

135
118

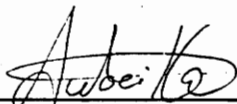
**A MICROCOMPUTER MODEL FOR ASSESSING THE RELATIVE
RISKS AND VULNERABILITIES OF STREETS &
JURISDICTIONS TO THE SHIPMENT OF HAZARDOUS MATERIALS**

by

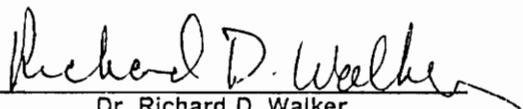
Charles E. Taylor

Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
Master of Science
in
Civil Engineering

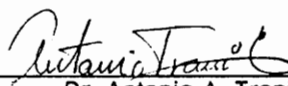
APPROVED:



Dr. Antoine G. Hobeika, Chairman



Dr. Richard D. Walker



Dr. Antonio A. Trani

January 17, 1990

Blacksburg, Virginia

C.2

LD
5655
V855
1990
T394
C.2

**A MICROCOMPUTER MODEL FOR ASSESSING THE RELATIVE
RISKS AND VULNERABILITIES OF STREETS &
JURISDICTIONS TO THE SHIPMENT OF HAZARDOUS MATERIALS**

by

Charles E. Taylor

Civil Engineering

(ABSTRACT)

The comprehensive planning of transportation systems resource allocations and operating regulations so as to minimize the danger to localities from hazardous materials shipments is a growing concern among transportation planners. Standing in their way are a number of difficulties inherent in the data collection and modeling practices currently in use. Additionally, such current practices do not afford practical means for comparing large numbers of jurisdictions which is necessary for equity among jurisdictions and cost effectiveness.

In response to these difficulties, this research is intended to develop a microcomputer based model to quantitatively compare the susceptibility of different streets and jurisdictions to the resulting effects of different types of hazardous materials accidents. Implied in the development of this model are such worthwhile considerations as: ease of use, maximum ability for user customizing, ability to work with existing and future data and data types, and clarity as well as variety of output formats. An evaluation of the appropriateness of this model for 1984 through 1987 Pennsylvania data is then undertaken. In addition, a brief assessment

of the applicability of this macro level model in the total risk reduction environment is incorporated.

Acknowledgements

In appreciation, the author would like to recognize the guidance, encouragement and assistance of Dr. Antoine G. Hobeika, Director of the Center for Transportation Research at Virginia Tech and Chairman of my thesis committee. Additionally, I would like to recognize the help offered by Dr. Richard Walker and Dr. Antonio Trani in serving on my committee. A special indebtedness is owed to Dr. Siamak Ardekani for his advice and encouragement during these efforts.

The contributions of the staff of the Center for Transportation Research are also gratefully acknowledged. I wish to call special attention to the rest of the hazmat project team: Mr. (soon to be Dr.) Sigon Kim and Mr. Rajagopal Sethuraman.

Thanks for tasks performed by organizations outside of the university community which were in conjunction with this work are also in order. The Pennsylvania Department of Transportation's support and efforts in mapping and accident information were of timely assistance. Water supply data furnished by the Pennsylvania Department of Environmental Resources was also appreciated. The efforts of Dr. Phani Raj of TMS, Inc. in hazmat impact area modelling were instrumental. The advice of Dr. Eugene Russell of Kansas State University and Dr. Theodore Glickman of the Center for Risk Management Resources for the Future, Inc. (Washington, D.C.) was also most appreciated. Also, the data collection efforts of Keystone Management Systems, Inc. were invaluable. In particular, I would like to

acknowledge the contributions of the following individuals: Mr. Daren Coudriet, Ms. Kelly Kiraky, Ms. Debra A. Andre, and Ms. Paula (V.) A. Brown.

The highest measure of gratitude I must reserve for my parents for their spiritual, financial, and editorial support. I dedicate this work to you both.

May God add His richest blessing on each of you.

