

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600



Order Number 9510683

**The Road Utilization Learning Expert System (RULES): An
expert system for emergency vehicle routing and control**

Listowsky, Philip, Ph.D.

City University of New York, 1994

Copyright ©1994 by Listowsky, Philip. All rights reserved.

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106



it

THE ROAD UTILIZATION LEARNING EXPERT SYSTEM (RULES):
AN EXPERT SYSTEM FOR EMERGENCY VEHICLE
ROUTING AND CONTROL

by

PHILIP LISTOWSKY

A dissertation submitted to the Graduate Faculty in Computer Science in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

1994

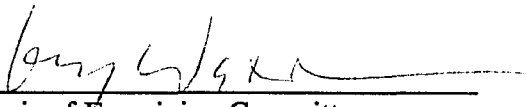
© 1994

PHILIP LISTOWSKY

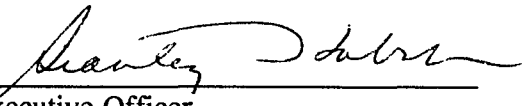
All Rights Reserved

This manuscript has been read and accepted for the Graduate Faculty in Computer Science in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

9/16/84
Date


Chair of Examining Committee

Sept. 22, 1994
Date


Executive Officer

Dr. Samuel Davidovics

Dr. Jacob Shapiro

Dr. Thomas C. Wesselkamper

Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

Abstract**THE ROAD UTILIZATION LEARNING EXPERT SYSTEM (RULES):
AN EXPERT SYSTEM FOR EMERGENCY VEHICLE
ROUTING AND CONTROL**

by

Philip Listowsky

Adviser: Professor Jerry Waxman

The major objective of this research is the description of a process for the design and production of a computer expert system which emulates the vehicle routing decision making and expert knowledge processes of human expert emergency service professionals. A project goal is the production of a system which places this expert knowledge at the disposal of non-expert emergency services personnel. It is expected that this will facilitate optimal emergency services personnel and resource utilization by effectively allowing *all* personnel to function as effectively as the *expert personnel*. The knowledge-based, Road Utilization Learning Expert System (RULES) determines the best route to get from a starting location to a given destination at different times and under varying conditions. Several techniques are employed, including the production of inference rules, the coding of a knowledge-base, and applying heuristic solutions to a special routing problem not soluble by ordinary algorithmic methods.

A rule-based system was formulated from knowledge of significant factors that may influence path choices, and expert considerations of how these factors interact with each other. One source for this information was a survey of professionals in the emergency services dispatching field, conducted to determine critical factors

influencing route decisions. In addition to providing raw data used in weighting factors which affect the routing decision making process, the participants were queried about their need for a system like RULES. These survey results indicated that about 70% of emergency services chiefs nationwide would trust a computer with the task of dispatching their units. These respondents also chose a computer system containing the knowledge of all human experts in the department, as a method that elicits the greatest confidence and trust. We have designed a strategy for the gathering of knowledge and the production of a rule-of-inference model from this information. A description of techniques which have been developed for the testing, operation, and maintenance of this model are also presented. The long term significance of the original methods created and described here is in their providing a method for producing expert systems which emulate the expert decision making processes of human emergency services experts.

ACKNOWLEDGEMENTS

The author wishes to sincerely thank Professor Jerry Waxman for the opportunity to share in his enormous wealth of scientific knowledge. The author is also grateful to Professor Robert Goldberg for his selfless dedication in administering inspirational guidance, and for the application of his technical skills which were so often necessary in the execution of this task. Professor Thomas C. Wesselkamper consistently provided valuable encouragement for this work from inception through conclusion. Professor Stanley Habib also offered advice and encouragement for this work. Finally, the contributions of Professor Jacob Shapiro and Professor Samuel Davidovics are gratefully acknowledged.

Table of Contents

	<u>Page</u>
I. OVERVIEW AND THEORETICAL FOUNDATIONS	1
1. INTRODUCTION	1
1.1 Motivation	1
1.2 Background	6
2. REVIEW OF RELATED WORK	10
2.1 The Application of Expert Systems	10
2.2 Computer Systems for Routing Problems	14
3. RULES PROJECT OBJECTIVES	20
3.1 Project Goals	20
3.2 System Design Specifications	22
II. THE DESIGN AND PRODUCTION OF THE RULES SYSTEM	23
1. Design Goals	23
1.1 Scope of System Coverage	23
1.2 Input/Output Expectations	24
1.3 System Maintenance and Upgrades	25
2. RULES Resources for Data Collection and Processing	26
2.1 Information Sources	26
2.1.1 Raw Data	29
2.1.2 Interviews	31
2.1.3 Subject Literature	33
2.1.4 Survey of Experts	34
2.2 Expert System Development Tool	47
3. RULES Project Architecture	48
3.1 I/O and User Interface	48
3.2 Information Flow	50
3.3 Information Management	51

Table of Contents (contd.)

4.	Coding and Execution of RULES	53
4.1	Transforming Expert Knowledge into Rules	53
4.2	Running the RULES System	60
5.	Verification, Validation, and System Testing	61
5.1	Verification	63
5.2	Testing and Validation	64
III.	CONCLUSIONS AND OBSERVATIONS	68
1.	System Assessment and Project Conclusions	68
2.	Areas for Future Expansion of RULES	68
	APPENDICES	71
A1.	RESOURCES USED IN THE PRODUCTION OF RULES	71
A1.1	Survey of Emergency Services Personnel	71
A1.2	Traffic Data Samples:	74
A1.2.1	Example of N.Y.C. D.O.T. Data	74
A1.2.2	Example of N.Y.S. D.O.T. Data	77
A1.2.3	Example of U.S. D.O.T. Data	78
A1.3	National Climactic Data Center Weather Data	79
A2.	SUPPORT FOR THE RULES PROJECT	82
A2.1	Support from Emergency Services (LAPD Cooperation)	82
A2.2	Support from Dept. of Transportation (NYCDOT Experts)	83
	REFERENCES	84

Tables and Figures

<u>Tables</u>	<u>Page</u>
I. Traditional Driving Instruction for Emergency Vehicle Drivers	8
II. Advantages of Applying a Knowledge Based System	11
III. Results of Diderich Survey	14
IV. Information Sources for the RULES Expert System	28
V. Survey Results: Service Types	36
VI. Survey Results: Department Sizes	36
VII. Survey Results: Number of Vehicles	36
VIII. Survey Results: Area Covered	37
IX. Survey Results: Unit Dispersal	37
X. Survey Results: Response Time	37
XI. Survey Results: Distance Traveled	37
XII. Survey Results: Communication	38
XIII. Survey Results: Choosing Units	38
XIV. Survey Results: Choosing the Best Route:	38
XV. Survey Results: Method Trusted for Dispatching	39
XVI. Survey Results: Trust in Computers	40
XVII. Survey Results: Traffic Flow Predictors	41
XVIII. Survey Results: Current System Effectiveness	41
XIX. Survey Results: Future Systems	42

Tables and Figures (contd.)

<u>Figures</u>	<u>Page</u>
1. Basic Incident Response Scenario	3
2. Emergency Services Situation: Incident Response	4
3. Diagram of RULES System Usage	21
4. Traffic Volume Measurement and Flow Rate Computation	31
5. Input/Output Relationships in RULES	48
6. Sample Screen Display for RULES	49
7. Sample Output on RULES Screen Display	49
8. Information Flow in RULES	50
9. System Management Relationships	52

I. OVERVIEW AND THEORETICAL FOUNDATIONS

1. Introduction

1.1 Motivation

The generic vehicle routing problem has been investigated in great detail (Golden 1986). Most attempts were applied to commercial delivery applications and were executed with straightforward shortest-path algorithms or simple heuristics in the form of the traveling-salesman problem. However the emergency services routing problem involves a complexity, which does not lend itself to solubility with these traditional methods. An Expert System, the Road Utilization Learning Expert System (RULES) has been devised to address these complexities and generate solutions to emergency services routing problems. Although recent Expert System developments and Expert System theory are applied in the production of this project, new techniques are necessary to adapt the resources available to the problem at hand, and to emulate the emergency services personnel decision making process. Nearly all current Expert Systems work focuses on a limited domain of application areas. In addition to theoretical work in academic institutions, the systems are applied extensively in a narrow group of fields: medicine, electronics, mathematics, military science, law, chemistry, engineering, and computer systems. A few more areas receive some coverage: geology, space technology, process control, information management, manufacturing, agriculture, and meteorology. Law is well represented among the Expert System examples produced to date. Law *enforcement* had not been addressed

extensively by knowledge engineers, though many aspects of law enforcement are computerized. Computer Aided Dispatching (CAD) systems currently in operation consist of data pertaining to unit (emergency vehicle) status, unit availability, unit location, and incident response type and priority - *not* best-route selection. In fact, interviews conducted for the production of RULES revealed that emergency services officers' driving training covers only driving safety and car-stop safety, to the exclusion of route-selection. Officers are expected to become proficient at route-selection only with time as they gather experience (Stokes 1994). A long-range goal of the RULES project is that the techniques developed in the production of this expert system for solving the emergency vehicle routing problem, can, in the future, be extended and applied to other law enforcement problems (e.g. choosing the best unit for an incident, once RULES chooses the best route).

Emergency Vehicle operators are called upon to make routing decisions on a continual basis. In responding to an incident they must first determine the nature of the incident (emergency or non-emergency). They then assess current conditions which affect a route-decision (time, weather, traffic flow, roadway specific factors). Finally this information is assimilated and a best-route to the incident is chosen. A general representation of the problem is illustrated in figure 1. below.

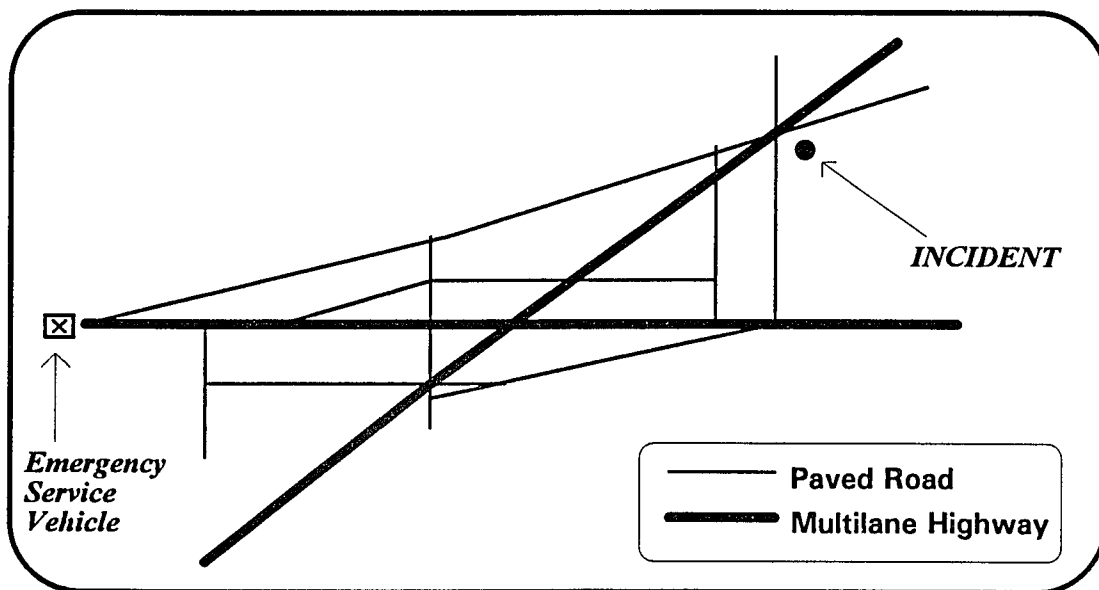


Figure 1. Basic Incident Response Scenario

The hypothetical case pictured above depicts a small segment of a road network. Most real world Emergency Services are faced with vastly more complex and extensive road networks. Familiarity with a city and the best ways to get from point to point, is a skill developed over time. In New York City, for example, it might take ten years for an officer to become an expert at choosing routes within one borough alone, much less over the entire city (Wolf 1994).

Figure 2. illustrates a more representative scenario of the real world routing problems facing emergency services personnel. It depicts a simplified representation of the New York City road network. Major roads, highways, and auto access routes are shown. Also depicted are the location of an incident (a bomb threat), two of the New York City Police Department's Emergency Service Unit bases, and the routes chosen by the human expert when presented with this scenario during an interview conducted in the production of RULES (Wolf 1994).

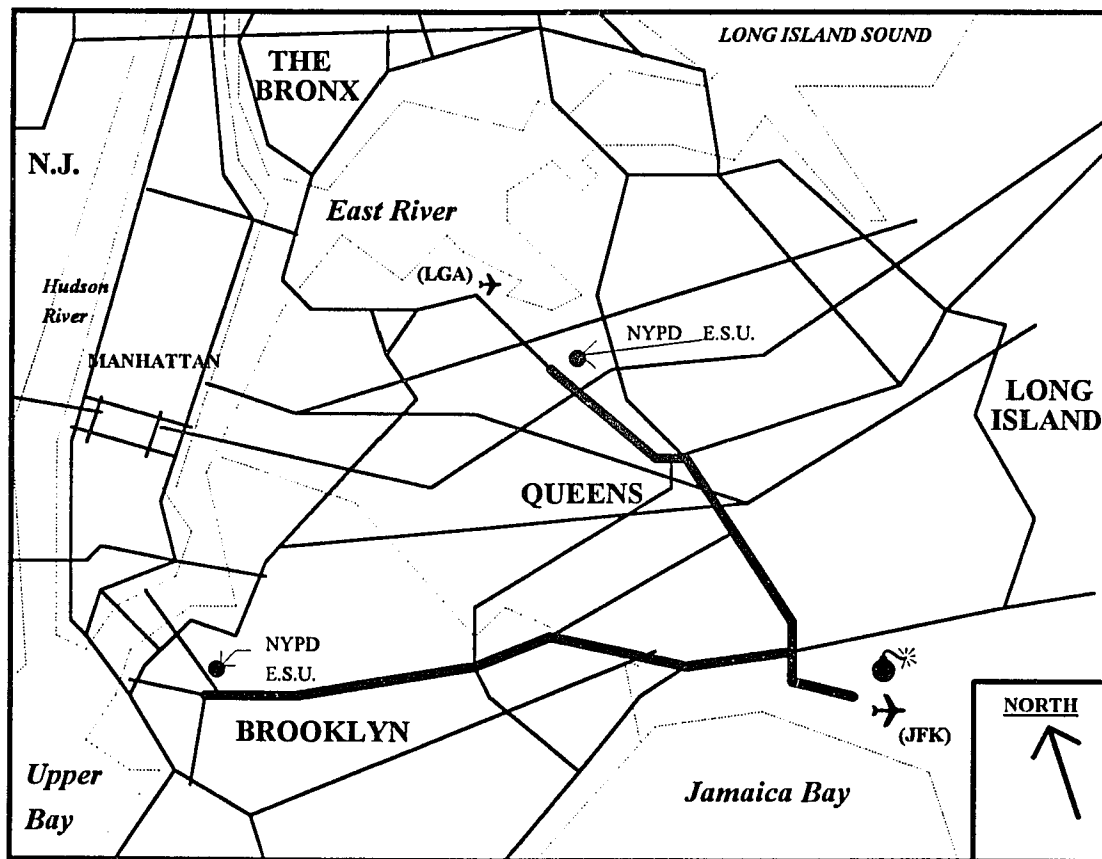


Figure 2. Emergency Services Situation: Incident Response

In this hypothetical situation, the E.S.U. vehicles must respond to a bomb threat at JFK airport. The thin lines in Figure 2. depict roadways - the thicker lines represent the best-route. The gravity of the situation dictates that the units arrive at the incident as quickly as possible. Human experts (i.e. experienced officers) apply their knowledge of the roads and conditions which affect each road, to the current situation, and choose the best path to the incident. RULES codifies that human expert knowledge, integrates current conditions data, and presents route recommendations. This system facilitates the selection of the best path, even if conditions dictate that a rookie officer respond to the incident.

The Road Utilization Learning Expert System (RULES) project is an expert system which effectively replicates the thought processes of human experts who dispatch vehicles and human experts who select routes. The goal of the RULES project is the production of a knowledge-based system which determines the best route to get from a starting location to a given destination at different times and under varying conditions. A rule-based system has been being formulated from knowledge of significant factors that may influence path choices as well as expert considerations of how these factors interact with each other. A survey of police and fire chiefs nationwide was conducted to gather information to form part of the core of RULES. Interviews of human experts in the emergency services and traffic control fields, were conducted. In addition, the rules for routing have been designed in conjunction with principles set down in emergency services manuals, and in traffic law. The data obtained by the survey of public service professionals also includes information about these experts' receptiveness to computers in general and expert systems in particular.

One of the primary shortcomings of the purely statistical approach to concept formation for such systems is that they lack the capability for the recognition of new patterns which become relevant - or the means to evaluate such patterns (Davis 1982). An interactive rule-based model allows for the recognition of new patterns, and provides maintenance facilities where such new rules can be presented to the expert and incorporated into the system, after accidental correlations are filtered out and valid new interrelations are discovered.

The limitations of traditional models also indicated the need for a new approach to the application of computer systems to emergency services in much the same way as some aspects of the stock market crash of October, 1987 illuminated flaws in program

trading. Donald B. Marron, Paine Webber chairman and former governor of the New York Stock exchange, said (Sanger 1987), "[from the crash] we learn that you can't let computers do all your thinking for you." There were several stages of program trading that caused the problem. Nearly everyone in the market had a computer system that sensed price discrepancies between the New York and Chicago markets. All of these systems would then automatically run sell programs for large portfolios of stocks worth millions of dollars causing a snowballing effect which manifested itself in the crash. There were two lessons however, that this experience teaches. The first lesson can be seen in the fact that some people made small fortunes from the events of the market crash. These were the investors who ignored the models' recommendations and used their own "expert knowledge" to determine the best purchase opportunities. An additional lesson is that when many users simultaneously consult a system that in theory is the best "model", the net result under some circumstances, can be disaster for everyone. The strategic goal of our survey is therefore to gather a foundation of expert knowledge from a large sample of experts.

