, the high left-turn volumes and high opposing speed may cause the traffic experts to choose the protected left-turn control strategy. On the second survey, all experts except one agreed that the choice for questionnaire rule 18 was between permissive and no left-turns. This scenario included prohibiting left-turns at the intersection, heavy opposing through and right turn volume (801 and above veh/hour), high traffic speed in driver's direction (30 and above mph), low left-turn accidents (0-5 per year), and D or E overall intersection level of service. These conditions caused some traffic experts to vary their choice between permissive and no left-turn treatments. From the safety point of view, fewer traffic accidents should occur at the intersection when left turns are prohibited. Therefore, retaining the prohibited left-turn control may be a good choice. However, from the delay and convenience viewpoint, when left-turns are prohibited at the downstream intersections and there is D or E overall level of service at the current intersection, it may be a good choice to implement permissive left-turn control because the traffic has nowhere to make left turns.

The fact that there is a choice between safety and delay in the reason for considering the development of an expert system. If the traffic engineer merely relies on computer software to find the lowest delay solution for the left-turn control strategy, the protected left-turn control will always be the worst choice because it takes too much green time from the other vehicles (directions). However, the use of permissive control may cause a safety problem, and it is not reasonable to prohibit left turns at all intersections. In both surveys, the safety factor was kept constant with the number of the left-turn accidents between 0 and 5 per year. However, potential safety considerations were embedded in other variables, such as the opposing traffic speed, the cross product of left-turn volumes and opposing through and right turn volumes. These safety factors can not be measured by the computer software. Therefore, if the objective function for the left-turn control treatment includes safety, efficiency, and delay factors, the expert system can provide an acceptable answer because the experts are expected to take all these factors into account.

Some inconsistency between the results of the first and second survey was expected because of the sample size. The fewer the number of interviewed experts, the more likely it is to get an inconsistent result. In fact, in the first survey, one expert selected two different treatments when the same conditions were presented twice. In the second survey, if two out of the four experts changed their mind, it could lead to the conclusion that the questionnaire rules are not consistent, even if the rule was based on a minimum 67 percent majority. On the other hand, if there were a 67 percent majority for one solution in a sample of 20 and two experts changed their mind, the rule would not change, and the solution would meet the consistency check.

4.8.2 INDUCTIVE RULES' VALIDATION RESULTS

In Table 4.7, where the inductive rules are marked with asterisks, it can be seen that the ID3 inductive rules exactly matched those of the experts. All expert system answers were the same as the traffic experts. Therefore, the ID3 inductive rules are considered to be valid representations of the experts.

4.9 REVISING THE PDC PROLOG PROGRAM

After calibrating the expert system, there were three questionnaire rules which were not consistent with the first survey results. All of these changes were the result of two or more experts changing their recommendations when provided with the same scenario. Therefore, the PDC PROLOG program was revised by removing these three rules under the assumption that they represent close choices. The elimination of rules based on only one response to these close choice scenarios is one of the benefits of conducting a consistency check.

4.10 DEVELOPING THE MULTIMEDIA EXPERT SYSTEM

A multimedia program is the integration of two or more media effects (text, graphics, sound, video, and animation) to express or illustrate a message or tell a story, and to be viewed and interacted with on a computer. In this study, Multimedia Toolbook 3.0 was employed as a media integration tool to combine video, audio, and graphics. Intel Smart Video Recorder Pro was used as a digitizing tool to convert from video tape to video file (.avi) and the Asymetrix Digital Video Producer was utilized as an editing video file (.avi) tool.

Multimedia Toolbook 3.0 is the product of Asymetrix Corporation. It runs in two different modes: author mode, in which the application is created; and the reader mode, where the user interacts with the creation. Multimedia Toolbook 3.0, as its name implies, operates like a book that has pages, and the reader can interact with each page, move from page to page, or jump to any page.

Multimedia Toolbook 3.0 is an object-oriented program. Therefore, while objects are easy to create, the relationship among objects needs to be explained by the user. The language used to explain this relationship is called script. The script contains information which explains what happens when the user clicks a button or moves a scroll bar from one place to another.