Table of Contents

1. INTRODUCTION	1
1.1 The Concern Over Hazardous Materials Shipping	1
1.2 What Can Be Gained From Risk Assessment?	4
1.3 Risk Assessment Concepts	8
1.4 The Issue of Vulnerability	11
1.5 Focus on Pennsylvania	12
2. OBJECTIVES	15
2.1 Purposes of the Project	15
2.2 Development of the Decision Support System	17
2.3 Development of a Live-On Data Base and Model	19
3. LITERATURE REVIEW	21
3.1 Data Bases	21
3.1.1 Introduction	21
3.1.2 Problems with Data Collection	22
3.1.3 Research and Special Programs Administration (RSPA) Data	23
3.1.4 Bureau of Motor Carrier Safety (BMCS) Data	25
3.1.5 Commodity Transportation Survey (CTS) Data	26
3.1.6 Truck Inventory and Use Survey (TIUS) Data	27
3.1.7 Uses of Existing National Data Bases	28

3.1.8 State Approaches	28
3.1.9 Remaining Data Needs	30
3.1.10 Potential Improvements in Data Bases	31
3.2 Models	34
3.2.1 Introduction	34
3.2.2 Different Model Types	34
3.2.3 Computing Risk	37
3.2.4 Other Models	42
3.2.5 Effects of Risk Reduction Strategies	44
3.2.6 Probability	45
3.2.7 Consequences	50
3.2.8 Response Capabilities	56
3.2.9 FHWA Guidelines and MRI revisions	59
3.2.10 Canadian Route Screening Method	69
3.2.12 SAFETI Computer Model	75
3.2.13 U.S. Coast Guard Model	78
3.2.14 Raj and Glickman Railroad Model	78
3.2.15 Saccomanno Model	80
3.2.16 Kansas State University (KSU) modeling	84
4. MODEL DESCRIPTION	89
4.1 Introduction	89
4.2 Probability	91
Consequences	94
4.4 Response Capabilities	102
4.5 Risk and Vulnerability Determination	105
4.6 Output Formats	108

5. COMPUTER MODELING CONVENTIONS	115
6. COMPUTER TESTING - Washington County, Pa.	123
6.1 Input File Information	123
6.2 Additions to Input File Information	125
7. COMPARATIVE ANALYSIS.	127
7.1 Testing Procedure	127
7.2 Risk Output for Washington County, Pa.	129
7.2.1 Basic Risk	129
7.2.2 Variations on Risk by Highway Type Parameters	132
7.2.3 Variations on Risk by Size of Impact Area	133
7.2.4 Basic Vulnerability	135
7.2.5 Variations on Vulnerability by Size of the Response Parameters	136
8. RECOMMENDATIONS	139
8.1 Introduction	139
8.2 Overall Improvements	139
8.3 Probability	142
8.4 Consequences	143
8.5 Response Capabilities	143
8.6 Need for Roadway Surveys	148
BIBLIOGRAPHY	150
Appendix A.	156
1. Default Hazmat Flows and Release Rates	156
2. Building Replacement Costs and Locality Cost Adjustment Factors	157
Table of Contents	viii

Appendix B. 162

VITA 195

LIST OF FIGURES

Figure 4-1	FLOWCHART	p. 90
Figure 4-2	IMPACT AREA	p. 97
Figure 4-3	CORRIDOR WIDTH	p. 97
Figure 4-4	PRINTED RESULTS	p. 110
Figure 4-5	RISK PROFILE	p. 112
Figure 4-6	VULNERABILITY SURFACE	p. 113
Figure A-1	LOCALITY ADJUSTMENT FACTORS MAP	Appendix A

LIST OF TABLES

Table 6-1	STREETS CONSIDERED	p. 124
Table 7-1	BASIC RISK STREETS	p. 130
Table 7-2	BASIC RISK MUNICIPALITIES	p. 131
Table 7-3	THRESHOLD WIDTHS	p. 134
Table A-1	EXCERPTS FROM BMCS...	Appendix A
Table A-2	PennDOT HIGHWAY CLASSES	Appendix A
Table A-3	MacroRADSS DEFAULT VALUES	Appendix A
Table A-4	COSTS FOR BUILDINGS	Appendix A
Table A-5	BUILDING MIXES	Appendix A
Table A-6	GENERAL URBAN/RURAL COSTS	Appendix A
Table A-7	LOCALITY ADJUSTMENT FACTORS TABLE	Appendix A

1. INTRODUCTION

1.1 The Concern Over Hazardous Materials Shipping

As our society expands in size and technology, the problem of safe transportation of hazardous materials grows in volume and complexity. These shipments refer to a variety of cargoes including such diversified products as gasoline for cars, anhydrous ammonia for fertilizers, and radioactive wastes. As of 1980, more than 55,000 toxic substances valued at nearly \$146 billion, were produced in the United States [26]. Roughly 4,000 distinct hazardous materials are currently recognized in Section 49 of the Code of Federal Regulations.