1.2 Background

Most major metropolitan regions throughout the world are currently facing severe traffic flow problems on their highways and access roads. Construction of new roads, and the addition of lanes to existing thoroughfares have only seemed to exacerbate the problem, as any improvement in traffic flow seems to attract more vehicles to such roads and any flow gains are soon lost. Motorists caught in this inevitable traffic are often faced with a choice of routes. Those who are very familiar with the region they are traversing gather input from radio traffic reports, weather reports, perhaps CB transmissions, and other sources. This information is then assimilated (in their minds) using recollections of the various factors affecting flow on

particular roads. The expert motorist then makes route decisions which affect their arrival at the destination in the minimum amount of time and with the fewest disruptions. For critical applications, such as dispatching emergency service vehicles, effecting good response times demands the choice of the most appropriate route in an efficient manner.

Recent policy initiatives emanating from the Executive offices of the United States Government include emphasis on focusing "national efforts" toward certain critical technologies. The executive office of the President of the United States recently released a strategy paper on "Technology for America's Economic Growth, A New Direction to Build Economic Strength" (Clinton and Gore 1993). The presidential directive emphasized that "providing a world class transportation sector will require the nation to meet the challenges posed by increased congestion". The document specifies the need to increase research into technologies that lead to the development of "smart highways". Specific technologies supported by this initiative include automated traffic monitoring and the distribution of planning information to vehicles.

Similar concerns have previously been expressed by the US Department of Transportation in its strategic plan report to Congress on an Intelligent Vehicle Highway System (Card 1992). The basis of this IVHS plan includes providing enroute emergency vehicles with traffic information and route guidance. This critical application domain must include human expertise in order to satisfy the "smart" system criteria. During crises, these public service professionals rely on prior experiences to supplement traffic volume and congestion information provided by historical or, purely statistical and simulated data approaches. It is these considerations and the need to emulate the cognitive processes of the human expert, that suggest the development of an expert system for emergency vehicle routing.

The route-choosing function of emergency services personnel is one of the few aspects of their professional careers for which there has traditionally and nearly universally, been no training. New York City police officers take a four day driver training course, the primary focus of which is driving safety (Rachlin 1991). Similarly, advanced driving related instruction police officers later receive (i.e. courses in car-stop techniques) make no mention of route selection techniques. The officer is expected to become proficient in choosing the best route to an incident, only by accumulating on-the-job experience. They are told during the four day initial training course: "When a cop has to rush to a job, he has to know where the bottlenecks are so he can avoid them." Table 1. below illustrates the focus of the current driver training course offered to new recruits of the NYPD by the Driver Training Unit at Floyd Bennett Field in Brooklyn, New York.

DAY 1		DAY 2		DAY 3		DAY 4
<i>morning session</i>	<i>afternoon session</i>	<i>morning session</i>	<i>afternoon session</i>	<i>morning session</i>	<i>afternoon session</i>	<i>driver exam</i>
<u>Classroom:</u> overview of need for safe driving	<u>Driving:</u> coordination, braking, acceleration, steering, control, judgement, reverse maneuvering	<u>Classroom:</u> driving in bad weather, at high speeds, control issues (friction, velocity, inertia, forces, weight), vehicle inspection	<u>Driving:</u> driving practice, mock-patrol - observation practice	<u>Classroom:</u> traffic regulations, emergency vs. non-emergency issues	<u>Driving:</u> preparation and practice for the emergency vehicle operators course (EVOC) driving skills test	EVOC test

Table I. Traditional Driving Instruction for Emergency Vehicle Drivers

The dispatchers who inform emergency services personnel of incidents to which the unit must respond are also not trained in best-route selection. They are not typically called upon to suggest a best route to an incident though - the driver typically makes the route decision (Wolf 1994). The emergency services dispatcher is expected only to screen calls for the appropriate agency, and to gather information on the nature, seriousness, and location of the incident. This data is then broadcast to the emergency

services units. In some departments the dispatcher considers other information as well when dispatching units. This information may include the type of units available, the number of units available, and the location of the closest units. The dispatcher is not expected to be (and typically is not) an expert on route decisions. Dispatcher training focuses on clerical speed and accuracy, name and numbers comparisons (getting addresses right), following instructions correctly, and spelling and typing skills (Steinberg 1991). Human experts were thus sought for this project from the ranks of the emergency services officers, and not from among dispatching personnel.

2. Review of Related Work

2.1 The Application of Expert Systems

Recent Expert Systems research and development have provided the knowledge-engineering community with critical new tools and techniques for the development of Rule-of-Inference based systems. A knowledge-based system is *"a computerized system that uses knowledge about some domain to arrive at a solution to a problem from that domain. This solution is essentially the same as that concluded by a person knowledgeable about the domain of the problem when confronted with the same problem"* (Gonzalez, 1993). Such systems are distinguished from conventional algorithmic programs in a number of ways, the separation of knowledge from how it is used, the use of highly specific domain knowledge, and the heuristic nature of the knowledge. Expert Systems are particularly applicable to environments with associational knowledge acquired through observation and experience. The route-choice decision making process of emergency services personnel is ideally suited for emulation by such Expert Systems. There are several disadvantages to Knowledge-Based systems: The solution may not always be correct (as in any heuristic-based system), knowledge is limited to the domain of expertise (the system can not know when a problem is outside of its expertise, and that attempting a solution in such cases would be pointless and incorrect), and the computer system lacks common-sense knowledge - with the exception of common-sense knowledge that had been represented explicitly in the system. These factors are relevant in nearly all Artificial Intelligence projects, yet the advantages of Knowledge-based systems often outweigh those flaws and building systems is then deemed desirable. The advantages of such systems, as

they apply to the Road Utilization Learning Expert System project are outlined in Table II. below.

1) Wide distribution of scarce expertise: Every officer gains access to expert officer knowledge.
2) Ease of modification: Knowledge-base is on a centralized computer, and the code is modular.
3) Consistency of answers: Once the "expert" decision-making process is codified it is consistent.
4) Perpetual accessibility: RULES is accessible twenty four hours a day, seven days a week.
5) Preservation of expertise: Unlike a human expert, RULES never retires, taking knowledge with it.
6) Problem Solution with incomplete data: Unlike algorithmic approaches, intelligent guesses are made.
7) Explanation of Solution: The rule-of-inference code is self-documenting.

Table II. Advantages of Applying a Knowledge Based System

The rule-of-inference (r-o-i) approach is particularly well-suited to the emergency services routing problem for several reasons. The modular nature of r-o-i programs conforms well to the nature of our data. Changes in road conditions, road size, and the like, typically occur in isolation from changes to other roads in different parts of a city. The uniformity of r-o-i code is also well suited to the RULES environment, since RULES' knowledge elements are all represented in the same format (there are not a large number of different data-structure types). Finally, the "naturalness", or the logical means of expressing the knowledge matches the r-o-i format. Specifically, when human experts were interviewed for this project, their replies and route choice descriptions were expressed verbally in an r-o-i style. The interviews with police experts from the Emergency Services Unit of the New York City Police Department - (Stokes 1994) and (Wolf 1994) - elucidated the difference between the ordinary driver's route decision making process, which can often be emulated by algorithmic means, and the emergency services decision making process, for which RULES has been designed. The ordinary driver must put more thought into the initial choice of routes. The emergency services driver makes that same initial decision based

on expert knowledge, but then can deal with problems that arise on the selected route in many ways (drive on shoulder, part traffic, drive in opposing lanes, etc.). The lack of an efficient algorithmic solution to the problem creates the need for the Expert System. The process of rule induction, or creating rules from tables of data (Giarratano 1994) afforded us with the opportunity to fill in any gaps in the RULES system not covered by the personal interviews.

Expert Systems research techniques recently developed were employed in the production of RULES. The emergency decision making process is a critical one which may effect life-or-death situations. Issues relevant to life-critical decision making processes are discussed in (Stratton 1992), which describes an Expert System that must assist in decisions which prevent aircraft crashes. Roadway conditions are constantly changing at most times hence issues of Expert Systems development for dynamic environments, such as those raised in (Narongdej 1993) needed to be addressed. The RULES project has been designed to facilitate system maintenance and upgradability. Revising a knowledge base to correct inaccuracies discovered over time, is discussed in (Feldman 1993). Also, constructing knowledge base extensions to existing Expert Systems was the subject of a dissertation (Lotto 1993).

The use of production system languages as a method of modeling the rules of inference of an expert system frequently prove difficult to understand, build and debug (Pasik and Schor 1984). This is probably due to their inability to effectively simulate human reasoning methods. The system of table driven rules presented by Pasik and Schor attempted to overcome the difficulty of encoding a unit of knowledge in a rule. In this scheme, the problem domain (ie. all of the production rules) is in long term memory. The given problem state to be solved is in what Pasik and Schor call working memory. After drawing the rules necessary for the case from the long term memory,

we create in working memory a relational system that more closely reproduces the expert's reasoning process. We work only with the information in the system that is needed for the current problem. Whenever a sub-problem is completed, transition rules fire to allow for the activation of the next rule set. This relational table method was used by Lerner and Cheng in *The Manhattan Mapper* (Lerner and Cheng 1983). As Pasik and Schor pointed out, this technique can be most helpful where expert systems and dynamic databases are linked. We have therefore considered and adapted these methodologies for use in RULES.

Our expert system contains a representation of the experts' knowledge, formulated into a set of rules expressing this information. There is a need to implement a well defined method for interactions between sets of rules, to insure that if some rule is added at a future time, no unforeseen or incorrect effects result. A number of such consistency checkers have been developed. Raatz and Drastal (Raatz 1987) describe a method that finds any conflicts between sets of rules as well as between individual rules, thereby maintaining the consistency and expandability of an entire rule base. These considerations are taken into account in the design of the current expert system. Another important consideration is that we restrict ourselves to data that actually affects the final outcome. The Socrates system (Ferrara 1988) seeks to identify the rules regulating the procedures providing knowledge to be applied in new situations. In doing so, Ferrara stresses the need for "confining the analysis to significant data only". We address this issue by insuring that our rules comply with such conditions at the outset.

The extent of acceptance and trust in the information generated by an expert system has been previously estimated in a survey conducted on Internet (Diderich 1992). Five hundred and thirty four persons responded to the aforementioned survey.

The population sample was a cross section of Internet users. The survey results are summarized in Table III. below.

<i>Would you trust an E.S. ?</i>	<i># of respondents</i>	<i>%</i>
YES	83	15.5
PARTIALLY	399	75
NO	40	7.5
NO REPLY	11	2

Table III. Results of Diderich Survey

Although the data in Table III. would seem to indicate that computer professionals have much less faith in expert systems than the police and fire chiefs participating in our survey, it may be noted that the Internet survey solicited responses from the general population (albeit limited to people with Internet access). Our survey was mailed to a population carefully selected to represent a valid cross section of public service dispatching professionals. Diderich had no way of controlling his survey population.

2.2 Computer Systems for Routing Problems

Algorithmic techniques have previously been employed to solve an array of vehicle routing problems. These computerized methodologies have been successfully deployed by operations research professionals in a number of specific routing applications. Most such systems have been applied to commercial delivery operations, as in the food delivery vehicle system used by Southland Corporation's 7-11 stores

(Golden and Assad 1986). Issues such as inventory, payload, and profit naturally play a more vital role in the computations executed in these and similar cases (Anily and Federgruen 1993), (Golden and Wasil 1987), (Baker and Schaffer 1986). In addition, purely mathematical approaches do not readily accommodate dynamic updates of knowledge and new factors affecting the environment of the application domain. The learning processes of the expert system are better suited for this role. Emergency services operations involve many other issues and concerns that cannot be directly formulated by mathematical equations.

Other vehicle routing solutions which employ algorithmic approaches to the commercial delivery routing problem, are presented in (Bramel 1993). The algorithmic processes, though not sufficient for the emergency vehicle routing problem, do have a place in the development of structures for assimilating data inputs available to the RULES system. (Sumner 1993) has developed one of many systems for providing real-time congestion data to drivers. Techniques for gathering data at a central location, processing, and transmitting that data, and displaying it in vehicles, are described. Some of the data sources for such systems, which are common to RULES data sources, are traffic sensors, historical data, and anecdotal data. (Sumner 1993) describes a data-fusion process wherein data are accumulated and aggregated into a single congestion-level data value for each road segment. A score is assigned to road segments, based on: road segment activity, road segment quality, and an aging factor (how much time before the data is expected to become obsolete). This system and similar systems only indicate congested links and not other factors that can affect the speed of emergency vehicles. Many similar traffic monitoring and control systems have been designed since the earliest types of modern computer and switching equipment were developed, including: (Soderberg 1961), (Barker 1966), (Zachman 1971), (Kohnert 1975), (Narbaitis 1975), (Ceseri 1977), (Tomkewitsch 1982), and

(Madnick 1988). Systems for implementing map displays in vehicles include: (Dahan 1983), (Saito 1986), (Takanabe 1988), and (Yamada 1989).

The expert system employed in the RULES project addresses issues unique to the emergency services routing function. There are three phases in the emergency vehicle dispatching process. First, dispatching personnel determine which units RULES will consider in its evaluation by factoring in unit locations and current unit activity/inactivity. Second, though they are not the primary customer of RULES, the dispatchers may use RULES to determine which available units would be capable of responding in a timely fashion. Primarily though, when responding, the assigned unit uses the route recommendations provided by RULES. The first issue has previously been addressed; Goldberg and Szidarovszky (1991) described the use of the Hypercube Model in the evaluation of busy probabilities for EMS vehicles. Ball and Lin (1993) addressed the need to deploy emergency services resources in particular numbers at specific locations to provide for response to incidents in a minimum amount of time. The second and third phases are unique in the case of emergency services dispatching, and hence are the focus of RULES.

While it is true that part of the police officer's thought processes involve considerations of the location of heavy traffic, the experienced officer has expert knowledge that supersedes such information. Attempts to "determine vehicle flows on each link at each instant of time resulting from drivers using instantaneous minimal time routes" (Ran 1993), seem to have a rational and comprehensive foundation. However, all of the previously described systems ignore real world considerations which frequently are very relevant to emergency vehicle operations. For example, if an accident occurs at point X on road A, the historical data, the road-side sensors, and the stochastic model, may all indicate to police officer Jones that road A is a poor

choice since traffic flow is 0 m.p.h. on it, and that the unit should detour via road B. Officer Jones, the human expert, knows however, that radio traffic reporters have just begun telling motorists to use road B (hence it too shall shortly be congested), and that road A has a wide shoulder by which the officer can speed to the accident site. Many other "smart" factors come into play in the emergency vehicle realm. If there is no shoulder, the expert officer might sometimes determine that it would be safe and effective to travel west in the eastbound lanes (lights and sirens on, of course). Similarly, due to their official right-of-way, emergency service vehicles can force immobile traffic to part to the sides and hence travel between lanes (in a narrow two lane tunnel, for example). The nature and variety of the data comprising the officer's expert knowledge defy the capabilities of existing stochastic models. The expert officer is aware of subtle items that have dramatic impact on traffic patterns. These may include: the nature of the drivers on roads at different times ("Sunday drivers"), in different seasons (effects of the officer's snow tires, etc.), and intimate knowledge of direction of congestion at the various rush hours.

Surveys of emergency services communications facilities have previously been conducted. The Los Angeles Police Department conducted a survey of major cities' communications facilities (Walsh 1990). Police departments surveyed therein included only those of Baltimore, Chicago, Dallas, Detroit, Milwaukee, New York, Philadelphia, Phoenix, Tulsa, and Washington D.C. Nine cities used some form of Computer Aided Dispatching (CAD) system. Features provided in these CAD systems included unit recommendation, incident histories, and unit status data. Some elements desired for future systems were computer mapping and unit locating. It was also found that less than half of the communications systems had an interface with their radio system. Our survey verifies these concerns. In addition however, as described

earlier, the current survey provides specific details which assure that RULES meets real-world requirements.

Computer aided dispatching systems have been employed by emergency services units to cut response times, disperse vehicle fleets, and automate incident reporting for Police and Fire departments throughout the country. Most of these systems are still primarily dependent on a human expert's presence "in the loop". The Pennsylvania Emergency Management Agency (Gantz 1990), for example, has a network of systems that contain current maps and database information. This information is used to choose equipment for deployment as well as for assigning dispatching routes. The system does not make those choices independently though it provides the human expert with all the information needed to make the choice.

A number of systems provide as output an estimate of the best route. None, however, model the human experts reasoning process; rather, these systems attempt to provide a mathematical model based on static formulae and simplistic interpretations of data sampled from dynamic sources. John Tibbets, system status manager of Albuquerque Ambulance (AA) explained this need: (Sena 1990) "It's difficult to find good paramedics. It's even more difficult to find crews who have an expert knowledge of all the streets in a city the size of Albuquerque". The Etak emergency response system that AA uses provides traffic flow data which human experts then consider in executing routing decisions. Similarly, the Integraph DMS system (Sena 1990) allows the user to select a best route based individually on such parameters as minimum time, minimum distance, minimum number of turns, minimum number of intersections, or minimum risk to vehicle. A preferable solution would allow dispatchers (or drivers) without expert knowledge to consult an expert Computer Aided Dispatching system for effective rapid deployment. The AA system currently used

(Etak) paid for itself in less than a year and improved response time dramatically. The addition of expert systems technology would yield an even more effective dispatching system.

Expert models have been designed to facilitate optimal emergency department *resource utilization* (Kelley 1993). An expert model has also been attempted to help *ordinary vehicles* navigate and choose routes (Waterman 1986) - though such systems are composed of a combination of simple "divide-and-conquer" methods, pre-computed routes, and Dijkstra's shortest path algorithm. Until RULES however, no system has been devised to take into account all of the special considerations of the emergency services vehicle routing problem.