The first step in the process is to capture the video as a digital computer file (.avi). After digitizing the video, the video must be trimmed and reproduced or recompressed to size the image (.avi file) to fit the Multimedia Toolbook 3.0 requirements.

The multimedia left-turn control expert system was constructed using the tools described above. It contains two parts: one is the input window used as a data entry allowing users to select any combination of the input variables. Note that these selections are exclusive (i.e. single selection). Once the user selects any combination of inputs and pushes the "**result**" button, the suggested left-turn control strategy and a data entry summary will be displayed. If the user would like an explanation of why these variables are related to the result or what the left-turn control guidelines are, the user can push the "**right arrow**" button to see the video tape. Note that the video stage in the program looks like a VCR which can be rewound and paused repeatedly. The video tape's source was created by taping Dr. William C. Taylor of Michigan State University. The contents of Dr. Taylor's comments have been summarized in the text window located below the video stage. In addition, pictures showing experts who contributed their knowledge to this KBES are posted on the right side of the video screen.

CHAPTER 5 SUMMARY

5.1 SUMMARY

This paper first described the development of the ITAGI system, then illustrated the use of the ITAGI system to conduct a safety analysis of SCATS. Second, this paper described the development of a multimedia left-turn control expert system. This expert system was designed to use the ITAGI system as a data source. Using data from intersections in the City of Troy, and the results of a questionnaire, the expert system generated a set of questionnaire rules and developed additional inductive rules by using the ID3 algorithm. These rules were tested using both a consistency check and a Turing test. These exercises have demonstrated that **both the ITAGI system and the multimedia left-turn control expert system are useful tools** in conducting traffic engineering studies. The following objectives of this study have been met:

1. **Production of a graphic interface capability for the City of Troy**. The ITAGI system has embedded several hundred customized maps, color-coded graphics and information associated with intersection(s) or road segment(s) in the City of Troy, Michigan. The data available to the user for any location include: number and type of traffic accident, number of traffic lanes, level of service, intersection delay, accident rate, traffic volume, and average travel speed on the major corridors. Once a location or a set of locations is specified, the number and type of accident (angle, turn, rearend, and others) for the years 1989 through 1994 can be displayed in a bar chart, or pie chart

format. Detailed information concerning this graphic interface capability is contained in section 3.2. Several examples of the use of this tool are provided in section 3.6. The traffic accident rate data available in the database were used in developing the **route guidance system** and **quality control charts**. As an example of an ATIS, the ITAGI system is programmed to select the safest path between any two locations in the network. The details of the safest path theory used in the route guidance system is described in section 3.4. Another system contained in the ITAGI system is the quality control charts for traffic accidents. The use of the quality control chart to determine the high accident locations and road segments (outliers) necessary for a Highway Safety Improvement Program (HSIP) is illustrated in section 3.5.

2. **Development of a GIS capable of locating accidents in the City of Troy**. A GIS is a useful decision support tool for roadway information systems because it provides a visual display of a transportation network and associated spatial data. The ITAGI system provides a convenient format for the user to obtain the specified information from the map. Rather than being limited to textual queries, it is possible to perform geographic queries. The user simply selects the desired points on the computer screen, and acquires the desired information. This capability is described and illustrated in sections 3.3.1 and 3.3.2 for intersection selection(s) and sections 3.3.3 and 3.3.4 for midblock selections(s). Examples based on this capability are contained in section 3.6.

3. **Development of a multimedia left-turn control expert system.** Multimedia techniques were employed to demonstrate a knowledge-based expert system (KBES) for selecting the most appropriate left turn control strategy at an intersection. The ITAGI

system was integrated with the expert system to demonstrate how data can be accessed to assist the decision maker (traffic engineer) determine the appropriate left-turn control strategy.

5.2 THE RESULTS OF ANALYSES USING THE ITAGI SYSTEM

The ITAGI system was designed as a tool to graphically display traffic characteristics data that can be used to evaluate changes in the traffic control system. Studies were conducted to evaluate the effect of SCATS and left-turn control strategy changes implemented at specific locations in the City of Troy, Michigan.

5.2.1 BEFORE AND AFTER SCATS ACCIDENT CHANGES

In the evaluation of SCATS, the ITAGI program was used to conduct an analysis of traffic accidents and injury accidents before and after SCATS was installed. The conclusion reached is that while certain accident types decreased after the installation of SCATS, overall there was no significant reduction in the accident frequency or severity.