In summary, existing vehicle routing systems primarily use algorithmic techniques. They gather and report traffic flow data obtained from visual observation and/or roadside sensors. Some systems employ stochastic models to determine vehicle flow at some instant of time, based on its assessment of the probable decisions of drivers choosing minimal time routes. The higher end systems provide graphical map displays. But finally, route recommendations are almost always based exclusively on traffic flow rates. These systems are ideal for commercial delivery operations, and have in a few cases been adapted for limited use by some emergency services organizations to assist their human dispatchers in suggesting routes to personnel in vehicles. These systems do not however meet the needs of emergency services. The symbolic logic and heuristics of an Expert System are required to provide good routing suggestions to emergency services personnel. The development of new methodologies for combining all of the information needed for such a system has been the core of the RULES project.

3. Rules Project Objectives

3.1 Project Goals

The concepts defining the expert system for route selection discussed in this paper may be applied to any metropolitan area. For the purposes of developing a practical implementation of the idea, we have chosen to apply it in the New York City metropolitan area. The type of problem the system attempts to solve is illustrated by the following example. The emergency services vehicle operator who wishes to go from Queens to Manhattan selects from a plethora of roads, streets, expressways and combinations thereof. In addition, he faces a choice of many East River bridges and tunnels. Under ideal conditions it may seem obvious even to those unfamiliar with the traffic flow in this region, that the large Tri-Borough Bridge is a more sensible way to get across the East River than the narrow 138th street bridge. Unfortunately however, ideal conditions are very rare. For instance, the cab driver, the *expert* police officer, or the seasoned commuter may know that route I278 in Brooklyn (The Brooklyn Queens Expressway) is undergoing re-construction and readily floods in heavy downpours, therefore making the Midtown Tunnel and the FDR Drive a quicker substitute on certain days. Such expert knowledge saves informed people much time and effort. Under certain traffic conditions Queens Boulevard, with all of its traffic lights, is quicker for an emergency services vehicle with lights and siren on, than the congested Long Island Expressway. These rules of the road are not on maps, where the shortest and quickest distance between two points appears to be the thick red roads in the straightest line between the origin and destination.

The critical nature of the need for RULES can be seen in the report of (Barancik 1993) on the emergency services response to the Avianca Airlines crash of 1990. It was found that congestion and poor route-selection by the many amateur volunteer rescue workers who responded on the few access roads to the crash site, may have led to an increase of 20% in the death toll. An emergency services department using RULES is able to provide all of their personnel with instant access to expert knowledge which formerly had been only in the domain of expert personnel. RULES is a new approach to the vehicle routing problem which specifically addresses the issues relevant for emergency services vehicles. This entailed the production of a rules-of-inference model unique to the emergency services field, and the integration, where applicable, of this model with the algorithm methods for solving vehicle routing problems. The goal of the Road Utilization Learning Expert System (RULES) is to provide the emergency services vehicle operator with the best-route information that human experts on traversing New York City would have at their disposal. A centralized computer system, which may be accessed from remote sites, contains the rules-based expert system (see Figure 3. below).

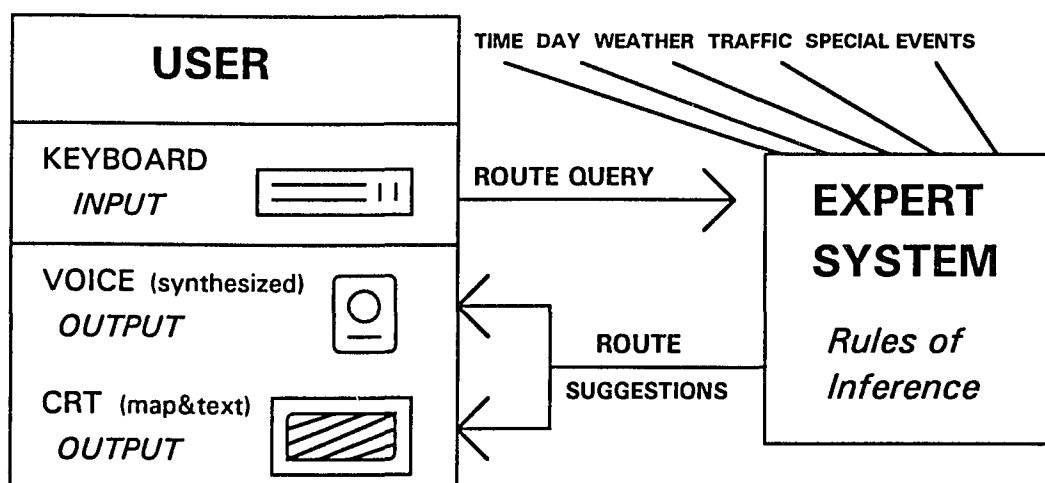


Figure 3. Diagram of RULES System Usage

3.2 System Design Specifications

The first consideration in formulating a requirements specification for RULES was an assessment of the problem at hand and a feasibility analysis of the project. The system user was identified, the project goal, input, output, system features and priorities were delineated. Hardware, interfaces, reliability criteria, and system maintenance techniques were then formulated. Most of these items are covered in detail in Sections 1 to 3 of Part II. Finally, methods for validation and verification, and a system test specification were devised, and are described in Section 5 of Part II.

Section 2 of Part I of this dissertation explained a portion of the feasibility analysis that led to the decision to implement RULES. Specifically, it was determined that a problem does exist (the emergency services vehicle routing problem) and that a Knowledge-Based solution is called for. When we report on the results of our survey (Section 2.1.4 of Part II), we explain that there is support in the field for such a project. Finally, it was found that competent, articulate experts in the field were accessible for knowledge gathering interviews. All of the feasibility analysis requirements for expert system development, as enumerated in (Gonzalez and Dankel 1993) were thus achieved.

II. THE DESIGN AND PRODUCTION OF THE RULES SYSTEM

1. Design Goals

1.1 Scope of System Coverage

The RULES project encompasses the design and development of a system which presents route-recommendation suggestions to emergency services officers in New York City. Although the methodologies invented and the principles described within this dissertation on the RULES project may be adapted for any city (indeed, such adaptability of concepts was a major guiding principle in the system's design), it should be noted that, though some principles apply for all emergency services, many are applicable exclusively in New York City. Road specific idiosyncrasies, of course, are one such item unique to the current problem domain.

RULES, in its current form, does not contain a representation of *all* possible routes, since it does not know of every paved road in the region. Our purpose is to demonstrate the concepts that can be applied if a fully operational system were to be constructed in the future. Therefore only arteries necessary to effectively illustrate the concept were used. We then attempt to provide the route a human expert would have recommended. A driver may have thousands of ways to get from point A to point B, if one takes into account all city streets. Since only a few of these routes are reasonable in most cases, the expert system only considers a limited set of routes. The map of New York City, as far as the system is concerned has only the major auto

access routes. For example, the system knows of 42nd street, a major artery, but it does not know of 41st or 43rd streets.

1.2 Input/Output Expectations

Input to RULES is of three general forms. First, current environmental data from traffic sensors and weather reports constantly update current conditions variables. For the purposes of this project, it is impractical to implement an actual interface to the physical sensors on New York roadways. The structures within rules which would read such sensor data were however constructed, and a simulation of the real-world interface to such data is effected by feeding in historical data during test runs of the system. Historical data is used to detect patterns and thereby produce appropriate rules. This data was obtained from the New York City Department of Transportation (traffic flow data for all major arteries for 1988 to 1993) and from the National Climactic Data Center (weather data for the New York City region covering the same 1988 to 1993 period).

The second form of input is the actual query from the user; the emergency services personnel in the emergency services unit requesting a route suggestion. Finally, the third form of input pertains to conditions updates from human personnel or other reliable anecdotal sources which can update conditions and override sensor data where sensor data is deemed inadequate, inaccurate, or misleading. If, for example, traffic comes to a dead stop at an accident, the sensors downstream of the accident will show a clear road with no traffic flow problems. Under rush-hour conditions, the abnormal low traffic flow rate can indeed trip alarm flags and recognize that the situation is not normal. Under other or low traffic flow conditions however, in this

example a misleading all-clear condition for that road segment could be set, unless some human observer intervenes. We therefore recognize that, though maximum automation and minimal human intervention is our goal, some human oversight of all such systems is warranted.

1.3 System Maintenance and upgrades

System maintenance needs can be illustrated by consideration of an example of such an action. The tendency of a particular road to flood during heavy rain is a factor considered in the route decision making process. The road's drainage problems may one day be corrected thus eliminating this factor. It would be inappropriate to gather such roadway reconstruction data interactively, or on a daily basis. Rather system maintenance duties include a need to modify the rule-base when such situations arise. These situations are infrequent enough to warrant such system modification requirements. In addition, the modification is a simple task, due to the modular nature of the rule of inference structure. Less frequently, traffic law and emergency service vehicle practices and procedure might be changed. Such changes must of course be monitored and reflected by appropriate changes in the RULES system, when they occur. The historical data used to assist in the formulation of RULES is currently meaningful, but with the passage of time, will eventually become outdated. It is then be necessary to analyze a more recent data sample and compare the results of that analysis with the results of the previous analysis, and to identify necessary changes.

2. Resources for Data Collection & Processing

2.1 Information Sources

Expert System Knowledge-Bases are typically formulated from either information gleaned from interviews of human experts, from formal surveys of a group of experts, from literature and manuals on the problem domain, or from a combination of several of the above techniques. For RULES, we have used all of those traditional methods, and have integrated conclusions drawn from relevant historical data-bases as well, towards the formulation of the rules in RULES.

The primary sources as described in (Hart 1986) are observation, the questionnaire, the sampling of data records, and the interview. Hart notes that most human experts have never analyzed the way they use their diagnostic skills. The human experts do not necessarily think in terms of "rules" - they can apply methods but may have difficulty describing them. Several guidelines suggested by Hart were followed in conducting the interviews for the RULES project. These included, not imposing alien tools on the expert - i.e. encouraging the human expert to provide information in a natural way, and limiting interruption of the expert's thought processes - as Hart explains: "The knowledge engineer can seldom judge what is most relevant in the dialogue at the time, and might not know where the expert's train of thought is leading." All information was recorded in written form extemporaneously, and reviewed for consistency and accuracy immediately afterwards. The methods in which the human experts manipulated knowledge was broken down into facts, theories, and heuristics, which were then transformed into rules of inference. The issues focused on when interviewing the experts included, the order in which the expert approached the

problem, the relative importance attached to different items by the expert, and the ways in which the expert weighs data which the expert deems to be useful evidence.

Initially, a survey of emergency services experts nationwide, was assembled, implemented, and analyzed. Interviews were conducted of traffic routing experts at the New York State Department of Transportation, and at the New York City Department of Transportation. By distilling the knowledge gained from the examination of data and examples in literature on the subject, learning by induction, we acquired knowledge implemented in rules. This formulation of an analytical model based on components described in emergency services manuals, laws, and other sources which can identify knowledge structures, is described in (Parsaye 1988). The primary sources for the eventual confirmation of the validity of the RULES system were interviews with N.Y.P.D. commanders. A "kickoff interview" (Gonzalez 1993) had first been conducted with the commanding officer of the Emergency Services Unit (Stokes 1994). Then a Knowledge Elicitation Session was conducted with the planning officer of the unit. Since Gonzalez asserted that "the ideal location for the knowledge gathering sessions should be the expert's work area", the interviews were conducted at the headquarters of the N.Y.P.D. Emergency Services Unit in Flushing Meadows Park, New York. Likewise, the D.O.T. experts were interviewed at their offices in lower Manhattan, and in the State Office Building on Long Island. A summary of knowledge sources tapped by the RULES project, and their applications, is presented below in Table IV.

EMERGENCY SERVICES EXPERT SOURCES	TRAFFIC FLOW EXPERT SOURCES
<p><u>Survey of Human Experts:</u> A survey of critical factors and issues related to route selection was mailed to 500 police, fire, and emergency services departments nationwide. We received responses from more than 35% of the departments. The data was used in the design and construction of the RULES code (Goldberg and Listowsky 1994).</p>	
<p><u>Literature:</u> Manuals and sources analyzed and used in the formulation of rules for RULES included: "Law Enforcement Driving" (Auten 1989) "Patrol Administration" (Shanahan 1985) "Law Enforcement Handbook" (Rowland 1985) "The Making of a Cop" (Rachlin 1991)</p>	<p><u>Literature:</u> Traffic Law and Federal, State, and City traffic data annual reports were analyzed. A primary source for New York City specific route selection criteria was the recently published work of Samuel Schwartz (Schwartz 1993), Traffic Commissioner of the NYC ('82-'86), and NYC DOT chief engineer ('86-90).</p>
<p><u>Personal Interviews:</u> The following experts were interviewed: ●Lt. Thomas Stokes, commanding officer of the NYPD Emergency Services Unit (Stokes 1994) ●P.O. Timothy Wolf, planning officer for the NYPD Emergency Services Unit (Wolf 1994)</p>	<p><u>Personal Interviews:</u> The following experts were interviewed: ●Joseph Contegni, Operations Supervisor at the N.Y. State D.O.T. (Contegni 1992) ●Richard Roan, Traffic Planning Division supervisor at the N.Y. City D.O.T. (Roan 1993)</p>

Table IV. Information Sources for the RULES Expert System

2.1.1 Raw Data

The New York City Department of Transportation collects historical traffic volume data for all bridges and tunnels in the metropolitan area, the Manhattan central business district, and the N.Y.C.-Westchester and N.Y.C.-Long Island borders (Gellman 1992). Similar data for other regions of the country has also been collected and maintained by the U.S. Department of Transportation (Curry 1990). As explained earlier, this data was initially used when RULES was first designed. Subsequently, when the information is updated, and historical data for roads not previously covered are recorded, RULES must be maintained to accurately reflect this. Road-side traffic flow sensors are in place and operational for much of the Long-Island corridor (Zove 1982), and similar sensors are to be added to other important arteries to assist in providing real-time traffic flow data. We have seen that extensive research has been performed to determine the factors that affect a person's choice of roads. Some, in descending order of importance are: lanes available, intersections, speed limit, slow moving vehicles, signal delays, turns, pavement, road work, unexpected congestion, traffic, weather, accessibility, freeway, time of day, volume, travel time, route distance, route setting, habit, automobile condition, and flexibility of arrival time (Kwon 1990). All the above mentioned factors are taken into account as the system computes its estimate of traffic flow as they relate to the information to be used in the decision making process.

Much of the raw data is in the form of a count of the number of cars passing a particular point (see Appendix A1.2). This data must then be converted into some measure of congestion. (Soderberg 1961) explained the criteria for assessing congestion levels based on flow data, with the following "congestion index":

$$I = a \frac{N}{N_0} + b \frac{S_0}{S}$$

Where "I" is the congestion index,
 "N" is the number of vehicles per unit distance,
 "S" is the average speed of vehicles,
 "N(0)" and "S(0)" are normal values for N and S,
 and "a" and "b" are weighting constants reflecting the
 relative effects of vehicle density and speed.

From the above, Soderberg derived the following equation for the congestion index:

$I = dt(a'P + b')$ where "dt" is the time required for a vehicle to move between two fixed points,

and "P" vehicles pass the measuring point in one unit of time.

A formula for computing the volume of traffic flow was developed by (Apitz 1973):

$$SV (\%) = \frac{V(s) * 3600 (sec./hour) * 100\%}{CL * C/S * SF}$$

Where "SV" is the scaled volume as a percentage, "V(s)" is the number of actuations (of the traffic sensor) within one sample period, "CL" is the cycle length in seconds, "C/S" is the number of cycles per second, and "SF" is the scale factor. Hence, if for example, the cycle is one minute and each sample period comprises four cycles, the reference scale factor will be 900 vehicles per hour. If 30 vehicles then pass by the actuator during a sample period, then the scaled volume will be 50%. The data gathered by the NYC DOT, which we are using in RULES' production and operation, is collected by an actuator/sensor system which can be represented as depicted in Figure 4. below. Also depicted are the computations we used to convert traffic volume data to flow rate data, under normal congestion conditions.

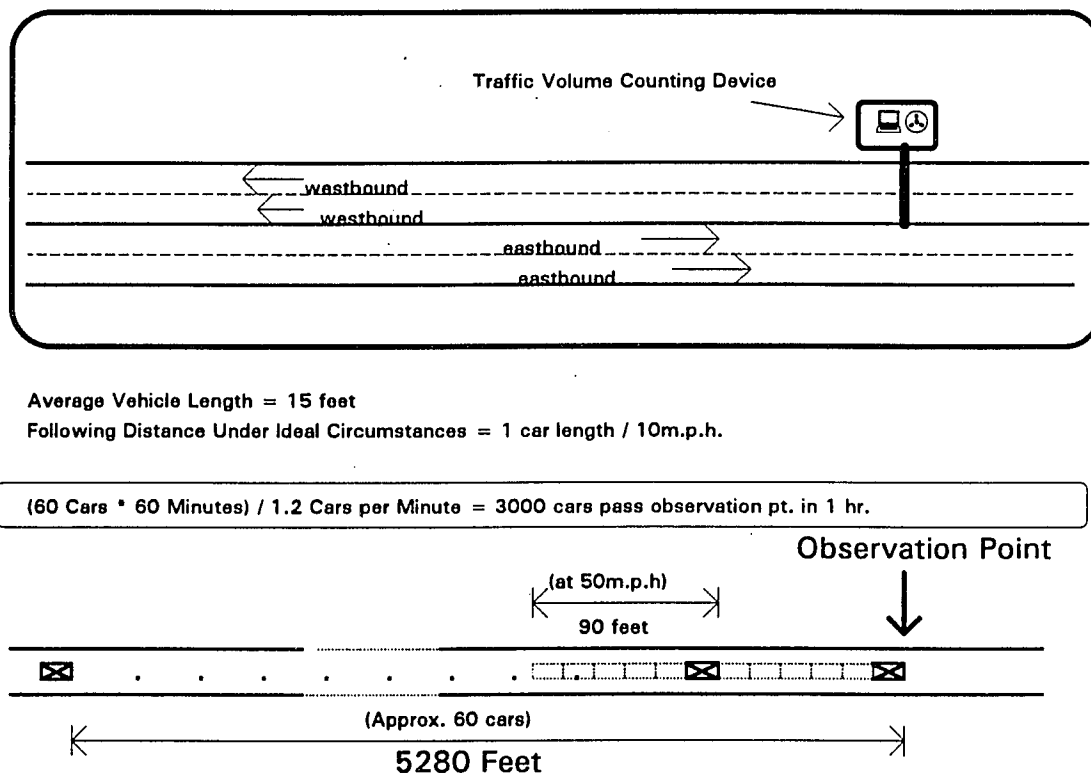


Figure 4. Traffic Volume Measurement and Flow Rate Computation

2.1.2 Interviews

The first interview was of Joseph Contegni (Contegni 1992), supervisor of the "Information For Motorists (INFORM)" System, at the New York State Department of Transportation. After a demonstration of the INFORM system's operations and a tour of the site, an interview was conducted. Mr. Contegni was asked to express his assessment of the factors affecting traffic flow, and the methods his facility employs to assist emergency services personnel in choosing routes to incidents. The INFORM site

does not recommend routes to emergency services units. They provide data on traffic flow and blockages to the units. Traffic flow issues and related knowledge obtained from this interview were noted and incorporated into the RULES design. The information provided at this site related primarily to major roads and arteries which traverse the city. More specific details on factors affecting traffic flow on all important access routes in New York City, were gathered from an interview of Richard Roan (Roan 1993). Mr. Roan, supervisor in the Office of Traffic Research at the New York City Department of Transportation Traffic Planning Division, provided specifics on the idiosyncracies of N.Y.C. roads and highways. His office also provided us with the New York City Traffic flow data.

The Emergency Services Unit of the New York City Police Department is tasked with the handling of incidents city-wide. Since personnel from local precincts rarely venture out of their patrol sector, it was apparent that the E.S.U. was both, a better source of information in constructing and verifying the knowledge base, and would be the likely best customer of an operational RULES. Lt. Thomas Stokes (Stokes 1994), Commanding Officer of the NYPD E.S.U., was interviewed first. His opinions on the route-choice decision making process were noted. A detailed, in-depth interview was then conducted of veteran Officer Timothy Wolf (Wolf 1994), personnel and planning officer of the ESU. Mr. Wolf was chosen for the interview after he had been identified by Lt. Stokes as the best expert on route-choosing decision making, under his command. The interview with P.O. Wolf was divided into two parts: First we gathered data on the decision making process, in much the same way as we had from the other resources mentioned earlier. Second, we presented P.O. Wolf with several scenarios and asked him to choose the best route and identify modifying factors. This information was then used to establish a test specification for Verifying the value and accuracy of RULES decisions (given the same scenarios as input to RULES).

2.1.3 Subject Literature

The New York State Traffic Law for emergency services vehicles, and the procedures enumerated in emergency services manuals, were transformed into components of the knowledge-base. The details of this process are explained in Section 4 of Part II in this dissertation.

2.1.4 Survey of Experts

A fundamental element of the daily routine of public service professionals such as fire and police personnel is the dispatching of vehicles to incidents. As explained earlier, these vehicles have a critical need for choosing the best route to an incident. A survey was therefore mailed to the offices of police and fire chiefs in the United States. A list of the chiefs of every department in the country (in excess of 6,000 cities) was obtained and a survey was mailed to police and fire chiefs of 250 of the largest and most representative cities - selected to insure a statistically significant sample (a total of 500 surveys were mailed out). A vital component of RULES, the weights of the critical factors (as chosen by emergency services personnel) involved in choosing the most appropriate path to a site, is determined partially by the relative weights assigned by the experts in this survey.

The concerns expressed in prior sections were incorporated into the design of the survey now described. The reader is referred to Appendix A1.1 for a copy of the survey and cover letter. The structure of the survey is as follows:

Questions 1-5:	general descriptive data (<i>department type, size, etc.</i>)
Questions 6-10:	incident response descriptive data (<i>distance, time, etc.</i>)
Questions 11-13:	queries about trust in computer based systems
Question 14:	survey of factors relevant in predicting traffic flow
Questions 15-19:	evaluation of dispatching system currently in use
Questions 20-25:	suggestions for future dispatching systems

Question 14 of the survey asks the respondent to rate the relevance of twelve critical factors for predicting traffic flow. Prior to this survey, extensive research has been performed to determine the factors that effect a person's choice of roads. The

factors affecting non-emergency services persons as well, which were previously considered included the following items: lanes available, intersections, speed limit, slow moving vehicles, signal delays, turns, pavement, road work, unexpected congestion, traffic, weather, accessibility, freeway, time of day, volume, travel time, route distance, route setting, habit, automobile condition, and flexibility of arrival time (Kwon 1990). The aforementioned study surveyed commuters' decision making at their trip origin and at the ramp to their primary corridor. Our survey incorporated many of the factors determined by Kwon to be relevant in modeling "on-line traffic demand". However, the population of our survey (by the nature of their occupations) represents expert opinions in these matters, and reflects the unique nature of emergency vehicle routing (vs. civilian vehicle routing). This knowledge thus obtained is applied to our expert system's development.

Some highlights of the survey results are presented below. The responses were nearly evenly divided between police (41.6%) and fire departments (42.1%). The third department type choice, "other" was indicated by 29 respondents (16.3%). These were comprised of general purpose 911 dispatching facilities used either by both fire and police, or by some combination of fire police and emergency medical services departments. We received responses from a number of major cities including: Los Angeles, Chicago, Baltimore, Boston, Detroit, Minneapolis, Cleveland, Philadelphia, Dallas, Houston, and Milwaukee. See Table V. to Table XIV. below for the results of questions 1-10.

Question 1: Service Type		
(178 responses)	# of respondents	%
Police Department	74	41.6
Fire Department	75	42.1
Other (general purpose 911 facility)	29	16.3

Table V. Survey Results: Service Types

Question 2: Department Size		
(177 responses)	# of respondents	%
1-100 Persons	48	27.1
101-500 Persons	84	47.5
501-3000 Persons	40	22.6
3001-20000 Persons	5	2.8

Table VI. Survey Results: Department Sizes

Question 3: Number of Vehicles		
(174 responses)	# of respondents	%
1-10 Vehicles	22	12.6
11-100 Vehicles	98	56.3
101-500 Vehicles	46	26.4
501+ Vehicles	8	4.6

Table VII. Survey Results: Number of Vehicles

Question 4: Area covered by department (sq. miles):				
Mean=32	Median=85.2	Min=.75	Max=840	(173 responses)

Table VIII. Survey Results: Area Covered

Question 5: Typical unit dispersal (vehicles/sq. mile):				
Mean=1	Median=2.033	Min=.07	Max=16	(144 responses)

Table IX. Survey Results: Unit Dispersal

Question 6: Average incident response time (minutes):				
Mean=4	Median=4.869	Min=1	Max=24	(164 responses)

Table X. Survey Results: Response Time

Question 7: Distance traveled in typical response (miles):				
Mean=2	Median=2.209	Min=.25	Max=11.6	(174 responses)

Table XI. Survey Results: Distance Traveled

Question 8: How does your department dispatch & communicate with units?		
(178 responses)	# of respondents	%
via radio only	135	75.8
via computer com. link	3	1.7
via both	40	22.5

Table XII. Survey Results: Communication

Question 9: What method is used to decide which units to dispatch to an incident?							
a) base personnel broadcast incident location, units in vicinity respond.							
b) base personnel manually track units and choose unit to assign.							
c) computer advises department on best unit to assign.							
(173 r.)	A	B	C	A&B	A&C	B&C	A,B&C
#	18	55	66	11	7	6	10
%	10.3%	31.4%	37.7%	6.3%	4%	3.4%	5.7%

Table XIII. Survey Results: Choosing Units

Question 10: How do dispatched units determine best route to incident?					
a) personnel in unit decide route based on their own knowledge.					
b) personnel at base tell personnel in unit best route.					
c) computer recommends best route.					
(178 r.)	A	C	A&B	A&C	A,B&C
#	169	1	6	1	1
%	94.9%	.6%	3.4%	.6%	.6%

Table XIV. Survey Results: Choosing the Best Route

All (178) respondents answered question 8 (see Table XII.), *How does your department currently dispatch and communicate with units?* : 98.3% of the departments communicate with units by radio and 24.2% of all respondents use computer based communication links. It is important to note that most of the 75.8% who answered "via radio only" do in fact have computers in their vehicles; they were just not used as a means for the personnel in the vehicle to talk to the base (the computers - "MDT's" - are used as mobile display terminals for tasks such as license plate queries). This observation can be confirmed based on the data received in the responses to the question 9 (Table XIII.).

When asked what methods are used to decide which units to dispatch to an incident (Table XIII.), of 173 responses, 26.5% (46) checked *(A):base broadcasts, units tell base if they can respond*, 47.3% (82) checked *(B):base personnel choose units to assign incident to*, and 51.4% (89) checked *(C):computer advises department on best unit to assign*. It should be noted however that the "computer advice" offered refers to queries of simple department data-bases, containing such information as personnel and equipment in particular units, and units' patrol sectors. A number of respondents checked more than one box. The results to the queries about trust in computer systems are presented in Table XV. and Table XVI. below.

Question 11: Ideally, which dispatching method would you have the greatest trust in?				
(168 r.)	Human Expert	Regular Employee	Standard Computer	Computer Expert Sys
#	38	12	7	117
%	21.8%	6.9%	4%	67.2%

Table XV. Survey Results: Method Trusted for Dispatching

Question 13: Would you trust a computer with the task of dispatching your units?					
(171 r.)	NO	With Skepticism	Yes	Very Definitely	Completely
#	18	36	67	37	13
%	10.5%	21.1%	39.2%	21.6%	7.6%

Table XVI. Survey Results: Trust in Computers

When asked which method they would have the greatest confidence and trust in, the overwhelming majority of respondents (117 - 67.2%) said a computer system containing the knowledge of all of their human experts would be best. In question 12, they wrote that their choice of ideal system was based on personal experiences with current computer based dispatching systems. Some dispatchers who selected the expert system as ideal, specified comments such as "more inclusive of all factors affecting unit selection." A number of these respondents suggested that as a method of validation, human expert consultants should be involved in this decision making process: "A dispatcher should have sufficient knowledge to make the final call." This also satisfied their concern of computer systems shutting down in the midst of a crisis. Question 13 asked if a computer would be trusted with the dispatching of units. The responses indicated that 68.4% would trust a computer.

The most important factors in predicting traffic flow were: time, day, and construction and weather patterns. Factors found to be of low significance were road speed limit and accident rate. Since emergency vehicles have the right of way in any traffic situation, road conditions that depend on physical layout of the roadways was less significant than traditional traffic flow predictors (as indicated by time on a given day) and uncontrollable patterns (such as weather and construction).

TRAFFIC FLOW PREDICTORS

1) time of day: 4.50	2) construction: 3.98	3) day of week: 3.95	4) weather: 3.48
5) holiday: 3.30	6) road condition: 3.27	7) lanes: 3.10	8) season: 2.81
9) alternates: 2.67	10) exit/entrances: 2.62	11) accident rate: 2.57	12) speed limit: 2.55

Table XVII. Survey Results: Traffic Flow Predictors

More than half of the dispatching systems currently in use have response times which were rated only moderately effective at best, in the section of the survey for rating current systems (see Table XVIII. below).

Questions 15-18: Rate effectiveness of your current dispatching system in each area.					
	ineffective	slightly effective	moderately effective	very effective	optimally effective
Provide all data needed	11 (6.4%)	11 (6.4%)	84 (48.8%)	62 (36%)	4 (2.3%)
Has good resp. times	10 (5.9%)	14 (8.2%)	63 (37.1%)	72 (42.4%)	11 (6.5%)
Resource util. is good	9 (5.3%)	24 (14%)	78 (45.6%)	54 (31.6%)	6 (3.5%)
reduce # of units	52 (31.9%)	39 (23.9%)	47 (28.8%)	23 (14.1%)	2 (1.2%)

Table XVIII. Survey Results: Current System Effectiveness

This indicates that there a real world need for dispatching and routing tools that will provide better response times. Most respondents did report that their current systems are at least moderately effective at providing units with all data needed, and effecting good resource utilization. The survey participants had also been asked how effective their current system is at reducing the number of units needed. Although most said that it was "ineffective" in this function - it was frequently indicated (hand written notes on the survey) that this question was inappropriate since "reducing the number of units" is not necessarily a desired goal - emergency services want to have more units than they typically need (to cover unforeseen developments).

Survey participants were asked to suggest special features that would enhance the fundamental dispatching and routing systems. Most (76.9%) of the respondents indicated that it is important that a computer-based routing function be included in any future dispatching system. A unit monitor feature was deemed desirable. The results of this question are detailed in Table XIX. below.

Questions 20-23: Rate importance of including each feature in future systems.					
	not important	slightly important	moderately important	very important	essential
Relay traffic conditions	16 (9.4%)	35 (20.5%)	60 (35.1%)	50 (29.2%)	10 (5.8%)
Choose best unit	4 (2.3%)	5 (2.9%)	17 (9.9%)	75 (43.6%)	71 (41.3%)
Suggest best route	19 (11%)	21 (12.1%)	64 (37%)	58 (33.5%)	11 (6.4%)
monitor unit locations	8 (4.7%)	11 (6.4%)	38 (22.1%)	47 (27.3%)	68 (39.5%)

Table XIX. Survey Results: Future Systems

An analysis of the results indicated a high level of correlation for many respondents between the "CHOOSE BEST UNIT" option and "MONITOR UNIT LOCATION" while simultaneously demonstrating a high level of correlation between "RELAY TRAFFIC CONDITIONS" and "SUGGEST BEST ROUTE." This trend occurs especially in the emergency service field because units in the field dispatched must remain on site to attend to the incident reported. The responses to questions 24-25 contained information specific to the concerns of particular departments once at a site but did not directly relate to dispatching per se.

The three most significant findings from the survey data are the high degree of trust in computer-based dispatching, the choice of an expert system as the ideal tool, and the relevance of various critical factors affecting the choice of routes. These findings are confirmed by correlating the responses to questions designed for that purpose.

The survey data indicated the high degree of trust emergency services personnel place in an expert system. It is significant that the survey population consisted of police and fire chiefs and not computer professionals whereas prior surveys reporting trust in expert systems have queried populations primarily composed of computer professionals (Diderich 1992). Thus the implementor and the end-user provide a favorable rating for computer expert systems. This was determined from the responses to questions 11 to 13. In question 13 only 10.5% said they would not trust a computer, and 21.1% said that they would trust a computer with some skepticism. The remaining 68.4% answered that "yes", "very definitely", or that they would trust the computer "completely". In addition, 67.2% of the respondents said that the ideal system would

be a computer which contained the knowledge base of their expert employees (question 11).

In question 12, where respondents were asked to provide any additional comments about their response to question 11, many of the professionals said that a human expert monitoring the output of the computer expert would be an indispensable verification and validation component of such a system. The RULES system, for this reason, incorporates several independent means of verifying that the best route chosen is appropriate. For example, the best route determined from the knowledge base of historical traffic flow data is compared with the best route determined by analyzing the data from dynamic inputs such as road-side sensors.

It is apparent from the evaluations of systems currently employed that most of the respondents are only moderately satisfied with the systems they use. Routing systems were found to be in demand since, when asked to suggest features desired in future dispatching systems, 76.9% said that suggesting the best route to get to an incident is "moderately important"(37%), "very important"(33.5%), or "essential"(6.4%). As indicated by the responses to questions 21 and 23, features most desired for such routing systems are choosing the best unit for an incident (41.3% said "essential") and monitoring the location of units (39.5% said "essential"). Thus, in addition to expressing a need for better systems, most police and fire department personnel in charge of dispatching have indicated that they want a system that suggests a best route, and would trust computers to make that decision. In fact the professionals considered an expert system ideal. They further suggested as a method of verification and validation that human experts monitor the computer-based decision.

The twelve part question 14 surveyed the relevance of various factors in predicting traffic flow on roadways . The responses have proven to be valuable in the design of RULES. It was found that *time of day*, *day of week* and *construction and weather patterns* were recognized as the most important predictors. The least significant predictor, according to the respondents, was *accident rate*. These results are consistent with the impressions logic would dictate: If a car is to get from point A to point B over route Q, the most important things to consider is if it is rush hour on a regular workday, and whether there is any disruptive construction or weather condition on route Q. Similarly, since accidents are not continuous phenomena on most roads most of the time (though they may significantly affect traffic flow when they *do* occur), this relevant factor was ranked low by the survey respondents. Thus, in RULES traffic reports are considered as a dynamic input (part of events). The rankings assigned by the respondents describe the weights assigned each factor in the RULES system.

It was found that nearly two thirds of police and fire chiefs in the nation's major cities rated their current dispatching system as only moderately effective, or worse, at providing units in the field with all data needed. In addition, half of the departments felt similarly that their current systems were only moderately effective at producing good response times, and in excess of two thirds rated their current system as only moderately effective at providing good resource utilization. This demonstrates that there is a critical need for better dispatching systems. In addition this survey provides the relative rankings of twelve factors critically affecting the dispatching decisions. The architecture of the Road Utilization Learning Expert System considers dynamic inputs provided from external sources and, based on the above weights and the knowledge base containing the history of the particular paths involved, provides an expert decision on the best selected path. Furthermore, about seventy percent of police and fire chiefs said that they would trust a computer with the task of

dispatching their units (and 68% said that a computer expert system would be ideal). The results of this survey clearly indicate that the production of the Road Utilization Learning Expert System is an important and necessary endeavor.