The intersection accident comparison shows that the number of traffic accidents in 1993, when the majority of the intersections in the city were equipped with SCATS controller, was lower than the number of traffic accidents in 1991 or 1992. In 1994 and 1995 the intersections experienced more accidents than in 1991, 1992, and 1993. This was not the expected result when implementing the SCATS system. There was a large increase in both total and injury accidents at intersections in the first six months of 1994 (after installation of SCATS). The midblock accident comparison showed similar results, where the number of traffic accidents in 1993 was lower than the number of traffic accidents in 1991 followed by an increase in 1994 and 1995.

5.2.2 LEFT TURN POLICIES

The effect of prohibiting left-turns at specific intersections was analyzed by using the aggregate bar chart and pie chart properties of ITAGI. These results show that left turns were prohibited starting in 1992 for northbound and southbound traffic at the intersections of Big Beaver/Crooks, Big Beaver/Livernois, and Big Beaver/Rochester. After implementing this control, the total number of accidents increased from 110 (1991) to 137 (1993), to 151 (1994). The result shows that the percentage of turn accidents remained relatively stable: 4% (1991), 7% (1993) and 4% (1994).

A statistical test was conducted to determine if the prohibition of left turns resulted in an increase in accidents in 1993 compared to 1991. The statistics test shows that the null hypothesis could not be rejected for either total accidents or turn accidents at significance level $\alpha=0.05$.

The effect of implementing protected left-turn control was also analyzed by using the aggregate bar chart and pie chart properties of ITAGI. Protected left turn control was implemented in 1992 at the intersections of Maple/Livernois and Maple/Rochester. As a result of this change, the percentage of turn accident decreased from 13% (1991) to 7% (1993). The total number of accidents also decreased in 1993, but both numbers increased again in 1994.

A statistical test was conducted to determine if the protected left turn strategy resulted in fewer accidents in 1993 than in 1991. The statistics test shows that the null hypothesis could not be rejected for total accidents, but it was rejected for turn accidents at significance level α=0.05.

5.2.3 TRAFFIC LANES IN MIDBLOCK LOCATIONS

Using the ITAGI program, differences in the number of traffic accidents occurring on 2-lane roads, 5-lane roads, and Boulevards were analyzed. From this analysis, the results show that:

1. The Boulevard segments had the highest number of traffic accidents, followed by 5-lane roads, and then 2-lane roads.

2. 5-lane roads have the highest percentage of angle accidents, then 2-lane roads, and then Boulevards.

3. After implementing SCATS in 1993, 2-lane roads showed a significant increase in the percentage of rearend accidents.

4. After implementing SCATS, the percentage of angle accidents on 2-lane roads decreased from 20% (1992) to 18% (1993), to 9% (1994), while the percentage of angle accidents on 5-lane roads increased slightly from 21% (1992) to 27% (1993), to 23% (1994). On Boulevards, the angle accidents increased from 7% (1992) to 8% (1993), to 9% (1994).

5.3 DEVELOPMENT OF A MULTIMEDIA LEFT-TURN CONTROL EXPERT SYSTEM

The objective of the multimedia left-turn control expert system is to provide assistance in making the trade-off between left-turn efficiency and safety among the three left-turn treatments: permissive turns, protected turns, and no left turns.

The knowledge base was constructed through a questionnaire survey of experts. The results were used to identify the questionnaire rules, which are shown in Table 4.2, Table 4.3 and Table 4.4. There were 21 questionnaire rules developed. Because not all combinations of all the variables were included in the questionnaire (by design), the knowledge-based expert system was forced to develop inductive rules using the ID3 algorithm. The inductive rules are shown in Table 4.6. To determine whether the questionnaire rules and inductive rules developed by the expert system were consistent with views of the experts when they were presented with new cases, a model validation procedure was developed. The overall purpose of model validation is to determine if the expert system mimics the thought process of the experts. There were two tests involved in the model validation stage: a consistency check and a Turing test. There were two consistency checks used in this study. First, two identical questions were included in the original questionnaire (first survey) to determine if the answer presented by each expert was the same. One of the six interviewed experts failed to give the same answer when presented identical cases (case 10 and case 18 in Appendix A). Second, when the same case was presented on both the first and the second survey, three out of six selected questions were answered differently by at least one expert. The consistency check results shows that the experts did not always select the same strategy when presented with identical data sets. The logical reason for the traffic experts to change their mind is that the difference between the two strategies is small, and either of the strategies would be acceptable. Finally, the Turing test was performed to test if cases where the inductive rules obtained from the ID3 algorithm were consistent with the left turn control strategy selected by the traffic experts. All the cases derived from the ID3 algorithm passed the Turing test as all of the inductive rules matched those of the experts. Therefore, the ID3 inductive rules are considered to be valid representations of the experts.

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APPENDICES

Appendix A

The Expert System Questionnaire (First Survey)

Dr. William C. Taylor
Transportation program
Department of Civil and Environmental Engineering
Michigan State University

June 28, 1995

Objectives and Assumptions

The purpose of this questionnaire is to help us build an expert system for use in determining the appropriate left-turn control strategies at an urban intersection. In order to narrow the context that we have to consider, there are some assumptions to be made in this questionnaire:

- **Assume good intersection geometry.**
- **Assume there are no visual obstructions for drivers making a left turn.**
- **Assume the number of opposing lanes that must be crossed are not a problem.**

Left-Turn Control Strategies To Be Selected

1. **Permissive Left Turn Control**
2. **Protected Left Turn Control**
3. **No Left Turn**

Factors to Be Considered:

1. **Overall Level of Service at the Intersection**
2. **Left Turn Level of Service at the Intersection**
3. **Upstream and Downstream Intersection Level of Service**
4. **The Frequency of Left-Turn Accidents Per Year**

5. The Left-Turn Volume (VEH/HR)

6. The Opposing Thru and Right-Turn Volume (VEH/HR)

7. The Average Speed in the Driver's Direction (MPH)

8. The Average Speed in the Opposite Direction (MPH)

Please fill out this questionnaire using ONE of the three left-turn control strategies. Thank you.

Part I. Basic Information

Name: ____________________________

Education: _________________________
Discipline

____
Degree

How long have you been working in a transportation-related job?

__________________________________(years)

Employer Name:________________________

Position:_______________________________

Employer's Address

____

____
City State Zip Code

Your Phone: (_____) _______________

We appreciate your time. Thank you.

Part II. Questionnaire

Condition and Case Number	1	2	3	4	5	6	7	8
LOS - Overall								
C or Better					X	X	X	X
D or E			X	X				
F or Worse	X	X						
LOS - Left Turn								
C or Better					X	X		X
D or E		X	X	X			X	
F or Worse	X							
No Left Turn								
LOS - Upstream Left Turn								
C or Better				X		X		
D or E	X	X			X			
F or Worse			X					
No Left Turn							X	X
LOS - Downstream Left Turn								
C or Better					X			
D or E	X		X	X		X		
F or Worse		X						
No Left Turn							X	X
The frequency of left-turn accidents per year								
0 -- 5	X	X	X	X	X	X	X	X
6 -- 10								
11 and above								
Left- Turn Volume (veh/hour)								
0 - 100		X		X	X	X		X
101 -- 150								
151 -- 200								
201 and above	X		X				X	
Opposing Thru + Right Volume (veh/hour)								
0 -- 600	X	X	X	X	X	X	X	
601 -- 800								
801 and above								X
Avg. Speed in the Driver's Direction (mph)								
15 -- 19.9								
20 -- 29.9	X		X		X	X	X	
30 and above		X		X				X
Avg. Speed in the Opposing Direction (mph)								
15 -- 19.9								
20 -- 29.9		X		X	X	X		X
30 and above	X		X				X	
Suggested Left Turn Control Strategies								
Permissive								
Protected								
No Left Turn								