There exists a real-world need for emergency vehicles to arrive at incident locations in the shortest amount of time. Dynamic factors that predict traffic flow affect this decision and include weather and roadway conditions, and time of day. This survey of police and fire chiefs requested that these experts rate their current dispatching methods and provide information about the ideal future dispatching system. Most importantly, the opinions of these human experts on their perspectives of the importance and relationships of traffic flow factors was surveyed.

2.2 Expert System Development Tool

RULES has been implemented using the *C Language Implementation Production System* (CLIPS), a pattern-matching knowledge -based system shell, developed by the Artificial Intelligence Section of the Johnson Space Center of NASA. This system was chosen for its applicability to the tasks involved in RULES' design specification, its high portability, and its low cost.

Although CLIPS now supports object-oriented and procedural programming, its primary paradigm (supported by prior versions of CLIPS) has been rule-based programming. The set of actions to be performed in the course of our operations meets this style, and thus the CLIPS platform is ideally suited to the RULES project. The three primary components of CLIPS systems are a fact list, a knowledge-base of if-then rules, and an inference engine. In our case, the fact list contains data which represent the current state of the road network and relevant environmental factors. The if-then portion represent the route-selection problems which may face the user, and their solutions. With CLIPS the Rete algorithm is used to match patterns against facts to determine which rules to execute and when to execute them.

3. RULES Project Architecture

3.1 I/O and User Interface

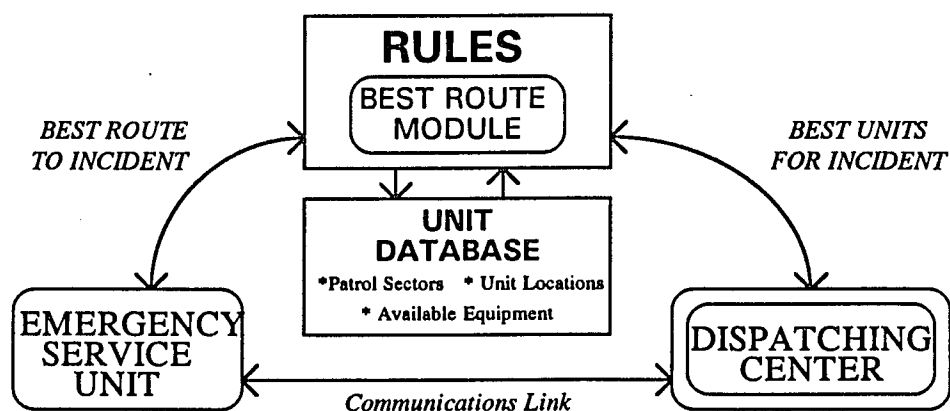


Figure 5. Input/Output Relationships in Rules

The RULES model, the resources RULES users require access to, and the RULES users are depicted in Figure 5. above. The dispatching personnel are in constant radio contact with the emergency services personnel in the emergency services vehicle (or "unit"). Ideally, the unit should be able to directly query RULES with a best-route problem - if there is a data-link in their unit (typically these are text-only terminals which are used primarily to check up on license plates and the like). Units equipped with the more sophisticated map displays could then receive output similar to that depicted in Figure 6. and Figure 7. below. If there is no data link at all, the unit may submit the best-route problem to the dispatcher via radio link (which all emergency services vehicles have), and the dispatching center report back on RULES' suggestion. The dispatching center itself can be a customer of RULES; The center may submit a best-route problem to be run for each of the units it is tracking. The dispatcher can then decide which unit is the best choice, based on RULES output.

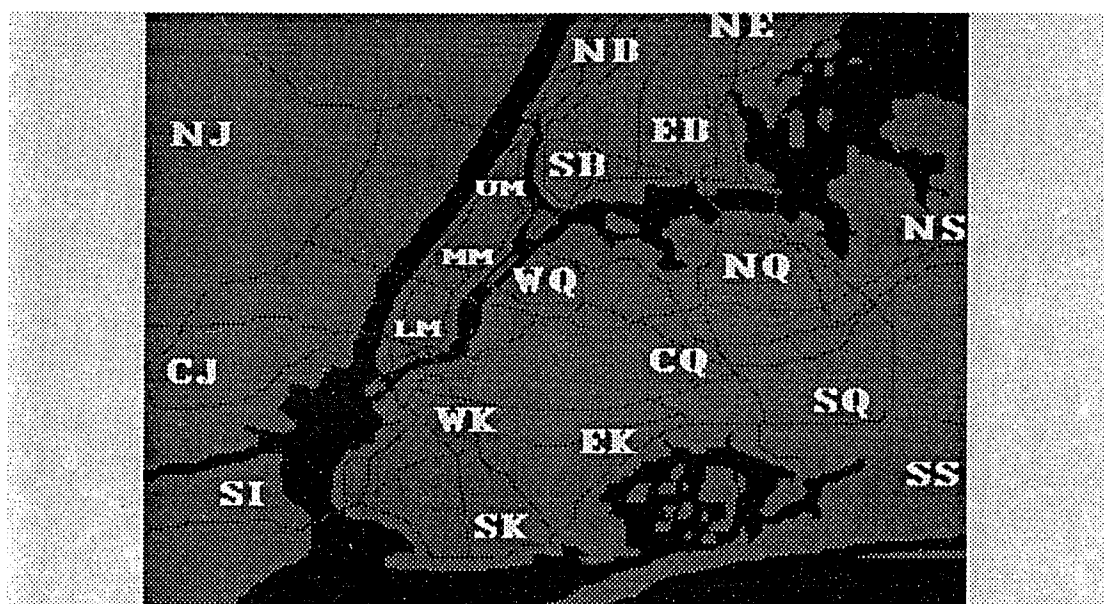


Figure 6. Sample Screen Display for RULES

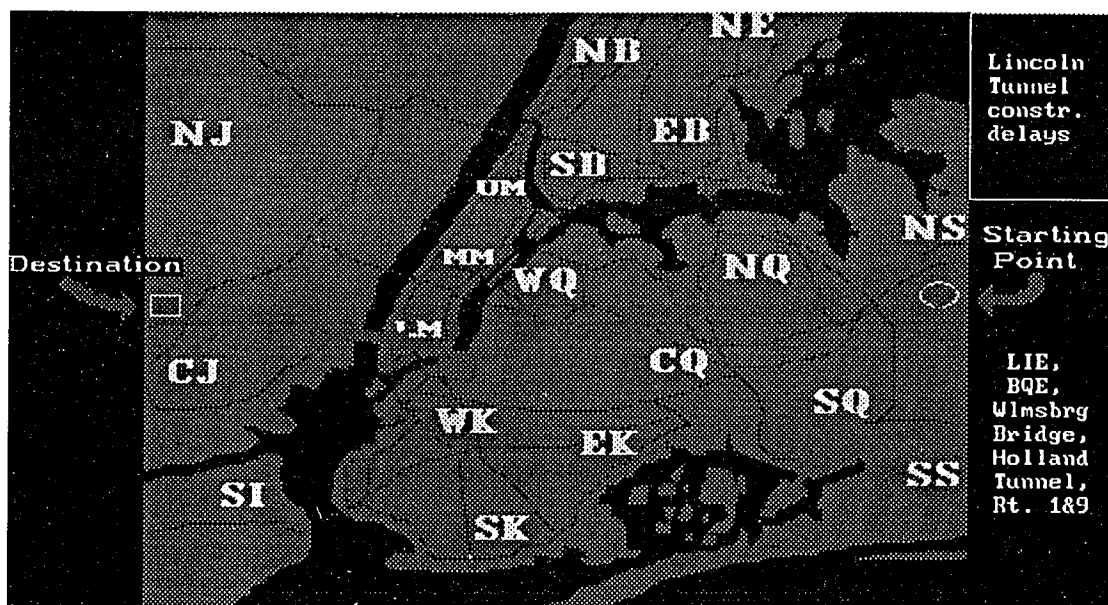


Figure 7. Sample Output on RULES Screen Display

3.2 Information Flow

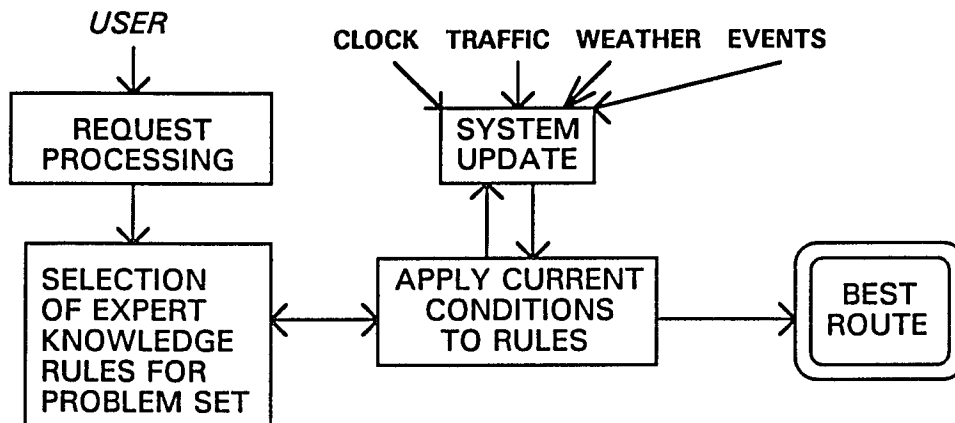


Figure 8. Information Flow in RULES

A representation of the structure and operation of the RULES system is shown in the above information flow diagram (Figure 8.). The survey reported earlier in this dissertation was designed to gather data which shall be a critical component of the "SELECTION OF EXPERT KNOWLEDGE RULES FOR PROBLEM SET" block in the figure above. The dynamic inputs (clock, traffic, weather, and special events) feeding into the "SYSTEM UPDATE" block of RULES were determined from the relative rankings assigned by the human experts responding to the survey. RULES operates best when it has access to a current database of historical traffic-flow data, both for validation purposes and to assist in the generation of the best route as well. Road-side traffic flow sensors are in place and operational in many arteries of major metropolitan areas (Zove 1982) and could directly assist in providing real-time traffic flow data.. Similar mechanisms are being installed in other important roadways. In addition, as described earlier, data describing typical hourly traffic flow for major roadways across the country for all the months of a given year has been collected and maintained by the U.S. Department of Transportation (Curry 1990). If traffic flow

data were not available dynamically for a given region, then RULES still has information from the historical data provided by those government studies. With each run of the expert system, the data set can thus be refined by utilizing statistical data feedback by-products as discussed by (Sobol 1992). The system thus learns more each time it is run.

3.3 Information Management

The core of our Expert System is the Inference Engine, in our case run by CLIPS, which sets the agenda. This core interacts with the knowledge-base which contains the rules. In the case of RULES, the knowledge base contains rules for road-choices under emergency conditions, which are largely road-dependent, and rules for non-emergency conditions, which are largely environmental-conditions dependent. The Inference Engine also interacts with the working memory where facts are stored. In RULES these facts include data on current traffic, weather, and event conditions, as well as more traditional, static information on road segment characteristics. The user interface connects to this inference engine core through an explanation facility which interprets route requests, and a knowledge acquisition facility that must update the knowledge base and the working memory when required.

The emergency services personnel in the units, and the dispatching personnel act only as system users - they play no direct role in system maintenance. Personnel in the logistics, operations management, and/or communications departments at the base must manage the system and maintain it, recognizing any need which may, and probably arise, to update the various components of RULES. These relationships are illustrated in Figure 9. below.

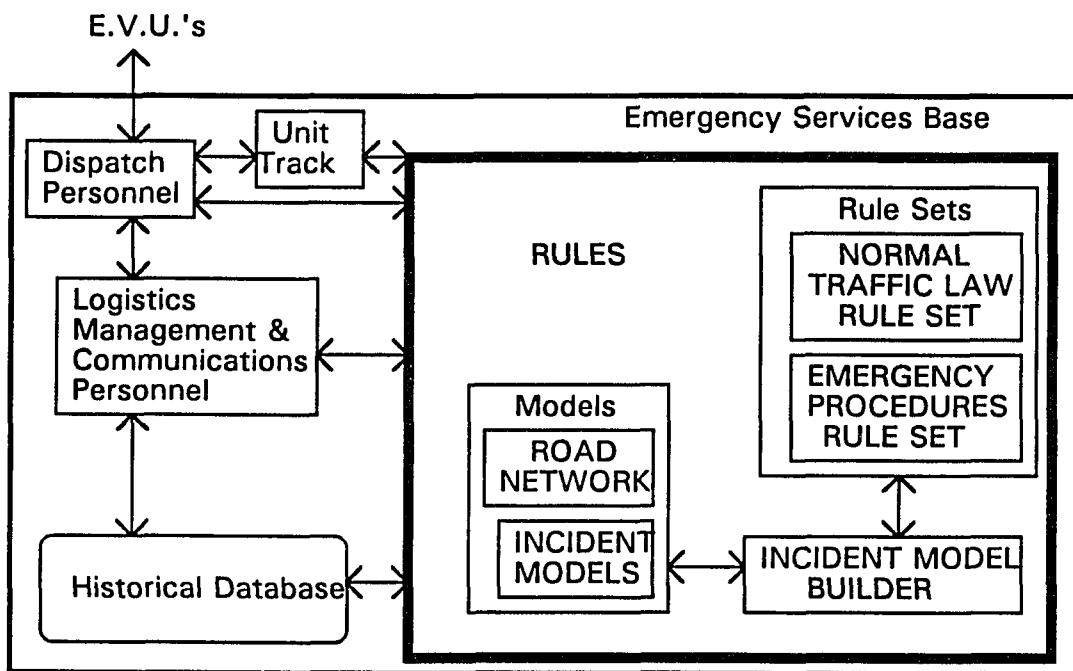


Figure 9. System Management Relationships

4. Coding and Execution of RULES

This section describes the process of writing program code for the RULES system. We do not present a detailed description of every line of code in this section. Rather, here we explain the development of representative segments of code, which illustrate the concepts of RULES' design. Since the primary focus of this section is the explanation of the RULES code development process (and not a tutorial in the usage of CLIPS), for the sake of clarity, most of the rules development described in this section are pseudo-code representations and not CLIPS code. A representative pseudo-code segment is however translated into CLIPS in this section, for purposes of illustration.

4.1 Transforming Expert Knowledge into Rules-Of-Inference

(Harrandi 1986) describes the three major components of an expert system as: (1) a knowledge/rule base that models the domain of knowledge, (2) the current problem state, and (3) control mechanisms for selecting knowledge structures, and applying them to a problem. In our case, item one (1) is a set of rules that specify when a particular road or crossing is a good choice for two primary sets of reasons: we are first concerned with the best route from point A to point B under general conditions (For example "*to get from Manhattan to JFK Airport in a non-emergency situation take the Williamsburg Bridge to the BQE to the LIE to the Van Wyck*"). Second, we have rules that provide instructions for dynamic emergency conditions (For example, "*In an emergency, if it is raining, to get from Manhattan to JFK Airport take the Mid-Town Tunnel to the LIE to the Van Wyck*" because the BQE's fact list indicates that this road floods severely during rain - and the interview with the human experts indicated that

lights and sirens will not help you get around *this* problem). Police procedures when responding to emergencies dictate the following general principles that we must apply to our rules: (Rowland 1985) "Whenever possible, use major arterial roads to get to emergency scenes, even if you have to go a few blocks out of your way.

- * Arterial roads usually provide the quickest route to locations at which emergencies are likely to take place.
- * Motorists travelling these routes are generally more alert because of the greater traffic flow and pedestrian activity.
- * Arterial roads should however be avoided during rush hours."

State Traffic laws usually regulate the conditions under which the emergency services vehicle operator may use lights and siren. These laws then specify which exceptions to normal traffic laws are then applicable to facilitate a quicker response. New York State Vehicle and Traffic Law Title 7 Article 23 ("Obedience to Traffic Laws") Section 1104 ("Authorized Emergency Vehicles") states that emergency services personnel responding to a real emergency situation, when driving in an emergency services vehicle, with lights and siren activated, may: park, stop or stand in normally prohibited zones, may ignore red lights, stop signs, one-way streets, may exceed the speed limit, and may use any road surface available (provided reasonable caution is exerted). This translates roughly into the following pseudo-code:

```

IF    (VEHICLE = EMERGENCY_TYPE
      AND
      SITUATION = VALID_EMERGENCY
      AND
      LIGHTS_&_SIREN = ON_CONDITION)
THEN
      DRIVER_OPTIONS = SET OF
                      (STOP_ANYWHERE,
                       STAND_ANYWHERE,
                       PARK_ANYWHERE,
                       IGNORE_REDLIGHTS,
```

IGNORE_ONEWAYS,
 EXCEED_SPEEDLIMIT,
 USE_ANYROAD)

The corresponding CLIPS code would be the following:

```
(defrule emergency_response_options_available ""
  (and (emergency_response_type valid)
        (vehicle_lights_and_siren on))
  =>
  (assert (vehicle stop anywhere))
  (assert (vehicle stand anywhere))
  (assert (vehicle park anywhere))
  (assert (vehicle redlights ignore))
  (assert (vehicle oneways ignore))
  (assert (vehicle speedlimit exceed))
  (assert (vehicle drive anyroad)) )
```

Harrandi's Item (2), the current problem state, can be described for our scenario using the following hierarchy of circumstances:

GENERAL:

DAY is a choice of
 weekend_holiday, (weekend & holiday are treated the same way)
 weekday is a choice of
 morning_rush, postweekend: Y or N?
 mid_day,
 evening_rush, preweekend: Y or N?
 night

WEATHER is a choice of
 normal,
 rain,
 snow,
 ice,

ROADS :

OBSTRUCTION is a choice of
 construction,
 police_action is a choice of
 demonstration,
 accident,

other (fire, spill, etc.)

A general problem state could then be: [preweekend,evening_rush,rain]

The road specific state could be: [FDR_Drive: accident,
BQE: construction,
42_Street: demonstration]

The third item (3) Harrandi describes includes the control structures; a blending of (1) and (2), into rules that recommend a course of action, given the problem state described. The user enters current location and destination on a mobile terminal in the vehicle while en-route. Based on these inputs, the time and day, current weather and traffic conditions, and any special events, the expert system determines the best route and output it to the user through the data terminal, voice generation, or via map display, depending on the available equipment.

There are two types of rules which we consider in the creation of our expert system: "definitional rules", and "heuristic rules" (Harmon and Sawyer 1990). In definitional rules the inference establishes a relationship between the terms. Heuristic rules allow inferences based on incomplete evidence. To illustrate, our definitional rules include rules such as:

```
IF ROAD_X_CONDITION = IMPASSIBLE
THEN ROAD_X_FLAG = REJECT_THIS_ROUTE
```

The heuristic rules are of the form:

```
IF ROAD_X_CONDITION = LANE_CLOSED
AND ROAD_X_SHOULDER = DEBRIS_&_BROKEN_GLASS
AND TIME = RUSH_HOUR
THEN ROAD_X_FLAG = POOR_ROUTE
```

Note that in the first case the route is rejected outright, whereas in the second case, the expert system must weigh the alternate options, and perhaps come to choose this route.

Some of the considerations the human expert emergency vehicle operator takes into account when selection a route are (Auten 1989): traffic volume, traffic speed, the presence of pedestrians (on service roads, etc.), the unpredictable nature of other drivers actions (particularly on holidays and weekends), and conditions likely to develop during the response (people reacting to your lights and siren by slowing down in front of you). Auten also describes the influence of road surface type (potholes, bumps, etc.), lanes, shoulders, and exits. Most of these items, and the importance assigned to them match the results of our survey of emergency services professionals, and are thus converted into rules (rule induction), and components of rules. The RULES system uses three levels to measure traffic conditions: HEAVY volume, MEDIUM volume, and LIGHT volumes. Auten confirms that these are a sensible way of defining congestion types when making the route decision. They are defined in the following way in (Auten 1989):

Heavy volume = all lanes occupied, intervals between cars are minimal, slow flow

Medium volume = intervals greater, but there is some "bunching" and slowing

Light volume = no obstructions to emergency vehicles in passing lane

"Knowing *when* to use a shortcut is as important as knowing the route", says (Schwartz 1993). Many important general rules, applicable to New York City roads, were induced from the aforementioned source. One general purpose rule:

IF HIGHWAY_X_SPEED < 15mph THEN USE ALTERNATE

What this typically translates into is, exit and use the service road, if there is one. Schwartz points out the particular problems some roads have at specific times. He explains that the L.I.E. eastbound is to be avoided on Fridays, 2PM - 8PM, from April to November (weekend getaways on Long Island). For the same reason the L.I.E. westbound is to be avoided on Sundays, 3PM-9PM, from June to September (traffic coming back from the beach getaways). In the winter, Schwartz asserts, the L.I.E. from exit 68 to exit 70, is particularly treacherous when there is snow. He points out that when choosing East River crossings into Manhattan, one should note that the toll crossings are lighter than the free crossings on weekends, whereas the reverse holds true on weekdays. Items such as this can be useful for emergency services officers, as well as for ordinary drivers. Schwartz further states that traversal of mid-Manhattan is a poor route choice particularly on Wednesday, matinee day, from 1PM - 2PM and again from 4PM - 5PM. From November to January, Sixth Avenue to Eighth Avenue, from 43rd to 53rd Streets, are best avoided.

In general, northbound traffic on the Manhattan arteries is slow from 4PM to 7PM, and southbound traffic is slow from 10AM to 4PM. The Queens-Midtown Tunnel, the Queensboro Bridge, and the Lincoln Tunnel all lose outbound lanes, but gain inbound lanes during the morning rush-hour. The reverse holds true for the evening rush. All of these factors are components of the attributes that make up the fact list for each route.

A system of road-bed sensors, video monitors and route guidance billboards is currently operational for the L.I.E., the Grand Central Parkway, the Northern State Parkway and most on the Long Island east/west corridor. This system, called

INFORM, is run by the New York State Department of Transportation (its current supervisor of operations, Joseph Contegni, was one of the experts interviewed for the RULES project knowledge-base production process). One of the principle uses for the INFORM system, as described in its design document (Zove 1982), is expressed as follows: "Rapid police response to incident locations can be facilitated by obtaining information on the best route to take ... by consulting with the INFORM control center." Several items found in the INFORM design document were helpful to the RULES project.

The INFORM project identified the speed improvement experienced by choosing various alternate to remaining on a heavily congested L.I.E. It was found that in such cases, taking the service road can increase average speed by 7 to 9mph. Taking contiguous streets, where they are convenient and accessible, increased average speed by 19 to 32mph. The INFORM project also adapted the following incident detection algorithm to identify congestion:

```
Test1: IS AVOCUP - AVOCDN >= THRESH ?
      REPEAT Test1 UNTIL TRUE (if true check the location via video cameras, etc.)
      IS AVOCUP >= OC2 (make sure it isn't just normal congestion for this hour)
      Investigate Cause of Blockage
Test2: IS AVOCUP - AVOCDN < THRESH (has it cleared up yet?)
      REPEAT Test2 UNTIL TRUE
```

Where AVOCUP is the AVerage current OCcupancy at the UPstream Sensor, AVOCDN is the average current occupancy at the downstream location, THRESH is the congestion threshold coefficient, and OC2, a function of the particular site is the bottleneck capacity for that particular site.

This algorithm allows the INFORM operators to automatically detect incident occurrences, detect the conclusion of the incident, and identify abnormal congestion vs. normal congestion. RULES uses a similar semaphore-type system to set dynamic data facts relating to congestion conditions that may appear and disappear at unpredictable intervals.

4.2 Running the RULES System

The user indicates the current location and the location of the incident to find the best-route to. RULES outputs a description of the best route. During this run RULES may perform the following operations to confirm the validity of advice:

Select the first choice best route based on expert criteria in the knowledge-base.

Given: the preferred path from Start to Finish is composed of
road1 + road2 + road3... + roadN

Where "X" is each successive road -

- 1] compute a time for each roadX using historical data:
 - *determine current time
 - *find historical average speed for that time on that road
 - *multiply road speed by road's length
- 2] compute a time for each roadX based on current conditions:
 - *determine current time
 - *sample current conditions on roadX (roadside sensors and/or traffic monitors)
 - *multiply road speed by road length
- 3] find mean of "1]" and "2]"
- 4] record this time estimate (first time), or add this value to time estimate sum
- 5] wait mean value computed (this is the amount of time user should spend on roadX)
- 6] move to next roadX
- 7] return to step 1 and repeat process, until roadN is reached
- 8] compare actual time with time estimated by this process

5. Verification, Validation and System Testing

It is often stated that the distinction between verification and validation of a system is that verification is "building the system right" and validation is "building the right system" (Bahill 1991). Indeed, when testing RULES we have both verified that the specifications were correctly implemented, and we have validated that the system meets the requirement and produces correct, meaningful output.

The advice rendered by the RULES is only useful if it is at least as accurate as the advice the human expert would have offered. Since our system is based on the sum of knowledge of many human experts, as well as real-time and historical data, we expect that the system's advice is in fact be better than a single human expert's advice. The design of RULES incorporates some self-validation processes designed to address the issues raised by Shamsudin, Kwon, and Marathe, for the validation of their expert systems. Shamsudin's Net Manager network traffic management system (Shamsudin 1991) discusses the problems of maintaining performance in a real-time system when there is a need to diagnose the knowledge-based analysis. The design of RULES allows it to overcome these obstacles since, if desired as discussed earlier, RULES can diagnose system performance as part of the process of validating output after every usage of the system. This is possible because our system already has at its disposal all of the resources necessary to gather the data required for validation. One of the factors which may then determine the roads RULES will choose is historical and expert data on the traffic flow on a given road at the time in question. The utilization of such performance and operation statistics facilitates the construction of an effective knowledge base. Data feedback by-product utilization is described in (Sobol 1992). With the historical data, the system is capable of estimating the speed of travel on these

roads, and where the user should be at any time during the trip can be determined. Therefore, after the system provides the best route output to the user, it may begin an alternative form of validation.

Kwon's On-Line Traffic Demand and Diversion in Freeway Corridors model (Kwon 1990) is similarly validated (though on a much narrower scale than in RULES) with real-time data collected at several locations. Any deficiencies in the Freeway Corridor model would have been more identifiable if more data were available. Kwon concluded that volume prediction performance "can be significantly improved if more historical data and the upstream volume information are available in real time". The historical data built into RULES, as well as RULES' learning capability (incorporating new observations of traffic flow on the various arteries, based on information collected continuously by RULES' sensors), allow our system to meet this demand for information.

Validation of CRAFT - Marathe's expert power system dispatcher's aid (Marathe 1990) , is accomplished through the classification of the system's outputs into three categories:

Type 1: Output was identical to the human expert's actions.

Type 2: Output was different from the human expert, but valid for the fault detected.

Type 3: The system's suggestions were invalid, or failed to detect fault.

Marathe's CRAFT was reported to present Type 1 results 85% of the time. The Type 2 results occurred where additional knowledge available to the humans had not yet been integrated into the expert system (and are thus easily corrected by updating the system).

In dealing with Type 3 results, a determination had to be made whether the triggering event was rare enough so as to not warrant extensive broadening of the system. A suggested method of handling such problems was that in all such cases, a (human) dispatcher is notified that the system has detected a fault that is "outside its domain". The human may then assume control of that decision. We now describe the verification and validation performed on RULES after its construction.

5.1 Verification

Consistency and completeness checking was the focus of our verification process. This was a rather complicated task since there were variety of sources contributing to the construction of the RULES system. Most of the time the sources were compatible and effectively complementary. For example, the interview with P.O. Wolf, our human expert, yielded much the same information as our survey of 178 emergency services professionals. In fact, the similarity between the weight model we constructed based upon the survey results, and the interview results, verified that we had drawn accurate conclusions from our survey, and the design specifications were met. Whether this led to RULES yielding the correct output is covered below in the next section.

Further considering the factors that affect the decision making of emergency services personnel, we discovered the following: If we represent the weights assigned by the survey analysis, and the weights assigned by P.O. Wolf during his interview as pairs of the form: *attribute(survey weight , Wolf weight)*, the results were as follows: time(4.5 , 5), construction(3.98 , 4), day(3.95 , 4), weather(3.48 , 3), holiday(3.3 ,

3), road surface(3.27 , 1), lanes(3.1 , 2), season(2.81 , 3), alternates(2.67 , 1), exits/entrances(2.62 , 1), accident rate(2.57 , 1), and speed limit(2.55 , 1).

There is a striking relationship between the rankings. Both sources yielded the same top-priorities, as well as the same least-relevant factors. The order was almost identical. These factors assisted in verifying the requirements specifications which enumerated the need to properly represent the knowledge-base. This alone was not sufficient to complete the verification process. In addition we needed to correct or remove syntactic errors in the code. The possible rule errors that were sought and eliminated, where identified, were redundant rules, conflicting rules, subsumed rules, circular rules, unreachable rules, dead-end rules. Finally, missing rules were added.

5.2 Testing and Validation

(Gonzalez 1993) breaks the validation process down into two stages: (1) Informal validation - consulting the human expert to assess the quality of the system's output. and (2) Validation by testing - the development of test cases for output comparison (of course, acceptance criteria are then composed). We have chosen to follow this two step strategy of Gonzalez to Validate RULES. Ultimately the goal is to demonstrate that in nearly all cases (exactly how often is in fact the "acceptance criteria") the output of the RULES system is the same as the route suggestions a human expert offers.

First, P.O. Wolf, our human expert, was asked to assess the output decisions of several runs of RULES. In all cases, he described the choices of RULES as valid, and

the reasoning process by which he reached his conclusion matched the sequence of rules fired in RULES. Some of the specific issues covered with which he agreed included the following:

In bad weather the Grand Central Parkway (G.C.P.) and the L.I.E. are good choices, and the Belt Parkway, the Van Wyck Expressway, and many bridges are bad choices, due to flooding or slick surfaces.

Roadways with good surface conditions include the G.C.P., the Belt, and the Major Deegan, and bad surface conditions can be encountered on the Cross Bronx, the B.Q.E., the Van Wyck, and the L.I.E.

At this time, P.O. Wolf also offered some more suggestions for general purpose route selection. He explained that one of the most frequent decisions he and others might need to make in an emergency is choosing to ride on the shoulder, to ride on the service road or local streets, to ride in the left lane "pushing" everyone over, or to find an alternate route. These choices had been known to us from our other expert sources, and we had in fact included those issues in RULES. However, we had only treated these options as either good or bad choices for particular roads (i.e. the decision depends on the road). Wolf explained that this decision also depends on the current distance from the incident. This information, discovered during the validation interview can now be used to upgrade RULES.

The second part of the validation process was accomplished by supplying the following cases as input to RULES, and noting the rules that had been fired to reach each solution:

Test Case #1

problem: Flushing Meadows Park to the George Washington Bridge

solution offered by RULES: *GCP to Triboro to Harlem River Drive*

Test Case #2

problem: Flushing Meadows Park to JFK Airport

solution offered by RULES: *GCP to Van Wyck*

Test Case #3

problem: Flushing Meadows Park to the Empire State Building

solution offered by RULES: *LIE to Midtown Tunnel*

Test Case #4

problem: Downtown Brooklyn to Yankee Stadium

solution offered by RULES: *Manhattan Bridge to FDR to East River Bridges*

Test Case #5

problem: Downtown Brooklyn to JFK Airport

solution offered by RULES: *Atlantic Avenue to Pennsylvania Avenue*

Next, the "problem" in each of these cases was indicated on a map (a mark at the starting point and a mark at the destination) and P.O. Wolf was asked to indicate his choice of the best route (without seeing or knowing RULES' solutions). In every case he chose the exact same best-route as was chosen by RULES. When queried about the specific issues involved in each decision, he indicated a thought process which matched the sequence of rules fired in RULES. In Test Case #2 though, it should be noted that he said he might choose to ride along the service road of the Van Wyck to avoid the traffic. This was noted and applied to RULES knowledge base. The choices in cases 1 to 4 might be seen as logical best-route selections even for non-emergency services drivers as well. It should be noted that the non-intuitive (for non-emergency services drivers, at least) selection made in Test Case #5 reflects the unique nature of the factors that affect the route-decision making process of the emergency services expert. That RULES and the human expert chose the same solution, for the same reasons, demonstrates the validity the correctness of RULES' output. It should be noted that the

testing procedures described above are sufficient for our purposes (i.e. demonstrating the validity of a representative model). In order to test a fully operational RULES-like system, an exhaustive test-specification must be developed and implemented via extensive interviews with the emergency services experts. This testing process is beyond the scope of this project since it would not contribute to our goals, as explained earlier.

III. CONCLUSIONS AND OBSERVATIONS

1. System Assessment and Project Conclusions

The successful completion of a representative verification and validation process has demonstrated the overall success of the RULES project. It is expected that expanding RULES to cover all roads in the city it is applied to, rather than the subset of major arteries implemented in the current system, would lead to a system that can begin operations immediately as an important tool for emergency services personnel. The new techniques delineated in the RULES project for combining diverse resources and for applying an Expert System solution to a type of problem that had previously met algorithmic solutions, will hopefully contribute to progress in this realm of the Artificial Intelligence discipline. Finally, the methods and models used in the construction of this emergency services vehicle-routing system may be applied to the construction of Expert Systems which solve other problems facing emergency services organizations.

2. Areas for Future Expansion of RULES

Traditionally the focus in the emergency service profession has been exclusively on reducing response times. The investigations of Chelst and Jarvis (1979) have determined however, that there is a complex relationship between response time and probability of arrest (for police), or prevention of death from accidents and myocardial infarction (for EMS). The implication of that finding is that even though

time is obviously a critical factor, there are other items affecting the success of responses. Determining the most appropriate set of responding units might be best defined with the help of a future expert system implementation. This complementary system chooses the number of units and the best units for the response, based on the personnel and equipment in a given unit, and the circumstances of the incident. The user of such a system would again be the base/dispatching personnel.

An additional consideration would be any advice that RULES had concurrently offered to other users. For example, the very presence of an emergency service vehicle with lights and sirens activated may directly affect traffic flow on a road (motorists slow down when they see it). RULES would then be able to determine which roads may soon become congested, in addition to its fundamental capability to detect currently congested roads. This can be further complicated by the existence of multiple dispatching centers (Police, Fire, EMS) responsible for overlapping areas, the need of neighboring sectors to utilize some of the same arteries, and the occasional need for resource sharing between sectors. To accomplish this one may implement a network configuration of RULES. The vehicle routing network operations would be analogous to similar data-flow and routing problems in a computer network, but with roads taking the place of network lines, intersections in place of gateways and nodes, and individual vehicles filling the role of individual data packets. The system described in this work is a centralized computer that provides data to individual users at remote sites, based on expert knowledge, prior experience, and dynamic inputs of current traffic flow data. Ideally, we would like to add to these factors, the advice that the system is dispensing to other users. An additional item which would then factor into RULES' decision making process, would be any advice that RULES had concurrently offered to other users. RULES would then be able to determine which roads may soon become congested. To accomplish this we would implement a network configuration of

RULES. The vehicle routing network operations would be analogous to similar data-flow and routing problems in a computer network, but with roads taking the place of network lines, intersections in place of gateways and nodes, and individual vehicles filling the role of individual data packets.