Part II. Questionnaire

Condition and Case Number	9	10	11	12	13	14	15	16
LOS - Overall								
C or Better								
D or E							X	X
F or Worse	X	X	X	X	X	X		
LOS - Left Turn								
C or Better			X		X			
D or E				X				
F or Worse	X	X				X		
No Left Turn							X	X
LOS - Upstream Left Turn								
C or Better								
D or E		X						
F or Worse	X		X	X		X	X	
No Left Turn					X			X
LOS - Downstream Left Turn								
C or Better	X		X		X			
D or E								
F or Worse		X		X				X
No Left Turn						X	X	
The frequency of left-turn accidents per year								
0 -- 5	X	X	X	X	X	X	X	X
6 -- 10								
11 and above								
Left- Turn Volume (veh/hour)								
0 -- 100				X			X	X
101 -- 150		X	X		X	X		
151 -- 200	X							
201 and above								
Opposing Thru + Right Volume (veh/hour)								
0 -- 600	X	X	X		X			
601 -- 800				X				
801 and above						X	X	X
Avg. Speed in the Driver's Direction (mph)								
15 -- 19.9								
20 -- 29.9	X	X	X	X	X		X	X
30 and above						X		
Avg. Speed in the Opposing Direction (mph)								
15 -- 19.9								
20 -- 29.9	X	X	X	X		X	X	X
30 and above					X			
Suggested Left Turn Control Strategies								
Permissive								
Protected								
No Left Turn								

Part II. Questionnaire

Condition and Case Number	17	18	19	20	21	22
LOS - Overall						
C or Better						
D or E	X		X			
F or Worse		X		X	X	X
LOS - Left Turn						
C or Better						
D or E						
F or Worse		X				X
No Left Turn	X		X	X	X	
LOS - Upstream Left Turn						
C or Better			X			
D or E		X				
F or Worse	X			X	X	X
No Left Turn						
LOS - Downstream Left Turn						
C or Better				X		
D or E	X					
F or Worse		X	X		X	X
No Left Turn						
The frequency of left-turn accidents per year						
0 -- 5	X	X	X	X	X	X
6 -- 10						
11 and above						
Left- Turn Volume (veh/hour)						
0 -- 100	X		X	X	X	
101 -- 150		X				
151 -- 200						X
201 and above						
Opposing Thru + Right Volume (veh/hour)						
0 -- 600		X				
601 -- 800				X		
801 and above	X		X		X	X
Avg. Speed in the Driver's Direction (mph)						
15 -- 19.9						
20 -- 29.9	X	X		X		X
30 and above			X		X	
Avg. Speed in the Opposing Direction (mph)						
15 -- 19.9						
20 -- 29.9		X	X		X	X
30 and above	X			X		
Suggested Left Turn Control Strategies						
Permissive						
Protected						
No Left Turn						

Appendix B

The Expert System Questionnaire (Second Survey)

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January 26, 1996

Objectives and Assumptions

The purpose of this questionnaire is to help us build an expert system for use in determining the appropriate left-turn control strategies at an urban intersection. In order to narrow the context that we have to consider, there are some assumptions to be made in this questionnaire:

- **Assume the cycle length at each direction is less than 80 seconds, and the left-turn capacity won't be affected by the cycle length**
- **Assume good intersection geometry.**
- **Assume there are no visual obstructions for drivers making a left turn.**
- **Assume the number of opposing lanes that must be crossed are not a problem.**

Left-Turn Control Strategies To Be Selected

1. **Permissive Left Turn Control**
2. **Protected Left Turn Control**
3. **No Left Turn**

Factors to Be Considered:

1. **Overall Level of Service at the Intersection**
2. **Left Turn Level of Service at the Intersection**
3. **Upstream and Downstream Intersection Level of Service**
4. **The Frequency of Left-Turn Accidents Per Year**
5. **The Left-Turn Volume (VEH/HR)**
6. **The Opposing Thru and Right-Turn Volume (VEH/HR)**
7. **The Average Speed in the Driver's Direction (MPH)**
8. **The Average Speed in the Opposite Direction (MPH)**

Please fill out this questionnaire using ONE of the three left-turn control strategies. Thank you.

Part I. Basic Information

Name: ______________________________

Education: __________________________
Discipline

____
Degree

How long have you been working in a transportation-related job?

____________________________________(years)

Employer Name:______________________

Position:_____________________________

Employer's Address

____

____
City State Zip Code

Your Phone: (_____) ______________

We appreciate your time. Thank you.