"The best strategy or methodology for knowledge acquisition varies, though there can be little doubt that the success of an Expert System is determined by the quality of the knowledge acquired." - (Parsaye 1988)

APPENDICES

A1. RESOURCES USED IN RULES' PRODUCTION

A1.1 Survey of Emergency Services Personnel

August 10, 1992

Dear Public Service Professional,

We are conducting a survey of dispatching systems used by key Police Departments, Fire Departments, and Emergency Services. This study is being conducted in the Computer Science Department of the Graduate School and University Center of the City University of New York. Our goals are two-fold: First, to determine what types of dispatching systems are currently being used and how their users rate them. Second, we are interested in surveying the needs of these Public Service departments, to design even better systems in the future.

The results will be made available to all survey participants (If you would like to receive a copy of the results please provide the information requested below). We therefore respectfully request that you take a few minutes to complete the questionnaire and return it within the next week. Confidentiality will be maintained, and all responses will remain anonymous. **This survey has been carefully designed to facilitate its completion in a minimal amount of time. We estimate that it should take only 3 to 6 minutes to complete.** *Please note: Questions 11, 13 & 14 are the most important for our survey.*

Sincerely Yours,

Philip Listowsky
CUNY Grad. Center

Dr. Robert Goldberg
Queens College of CUNY

Yes, we would like a copy of the results.

Mail the survey results to:

PART 1: GENERAL INFORMATION*Please check box(es) or fill in where applicable:*

- (1) Service Type: 1. Police Department 2. Fire Department
 3. Other (please specify) _____
- (2) Department Size: 1. 1-100 persons 2. 101-500 persons
 3. 501-3000 persons 4. 3001-20000 persons
- (3) Number of Vehicles: 1. 1-10 2. 11-100 3. 101-500 4. 501 +
- (4) Area covered by department: _____ sq. miles
- (5) Estimate of typical unit dispersal: _____ vehicle(s) in use per square mile
- (6) Average unit incident response-time: _____
- (7) Distance typically traveled in response (from question 6): _____
- (8) How does your department currently dispatch and communicate with units?:
 1. via radio only
 2. via computer communications link
 3. both radio and computer link to vehicles
- (For questions 9 & 10, please check all answers that apply)*
- (9) What method is used to decide which units to dispatch to an incident?:
 a. base personnel broadcasts incident location, units in vicinity of incident will let base know they can respond
 b. base personnel manually track units at all times and choose units to assign incident to
 c. computer advises department on best unit to assign
- (10) How do dispatched units determine the best route to incident?:
 a. personnel in unit decide route based on their own knowledge
 b. personnel at base tell personnel in unit best route
 c. computer recommends best route
- (11) Ideally, which method of dispatching would you have the greatest confidence & trust in?
 1. A department employee generally acknowledged to be an expert in dispatching
 2. A department employee routinely assigned to that specific task
 3. A computer system bought "off-the-shelf" - but recommended by others
 4. A computer system containing the knowledge of all of your expert employees
- (12) Reason for choice in question 11 ? _____

- | | NO | With
Skepticism | Yes | Very
Definitely | Completely |
|--|--------------------|--------------------|-------------------------|--------------------|------------|
| (13) Would you trust a computer with the task of dispatching your units? | 1 | 2 | 3 | 4 | 5 |
| (14) On a scale of 1 to 5 (with 1 being <u>not relevant</u> and 5 being <u>most relevant</u>), please rate the relevance of each of the following in predicting traffic flow on roadways: | | | | | |
| ___ time of day | ___ day of week | ___ season | ___ holiday/not holiday | | |
| ___ lanes in roadway | ___ road condition | ___ weather | ___ accident rate | | |
| ___ construction | ___ speed limit | ___ alternates | ___ exit/entrance ramps | | |

PART 2: EVALUATION OF THE DISPATCHING SYSTEMS YOU USE

Please rate effectiveness in the following areas, of the dispatching system your department currently uses:

- | | slightly
ineffective | moderately
effective | very
effective | optimally
effective |
|--|-------------------------|-------------------------|-------------------|------------------------|
| How well does your current system: | | | | |
| (15) Provide units in the field with all data needed? | 1 | 2 | 3 | 4 5 |
| (16) Produce good response times? | 1 | 2 | 3 | 4 5 |
| (17) Consistently provide good resource utilization? | 1 | 2 | 3 | 4 5 |
| (18) Reduce the total number of units dept. needs? | 1 | 2 | 3 | 4 5 |
| (19) Does your department have plans to upgrade its dispatching system in the near future? ___ | | | | |

PART 3: SUGGESTIONS FOR FUTURE DISPATCHING SYSTEMS

Please rate the importance of including each item below in the design of a dispatching system:

- | | not
important | slightly
important | moderately
important | very
important | essential |
|---|------------------|-----------------------|-------------------------|-------------------|-----------|
| (20) Advise units of traffic conditions in area | 1 | 2 | 3 | 4 | 5 |
| (21) Choose best unit for a given incident | 1 | 2 | 3 | 4 | 5 |
| (22) Suggest best route for unit to get to incident | 1 | 2 | 3 | 4 | 5 |
| (23) Monitor location of all units at all times | 1 | 2 | 3 | 4 | 5 |

A1.2 Traffic Data Samples

A1.2.1 Example of New York City Department of Transportation Data

NYC Department of Transportation Traffic Volume Count Program

Grand Central Pkwy N/B @ Van Wyck Expwy
 Purpose: Studies for lane closing
 Req. by B. Morgenbesser

Queens
 Machine: 89
 Cassette: 60

	Tue 8/ 7	Wed 8/ 8	Thu 8/ 9	Fri 8/10	Sat 8/11	Sun 8/12	Mon 8/13
Mid-1	0*	0*	683	645	827	898	725
1-2 am	0*	0*	347	433	534	583	426
2-3 am	0*	0*	246	269	368	419	261
3-4 am	0*	0*	158	158	226	355	148
4-5 am	0*	0*	279	243	297	254	241
5-6 am	0*	0*	857	750	381	325	828
6-7 am	0*	5*	1,778	1,693	825	828	1,751
7-8 am	0*	0*	1,711	1,679	1,321	933	1,718
8-9 am	0*	52*	1,560	1,523	1,197	970	1,447
9-10 am	498	1,394	1,430	1,337	1,225	1,133	1,326
10-11 am	676	1,419	1,350	1,382	1,380	1,293	1,309
11-Moon	2*	1,530	1,372	1,389	1,385	1,268	1,342
Noon-1	2*	1,423	1,280	1,310	1,464	1,310	571
1-2 pm	7*	1,571	1,488	1,422	1,483	1,517	0*
2-3 pm	3*	1,608	1,438	1,642	1,586	1,622	0*
3-4 pm	8*	1,676	1,522	1,713	1,665	1,707	0*
4-5 pm	1*	1,650	1,731	1,672	1,712	1,637	0*
5-6 pm	1*	1,716	1,674	1,716	1,734	1,738	0*
6-7 pm	0*	1,624	1,636	1,653	1,758	1,705	0*
7-8 pm	1*	1,536	1,693	1,663	1,616	1,691	0*
8-9 pm	0*	1,450	1,462	1,533	1,417	1,608	0*
9-10 pm	0*	1,535	1,459	1,454	1,310	1,661	0*
10-11 pm	2*	1,573	1,431	1,480	1,412	1,588	0*
11-Mid	0*	1,146	1,075	1,165	1,352	1,076	0*
Totals	1,201*	22,908*	29,660	29,924	28,475	28,119	12,093*
7-10am	498*	1,446*	4,701	4,539	3,743	3,036	4,491
10am-1pm	680*	4,372	4,002	4,081	4,229	3,871	3,222
1-4pm	18*	4,855	4,448	4,777	4,734	4,846	0*
4-7pm	2*	4,990	5,041	5,041	5,204	5,080	0*
7am-7pm	1,198*	15,663*	18,192	18,438	17,910	16,833	7,713*

NYC Dept. of Transportation Traffic Volume Count Program

Van Wyck Exp S/B From Main Street
 Purpose: JFK Rail Link Study
 Req. by Diane Gellman

Queens
 Machine: ?
 Cassette: 7

	Thu 9/ 1	Fri 9/ 2	Sat 9/ 3	Sun 9/ 4	Mon 9/ 5	Tue 9/ 6	Wed 9/ 7
12-1am	0*	0*	231	220	263	129	180
1-2am	0*	0*	109	120	96	49	69
2-3am	0*	0*	70	88	53	38	55
3-4am	0*	0*	63	73	33	34	51
4-5am	0*	0*	74	70	55	54	79
5-6am	0*	0*	122	86	80	184	240
6-7am	0*	0*	224	136	149	467	584
7-8am	0*	0*	313	209	189	970	1,177
8-9am	0*	0*	358	247	204	884	1,156
9-10am	0*	0*	414	290	304	610	749
10-11am	0*	3*	473	369	405	509	561
11-12am	12*	0*	471	411	474	615	0*
12-1pm	0*	601	518	411	511	716	0*
1-2pm	0*	589	505	418	550	643	0*
2-3pm	0*	634	517	436	528	811	0*
3-4pm	0*	673	534	503	504	867	0*
4-5pm	0*	711	432	465	492	891	0*
5-6pm	0*	648	422	443	422	857	0*
6-7pm	0*	530	454	361	440	641	0*
7-8pm	0*	432	354	357	346	697	0*
8-9pm	0*	451	402	294	349	652	0*
9-10pm	0*	338	338	310	331	492	0*
10-11pm	0*	340	310	325	247	410	0*
11-12pm	0*	306	283	328	228	325	0*
Totals	12*	6,256*	7,991	6,970	7,253	12,545	4,901*
7-10am	0*	0*	1,085	746	697	2,464	3,082
10-4pm	12*	2,500*	3,018	2,548	2,972	4,161	561*
4-7pm	0*	1,889	1,308	1,269	1,354	2,389	0*
7am-7pm	12*	4,389*	5,411	4,565	5,023	9,014	3,643*

NYC Dept. of Transportation Traffic Volume Count Program

MANHATTAN

Amsterdam Avenue N/B Bet 185th & 186th Sts

Purpose: Yeshiva Mall Evaluation
 Req. by: Roz Diamond

Machine: 79
 Cassette: 92

	Mon Sep 14	Tue Sep 15	Wed Sep 16	Thu Sep 17	Fri Sep 18	Sat Sep 19	Sun Sep 20
Mid-1	-	133	119	144	149	148	257
1-2 am	-	80	77	84	103	118	171
2-3 am	-	39	37	48	63	76	129
3-4 am	-	27	30	32	26	67	102
4-5 am	-	26	21	20	34	51	87
5-6 am	-	37	44	48	39	48	57
6-7 am	-	99	113	91	99	67	69
7-8 am	-	242	236	231	227	94	83
8-9 am	-	145	138	148	109	82	70
9-10 am	-	124	119	107	114	116	160
10-11 a	-	139	140	124	148	167	179
11-Noon	70	137	133	178	130	187	176
Noon-1	210	149	167	168	167	215	227
1-2 pm	243	195	202	181	128	229	256
2-3 pm	200	188	172	173	183	242	319
3-4 pm	227	175	216	221	178	264	327
4-5 pm	167	165	216	189	181	274	374
5-6 pm	217	233	234	243	164	357	387
6-7 pm	244	237	291	256	188	339	321
7-8 pm	242	225	238	236	253	277	325
8-9 pm	223	247	238	228	273	299	255
9-10 pm	185	216	213	221	219	312	231
10-11 p	170	177	191	185	171	260	222
11-Mid	156	164	139	166	159	265	206
Totals	2,554*	3,599	3,724	3,722	3,505	4,554	4,990
7-10 am	-	511	493	486	450	292	313
10a-1p	-	425	440	470	445	569	582
1-4 pm	670	558	590	575	489	735	902
4-7 pm	628	635	741	688	533	970	1,082
7a-7p	-	2,129	2,264	2,219	1,917	2,566	2,879

A1.2.2 Example of New York State Department of Transportation Data

NEW YORK STATE BRIDGES BY AVERAGE DAILY TRAFFIC

STREET OR HWY	WHAT IT CROSSES	DK	SP	SB	SR	AVGDTR
RTE 678	908BX TO 678, RTE 908	4	4	3	30	189532
BQE E.LEG	31 AVE	3	4	3	32	175800
BQE E.LEG	31 AVE	3	5	4	48	175800
FROM BQE	VARICK AVENUE	N	3	4	46	169791
QNSBOR BR	NEW YORK STR, EAST RIVER	3	3	4	15	159559
RTE 495	COLLEGE PT B, FLUSHING RI	3	4	3	32	157430
L.I. EXP	80 TH. STREET	3	5	4	46	157430
RTE 495	RTE 25A , LI RR LOCAL ST	3	3	4	17	157430
FR 59 ST	FIRST AVE	4	3	3	2	157381
TO 62 ST	EAST 60TH ST, E61 STREET	8	3	3	30	157381
BQE W.LEG	RTE 907M ,	4	5	3	23	154468
L.I. EXP	CONRAIL-HELLGATE	4	4	3	4	133600
FDRD SB	907L & TERRA, 60 TH STREE	N	3	3	29	133325
RTE 278	138TH STREET, LEGGETT AVE	3	3	3	27	130836
TRIBOR BR	CITY STS & B, EAST RIVER	3	3	3	0	130836
FDRD	RELIEF	4	3	4	36	129585
RTE 907C	MILL BASIN	4	4	3	17	123989
RTE 907C	PAERDEGAT BASIN	4	3	3	18	123989
907CBELT SYSTEM	ROCKAWAY PARK	4	4	3	36	123989
FDRD SOUTH BOUND	RTE 907L , PROM BIN223216	4	5	3	0	123150
B-Q EXP	35TH AVE	4	5	3	37	116580
BQE E.LEG	TO BQE WEST , 32 AVE	4	4	3	32	116580
BQE W.LEG	31 AVE	3	5	5	74	116580
MANHTN BR	FDR DRIVE , RTE I 287	4	3	4	2	116235
RTE 907C	OCEAN PKWY	3	4	3	23	115000
RTE 907C	OCEAN AVE	3	3	4	34	115000
RTE 907C	BEDFORD AVE	3	4	4	49	115000
RTE 907C	GERRITSEN INLET	4	4	3	35	115000
GOWAN EXP	59TH ST , 907C TO BQE	3	3	4	30	113505
GOWAN EXP	RELIEF	4	3	4	32	113505
GOWAN EXP	RELIEF	4	4	3	32	113505
GOWAN EXP	RELIEF	4	3	4	32	113505
GOWAN EXP	AT CLINTON ST	3	4	4	43	113505
BQE EXP	MANHATTAN AV, HUMBOLDT ST	3	3	4	19	113505
KOSCIUSZKO BRIDGE	MORGAN AVE.E, LIRR ABANDO	4	3	3	18	113505
RTE 278	NASSAU ST , CONCORD ST	4	4	3	17	113505
RTE 87	RIVER ROAD , HUDSON RIVE	3	3	3	18	113039
HENRY HUD	AMTRAK	4	3	3	4	112516
RTE 678	COLLEGE PT. , RTE VWE	3	3	3	15	111874
WHITESTON	907MSOUTH BO, 907MNORTH B	3	4	3	17	111874
BROOKL BR	I278 BKN-QNS, FAR DR & CI	4	3	4	15	110432
RTE 907C	FRESH CREEK	3	4	3	18	110000
RAMP KB TO VWE NB	907MEB TO 67, RTE 908	5	4	3	12	106035
BRNX-WHITSTONE BR	EAST RIVER	4	3	3	4	105100
TO BQE NB	VARICK AVENUE	N	3	4	33	104625
FDRD	SOUTH STREET, RAMP D TO N	4	3	4	27	102486
RTE 907L	AVENAVE.C , EASTE.20ST	3	4	4	47	102486
BRPCX	E TRE.TREMONT AVE	3	4	4	54	96086
TRIBORO-NY TO RI	CITY STS.FDR, HARLEM RIVE	4	3	3	2	95217

A1.2.3 Example of United States Department of Transportation Data

Time	C. Wash. Bridge	Lincoln Tunnel	Holland Tunnel	Manhattan Total	Rayonne Bridge
12-1 am	3,542	1,498	1,004	6,044	53
1-2	1,594	788	518	2,900	21
2-3	1,125	526	397	2,042	36
3-4	968	339	297	1,604	18
4-5	1,062	385	411	1,858	51
5-6	1,872	659	1,100	3,631	159
6-7	5,530	1,665	2,273	9,468	585
7-8	9,051	2,499	2,394	13,944	992
8-9	8,489	1,833	2,065	12,387	654
9-10	6,414	2,325	1,817	10,556	416
10-11	5,695	1,900	1,882	9,557	278
11-12	5,645	2,273	1,717	9,635	317
12-1 pm	5,541	2,428	1,979	9,948	265
1-2	5,815	2,858	2,105	10,818	280
2-3	7,689	3,479	2,416	13,584	360
3-4	10,618	3,940	2,561	17,119	474
4-5	11,817	4,506	2,465	18,782	540
5-6	12,018	4,938	2,557	19,513	479
6-7	10,738	5,203	2,337	18,278	400
7-8	7,449	3,653	2,248	13,350	317
8-9	5,452	3,550	2,284	11,286	238
9-10	4,956	2,817	1,967	9,780	216
10-11	5,240	3,152	1,654	10,047	142
11-12	4,839	2,521	1,339	8,699	148
Total	143,199	59,844	41,787	244,830	7,449
7-10 am	23,954	6,657	6,276	36,887	2,062
10-1 pm	16,881	6,681	5,578	29,140	860
1-4 pm	24,122	10,317	7,082	41,521	1,114
4-7 pm	34,573	14,641	7,359	56,573	1,419

Fall 1986 New York-New Jersey Screenline
Outbound Traffic Volumes

A1.3 N.C.D.C. Weather Data Samples (contd.)

NEW YORK
SEPTEMBER 1987

STATION	TOT/1	DAY OF MONTH																					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	2
SHERBURN 2 S	3.44	.02		.08				.05	.16	.26	.01	.13	.50	.57	.04	.28	.26	.10	.25				
SOKAN BRUSH STATION	10.33						.20	.31	2.74		.07	1.14	2.16		.01	1.26	1.16	.08					
SLIDE MOUNTAIN	6.26	.60	.04				.19	.51	3.40	1		.07	.47	1.31		.10	.40	1.01	.15	.08			
STAMP OAK	4.37						.05	.22	.92	1		.30	.45		.03	.56	.40	.46	.02				
TULLY-HEIBERG FOREST	4.86	.04	.05	.17			1	.06	1.10	.49	.02	.45	1.07	.36		.12	.30	.32	.16	.25	.02		
UNADILLA 2 N	5.73	.61		.29			.32	.13	.85	1	.03	.82	1.25			.48	.64	.14	.13				
WALTON	5.64	.18	.01	.02			.04	1.00	2.60	.01		.25	.57		.02	.15	.50	.47	.06	.01			
WINTNEY POINT LAKE	4.92	.06	.16				.16	.05	.17	.33		.15	1.85	.26	.01	.06	.64	.34	.21	1			
WINOHAN 2 E	6.23	.20	.01				.04	.06	2.33			.04	.33	.63		.43	.38	1.53	.11	.06			
NORTHERN PLATEAU 03																							
BARNES CORNERS																							
BEAVER FALLS	5.14	.64	1	.35			.04	.64			.02	.05	1.21	.09	.01								
BIG HOUSE 3 SE	2.24	.29	.02	.06			.06	.15	.30			.57	2.10				.57	.44	.76	.03			
BOONVILLE 2 SW	6.60	.30	.12	.07			.08	.01	1.04	.01		.55	3.03	.20			.55	1.05	.52	1			
HIGHMARKET	7.52	.12	.27	.18	.01		.04	.02	.66	.05	1	.06	2.62	.00	1	1		.34	1.23	.64	.02		
HOPE	7.23	.22	.02	.02			.11	.09	1.37	.01		1	1.50	1.73	1			.71	1.49	.39	.06		
INDIAN LAKE 2 SW	6.02						.05	.05	.63	.05		.05	2.00	.65			.70	1.00	.27	.04			
LAKE PLACID 2 S	3.11						1	.14	.26	.03		.14	1.12				.40	.00	.08	.01			
LOHVILLE	5.02	.12	.01	.14			.20	.65				.04	1.50				.32	.74	.53	.04			
LIONS FALLS	6.88	.15	.10				.05	1.35	1		.02	1.29	1.35			.22	.65	.26	.01				
MEMPHIS 2 E	4.50	.04	.01				1	.01	.49	.02													
NORTH CREEK 5 SE	7.45	.15	1	.01			1	.62	1.49	.01		1	1.10	1.51			.99	1.66	.31	.11			
OLD FORGE	6.39	.23	.04	.05			.07	.39	.38	1		.61	2.57	.02		.01	.57	.04	.37	1			
PISECO	9.15	.25	.16	.06				.96	.06				2.42	1.72			1.12	1.66	.36	.07			
RAY BROOK	3.61	.10	.01	1				.44	.02	.01		1	1.10	.65			.03	.33	.07	1			
RECLUSE CORNERS	7.16	.04	.24	.03			.03	.36	.67	.01		.23	1.63	.01	.01	.02	1.27	.37	.45	.08			
STILLWATER RESERVOIR	5.63	.06	.07	.42			.05	.04	.60	.04		.08	1.94	.16			.56	.50	.63	1			
TUPPER LAKE SUMMIT	4.82	.14	.02				1	.01	.42	1	.05	.04	.08	.72	.01		.10	.46	.30	1.3			
MANAFKA RIDGER SCHOOL//	4.67	.06	.06	.01			.02	.04	.51								.07	.23	.55	.05			
COASTAL																							
BRIDGEMANPTON	7.11	.51					1	.06	.11		1	1	.79	.37		1	.64	.74	.54	1.65			
DIX HILLS	5.11						.03	.27	.25			.02	1.52	.05		.05	.63	.56	.15	.02			
DOBBS FERRY	5.48	.45					.63	.65	.02			.02	1.95	.02		1	.72	.66	1	.03			
GREENFORD POWER HOUSE	4.54	.73					.19	.36	.16							1	.50	.47	.26	.45			
ISLIP	3.28	.55	1				1	1.13	.03			1	.95		.01	1	.52	.47	1				
MINEOLA	3.00	.27					.03	.16	.03			1	1.30				.45	.53					
NEW TOWN AVE V BRKLYN	4.35	.15					.03	.02	.92	.01		.16	1.32		.04		.45	.30	.05	1			
N Y CENTRAL PK WSO CT	6.25	.32	1				.02	.20	1.25	1		.00	1.05	.01	.01	.47	.45	1	1				
N Y CENTRAL WSO AF	2.46	.20					.02	.02	.40	1		.06	1.15	.01	.01	1	.46	.16	1	1			
N Y LA GUARDIA WSO AP	5.22	.44	1				1	.17	.20	1		.05	1.00		1	1	.54	.30	1	1			
MT WESTERLIGH STAT 15	4.47	.33					.02	.16	.66	.12		.30	1.16	.07	.04		.63	.31	.14	.06			
PALMBOQUE 2 N	3.91	.67						.11	.11			.02	.85	.07			.63	.31	.14	.06			
RIVERHEAD RESEARCH FM	4.34	.37						.11	.17	.07		.04	.76	.06			1.13	.30	.51	.02			
SCARSDALE	4.50	.75						.27	.22	.07		1	.94	.07			1.11	.31	.25	.45			
SETAUKEE STRONG	5.11	.52					.22	.22	.62	.01		.02	1.26				.95	.23	.45	.02			
VANDERBILT MUSEUM	3.65	.50						.22	.17			.26	1.21		1		1.33	.44					
WANTAGH CEDAR CREEK																							

A2. SUPPORT FOR RULES PROJECT

A2.1 Representative letter of support from Emergency Services Experts (LAPD)

LOS ANGELES POLICE DEPARTMENT

WILLIE L. WILLIAMS
Chief of Police



TOM BRADLEY
Mayor

PO Box 30158
Los Angeles, Calif 90030
Telephone
(213) 485-3207
Rel #: 9.2

September 17, 1992

Mr. Philip Listowsky
City University of New York
CUNY Graduate Center
Computer Science Department
65-30 Kissena Boulevard
Flushing, New York 11367-0904

Dear Mr. Listowsky:

The Los Angeles Police Department is pleased to assist in your research on dispatching systems. Enclosed is the completed survey along with a copy of a survey we conducted in 1990 on Police Communications Facilities and Systems.

If you have any further questions or need more information, please contact Police Officer II Peter Walsh, Communications Division, at (213) 485-3230.

Very truly yours,

WILLIE L. WILLIAMS
Chief of Police

Carlo Cudio
CARLO CUDIO, Commander
Acting Commanding Officer
Support Services Bureau

Enclosure

A2.2 Representative letter of support from Dept. of Transportation Experts (NYC)



NEW YORK CITY
DEPARTMENT OF TRANSPORTATION
BUREAU OF TRAFFIC
TRAFFIC PLANNING DIVISION
40 WORTH STREET • NEW YORK, N.Y. 10013

Lucius J. Riccio, Ph.D., P.E.
Commissioner

February 5, 1992

Mr. Philip Listowsky
141-15 73rd Avenue
Flushing, N.Y. 11367

Dear Mr. Listowsky:

Mr. Peter A. Pennica has requested that I respond to your January 13th inquiry for historical data on New York City road usage.

We have historical traffic volume data for all bridges and tunnels throughout the City including the Manhattan-New Jersey and Staten Island-New Jersey crossings, as well as complete data on traffic entering the borough of Manhattan.

Similar data are available for traffic entering the Manhattan Central Business District (CBD) which is defined as the area south of 60th Street.

Traffic volumes crossing the Bronx-Westchester and Queens-Nassau borders are also available.

Additional traffic counts at specific intersections are on file; they are listed alphabetically in a catalog which can be examined this office.

If you have any questions you can reach me at 212-566-0751.

Sincerely,

Diane Gellman
Director of Data Analysis

REFERENCES

- Anily, S. and A. Federgruen** (1993). "Two Echelon Distribution Systems With Vehicle Routing Costs and Central Inventories", *Operations Research*, 41(1), pp. 37-47.
- Apitz, P.F.** (1973). "Traffic Volume Computer", United States Patent 3711686.
- Auten, J.H.** (1989). "Law Enforcement Driving", Thomas Books, Illinois.
- Bahill, A.T.** (1991). "Verifying and Validating Personal Computer Based Expert Systems", Prentice Hall, NY.
- Ball, M.O. and F.L. Lin** (1993). "A Reliability Model Applied to Emergency Service Vehicle Location", *Operations Research*, 41(1), pp. 18-36.
- Baker, E. and J. Schaffer** (1986). "Solution Improvement Heuristics for the Vehicle Routing and Scheduling Problem with Time Window Constraints", *American Journal of Mathematics and Management Science*.
- Barancik, J.I.** (1993). "Epidemeology of Fatal and Non-Fatal Injuries sustained in the Avianca Plane Crash", Brookhaven National Lab. report #52386, NY.
- Barker, J.L.** (1966). "Traffic Monitoring and Control System", US Patent 3275984.
- Bramel, J.D.** (1993). "Analytical Results and Algorithms for Vehicle Routing Problems with Bin-Packing Features", (Ph.D. dissertation) Columbia University.
- Card, A.H. Jr.** (1992). "Intelligent Vehicle-Highway Systems Strategic Plan", U.S. D.O.T. Report to Congress FHWA-SA-93-009, Washington, D.C.
- Ceseri, P.** (1977). "Electronic Traffic Control System", US Patent 4023017.
- Chelst, K. and J.P. Jarvis** (1979). "Estimating the Probability Distribution of Travel Times for Urban Emergency Service Systems", *Operations Research*, 27(1), pp. 199-204.
- Clinton, W.J., & A. Gore, Jr.** (1993). "Technology for America's Economic Growth, A New Direction to Build Economic Strength", Office of Science and Technology Policy paper, Executive Office of the President. Washington, D.C.

- Contegni, J.** (1992). Supervisor of *Inform* Operations - (Interview conducted at New York State Department of Transportation, Hauppauge, NY).
- Cudio, C.** (1992). Commanding Officer, Los Angeles Police Department Support Services - (Personal Correspondence)
- Curry, J.R.** (1990). "A Review of Information on Police-Reported Traffic Crashes in the United States - General Estimate System 1990", U.S. D.O.T. technical report, National Highway Traffic Safety Administration. Washington, D.C.
- Dahan, P.L.** (1983). "Video System for Plotting and Transmitting Video Traffic Information", US Patent 4398171.
- Davis, R. and Lenat, D.B.** (1982). "Knowledge-based Systems in Artificial Intelligence", McGraw Hill, NY.
- Diderich, C.G.** (1992). "Science Technology Society Program: A Survey" (in *French*), Department of Computer Studies technical report, Ecole Polytechnique Federale De Lausanne, Suisse.
- Feldman, R.** (1993). "Probabilistic Revision of Logical Domain Theories", (Ph.D. dissertation) Cornell University.
- Ferrara, F.M.** (1988). "Socrates: A System to Extract Rules and Knowledge from Existing Data-Bases". *SIGart Newsletter*, 104:21-25. Special Interest Group on Artificial Intelligence of the A.C.M., New York.
- Gantz, J.** (1990). "Graphical Dispatching", *Computer Graphics World*, May 1990, pp.31-33.
- Gellman, D.** (1992). Director of Data Analysis, New York City Department of Transportation - (Personal Correspondence)
- Giarratano, J. and Riley, G.** (1994). "Expert Systems Principles and Programming", PWS Publishing Co., Boston.
- Goldberg, J. and F. Szidarovszky** (1991). "Methods for Solving Nonlinear Equations Used in Evaluating Emergency Vehicle Busy Probabilities", *Operations Research*, 39(6), pp. 903-916.
- Goldberg, R. and Listowsky, P.** (1994). "Critical Factors for Emergency Vehicle Routing Expert Systems", *Expert Systems With Applications*, 7(4), pp. 589-602.

- Golden, B. L. and E. Wasil (1987).** "Computerized Vehicle Routing in the Soft Drink Industry", *Operations Research*, 35(1).
- Golden, B. L. and A.A. Assad (1986).** "Perspectives on Vehicle Routing: Exciting New Developments", *Operations Research*, 34(5), pp. 803-810.
- Gonzalez, A.J. and Dankel, D.D. (1993).** "The Engineering of Knowledge-Based Systems", Prentice Hall, NJ.
- Harandi, M.T. (1986).** "Applying Knowledge-Based Techniques to Software Development". *Perspectives in Computing*, Spring 1986:14-21.
- Harmon, P. and Sawyer B. (1990).** "Creating Expert Systems", Wiley, NY.
- Hart, A. (1986).** "Knowledge Acquisition for Expert Systems", McGraw Hill, NY.
- Kelley, D.J. (1993).** "Insights for Demand for Emergency Department Resources Based Upon a Probabilistic Model", (Ph.D. dissertation) Polytechnic University.
- Kohnert, D.K. (1975).** "System for Monitoring Traffic Conditions in Connection with the Control Thereof", US Patent 3906438.
- Kwon, E. (1990).** "Modeling On-line Traffic Demand and Diversion in Freeway Corridors", Ph.D. Dissertation, University of Minnesota, Minnesota.
- Lerner, M. and Cheng, J. (1983).** "The Manhattan Mapper". Expert Systems Project Report, Columbia University Department of Computer Science, 1983. (unpublished)
- Lotto, I.R. (1993).** "Computer-Assisted Synthetic Analysis: Stereochemical processing and knowledge-base extensions to the LHASA Program", (Ph.D. dissertation) Harvard University.
- Madnick, P.A. and Sherwood, R.W. (1988).** "Traffic Monitoring and Reporting System", US Patent 4792803.
- Marathe, H.Y. (1990).** "Development and Maintenance of an Online Expert System as a Power System Dispatcher's aid" Dept. of E.E., U. of Washington
- Narbaitis-Jaureguy, J.R. (1975).** "Route Surveillance System", US Patent 3919686.
- Narongdej, P. (1993).** "Interactive Man-Machine Learning in a Dynamic Manufacturing Environment", (Ph.D. dissertation) Stanford University.

- Parsaye, K. and Chignell, M.** (1988). "Expert Systems for Experts", Wiley, NY.
- Pasik, A. and Schor, M.** (1984). "Table-Driven Rules in Expert Systems". *SIGart Newsletter*, 87:31-33. Special Interest Group on Artificial Intelligence of the A.C.M., New York.
- Raatz, S. and Drastal, G.** (1987). "Patterns of Interaction in Rule-Based Expert System Programming". *Computational Intelligence*, 3:107-116, National Research Council of Canada, Ottawa.
- Rachlin, H.** (1991). "The Making of a Cop", Simon and Schuster, NY.
- Roan, R.** (1993). Traffic Analyst in the Traffic Planning Division of the New York City Department of Transportation - (Interview at NYC DOT, New York, NY).
- Rowland, D. and Bailey, J.** (1985). "The Law Enforcement Handbook". Methuen Publications, New York.
- Saito, T. and Moriyama, M.** (1986). "Audio-Visual Display System for Multiple Maps", US Patent 4630209.
- Schwartz, S.** (1993). "Shadow Traffic's New York", Fodor's Publications Inc., NY.
- Sekeran, U.** (1984). *Research Methods for Managers*, John Wiley & Sons, NY.
- Sena, M.L.** (1990). "Computer Aided Dispatching", *Computer Graphics World*, May 1990, pp.35-42.
- Shamsudin, A.Z. and Dillon, T.S.** (1991). "NetManager: A Real-Time Expert System for Network Traffic Management". Ph.D. Dissertation, La Trobe U. Dept. of Computer Science and Computer Engineering Technical Report No. 15/91 December, 1991. Melbourne, Australia.
- Shanahan, D.T.** (1985). "Patrol Administration", Allyn and Bacon Inc., Boston.
- Sledge, A.M.** (1993). Director of the Office of Research of the New York City Department of Transportation - (Interview at NYC DOT, New York, NY)
- Sobol, M.G.** (1992). "Using Statistical Data Feedback By-Products of Expert Systems", *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 22(3), pp. 568-580.
- Soderberg, J.W.** (1961). "Automatic Traffic Control", US Patent 2980887.

- Stokes, T.** (1994). Commanding Officer of the Emergency Services Unit of the New York City Police Department - (Interview at ESU HQ, Flushing, NY).
- Steinberg, E.P.** (1991). "Emergency Dispatcher", Simon and Schuster, NY.
- Stratton, D.A.** (1992). "Aircraft Guidance for Wind Shear Avoidance: Decision Making Under Uncertainty", (Ph.D. dissertation) Princeton University.
- Sumner, R.L.** (1993). "Cell Messaging Process for an in-vehicle Traffic Congestion Information System", United States Patent 5182555.
- Takanabe, K.** (1988). "Electronic Map Display System for Use on a Vehicle", US Patent 4780717.
- Tomkewitsch, R.** (1982). "Guidance System for Individual Traffic", US Patent 4357593 and US Patent 4350970.
- Walsh, P.** (1990). "Major Cities Survey of Police Communications Facilities and Systems", Los Angeles Police Department Communications Division Survey.
- Waterman, D.A.** (1986). "A Guide to Expert Systems", Addison-Wesley, NY.
- Wolf, T.** (1994). Personnel and Planning Officer of the ESU of the NYPD - (Interview at ESU HQ, Flushing, NY).
- Wright, K.** 1990. "The Shape of Things to Go". *Scientific American*, 5/90:92-101.
- Yamada, T.** (1989). "Map Display System", US Patent 4812980.
- Zachmann, H.C.** (1971). "Traffic Surveillance and Control System", US Patent 3626413.
- Zove, P.** 1982. "Integrated Motorist Information System", U.S. D.O.T. Federal Highway Administration Report FHWA/RD-82/108, Washington, D.C.