Part II. Questionnaire

Condition and Case Number	1	2	3	4	5	6	7	8
LOS - Overall								
C or Better	X		X					X
D or E				X				
F or Worse		X			X	X	X	
LOS - Left Turn								
C or Better		X	X					X
D or E	X			X		X	X	
F or Worse								
No Left Turn					X			
LOS - Upstream Left Turn								
C or Better						X	X	X
D or E			X					
F or Worse		X		X	X			
No Left Turn	X							
LOS - Downstream Left Turn								
C or Better	X		X		X			
D or E		X		X				X
F or Worse							X	
No Left Turn						X		
The frequency of left-turn accidents per year								
0 -- 5	X	X	X	X	X	X	X	X
6 -- 10								
11 and above								
Left- Turn Volume (veh/hour)								
0 - 100			X		X	X	X	X
101 -- 150								
151 -- 200								
201 and above	X	X		X				
Opposing Thru + Right Volume (veh/hour)								
0 -- 600			X	X	X			X
601 -- 800								
801 and above	X	X				X	X	
Avg. Speed in the Driver's Direction (mph)								
15 -- 19.9								
20 -- 29.9			X	X				X
30 and above	X	X			X	X	X	
Avg. Speed in the Opposing Direction (mph)								
15 -- 19.9								
20 -- 29.9	X		X		X			X
30 and above		X		X		X	X	
Suggested Left Turn Control Strategies								
Permissive								
Protected								
No Left Turn								

Part II. Questionnaire

Condition and Case Number	9	10	11	12	13	14	15	16
LOS - Overall								
C or Better								
D or E					X			
F or Worse	X	X	X	X		X	X	X
LOS - Left Turn								
C or Better				X	X			
D or E		X	X			X	X	X
F or Worse								
No Left Turn	X							
LOS - Upstream Left Turn								
C or Better					X			X
D or E								
F or Worse	X	X	X			X	X	
No Left Turn				X				
LOS - Downstream Left Turn								
C or Better	X	X	X		X			X
D or E				X				
F or Worse								
No Left Turn						X	X	
The frequency of left-turn accidents per year								
0 -- 5	X	X	X	X	X	X	X	X
6 -- 10								
11 and above								
Left- Turn Volume (veh/hour)								
0 -- 100	X	X	X			X	X	X
101 -- 150								
151 -- 200								
201 and above				X	X			
Opposing Thru + Right Volume (veh/hour)								
0 -- 600			X			X		
601 -- 800	X							
801 and above		X		X	X		X	X
Avg. Speed in the Driver's Direction (mph)								
15 -- 19.9								
20 -- 29.9	X							
30 and above		X	X	X	X	X	X	X
Avg. Speed in the Opposing Direction (mph)								
15 -- 19.9								
20 -- 29.9								
30 and above	X	X	X	X	X	X	X	X
Suggested Left Turn Control Strategies								
Permissive								
Protected								
No Left Turn								

Part II. Questionnaire

Condition and Case Number	17	18	19	20	21
LOS - Overall					
C or Better			X		X
D or E		X		X	
F or Worse	X				
LOS - Left Turn					
C or Better					
D or E			X		X
F or Worse					
No Left Turn	X	X		X	
LOS - Upstream Left Turn					
C or Better		X		X	
D or E					
F or Worse	X				
No Left Turn			X		X
LOS - Downstream Left Turn					
C or Better	X				
D or E					
F or Worse		X	X	X	
No Left Turn					X
The frequency of left-turn accidents per year					
0 -- 5	X	X	X	X	X
6 -- 10					
11 and above					
Left- Turn Volume (veh/hour)					
0 -- 100	X	X		X	
101 -- 150					
151 -- 200					
201 and above			X		X
Opposing Thru + Right Volume (veh/hour)					
0 -- 600		X			X
601 -- 800					
801 and above	X		X	X	
Avg. Speed in the Driver's Direction (mph)					
15 -- 19.9					
20 -- 29.9		X			X
30 and above	X		X	X	
Avg. Speed in the Opposing Direction (mph)					
15 -- 19.9					
20 -- 29.9	X		X	X	
30 and above		X			X
Suggested Left Turn Control Strategies					
Permissive					
Protected					
No Left Turn					