The terms “hazardous material” (or “hazmat”) and “dangerous goods” (prominent in other countries), are used interchangeably here. As pointed out by Shoemaker, “Many chemicals possess more than one hazard and all can be dangerous...” [48]. In an attempt to provide a standard meaning, Congress provided the following definition of a hazardous material “...in the 1974 Hazardous Material Transportation Act: ‘A substance or material which has been determined by the Secretary of Transportation to be capable of posing an unreasonable risk to health, safety and property when transported in commerce...’” [28].

According to the National Transportation Safety Board (NTSB), the U.S. Department of Transportation gave the following estimates of the volume of traffic in hazardous materials for the year 1981: [26].

- ** At least 4 billion tons of hazardous materials are shipped each year
- * At least 218 million ton-miles of hazardous materials are shipped every year
- * At least 250,000 shipments of hazardous materials (bulk and nonbulk) are made every day
- * About 10,700 shippers and 11,700 carriers are involved in hazmat transportation
- * At least 400,000 trucks regularly transport hazardous materials
- * Between 5 and 15 percent of all trucks on the road at any given time carry hazardous materials”

Even more alarming is the outlook for future shipments. The Midwest Research Institute (MRI) reported the volume of (hazardous) chemicals shipped in 1987 was about 80% greater than in 1971 [26]. While Pijawka, Foote, and Soesilo have concluded that “The percentage of highway and rail accidents that involve hazardous materials is increasing, the amount of damage per accident is escalating, and compliance with transportation regulations is eroding”[30].

These trends are alarming because uncontrolled hazmat releases represent a far greater danger to life, property, and the environment than is possible from other highway traffic. While, as previously stated, between 5 and 15 percent of truck flow involves hazmat traffic, FHWA notes that “... of the 621 most severe commercial carrier accidents investigated by FHWA between 1973 and 1976, those that involve HM (hazardous materials) accounted for 24.9 percent of the accidents and 57.3 percent of the property damage”[26]. Additionally, MRI cites during the period 1976 to 1984, an unpublished FHWA report indicated that over \$100,000,000 in property damage was reported. While the number of deaths and injuries reported was low relative to the total number of vehicle accidents (approximately 18 and 380 per year, respectively), the rapid rise in hazmat traffic during this period, mentioned in the

previous paragraph, implies that the earlier years in the data set are not really appropriate to judge the magnitude of the present situation. More importantly, the report does directly attribute 10 percent of fatalities and injuries to the release of hazardous cargo [26].

Over and above the inherent danger of hazardous cargo itself, one must consider the often unknown, perplexing nature of these materials on those involved in regulating such shipments, as well as on those called upon to respond to threatening situations. Ignorance of material characteristics can exacerbate a situation that would otherwise be non-threatening. This becomes a serious concern when we note a recent OTA report which concluded that over 75 percent of the nation's police and firefighters are poorly trained to respond to accidents involving hazardous materials [13]. The contrast between good and bad planning is clearly seen in actual examples. "Large scale incidents such as the Spanish campsite disaster in 1978 when more than 200 people were killed by the explosion of a liquified petroleum gas tanker have focused international attention on the gravity and importance of safety in the transport of hazardous materials" [60]. In an example of good planning, Rawls reports on the following incident referred to later as the "Miracle in Mississauga":

...a freight train carrying a mixed cargo including many chemicals derailed in the city of Mississauga, less than 20 miles from downtown Toronto. Among its freight were cars loaded with caustic soda, propane, chlorine, styrene, and toluene. ...there were three major explosions, 218,000 people were evacuated from their homes, the busiest stretch of highway in Canada was shut down, and more than 1000 emergency services personnel spent what was likely the busiest week of their lives...

No one died. The fire, which at the beginning of the incident was causing a different propane tank car to explode every five minutes, was brought under control and kept there for more than a week until the danger passed ... (Also) a potentially life-threatening cloud of chlorine gas was safely vented over Lake Ontario ... experts are quick to say, however, that the same incident could have been much, much worse if it had happened anywhere but in Mississauga [35].

The advantages to proper preparedness, both in terms of precautionary regulations and response suitability and readiness, are clear. We must also acknowledge that driver behavior and cargo preparation and handling are large

random influences on the spacial and temporal distribution of threatening hazmat situations. MRI reported that hazardous materials carriers (in a 1978 study by the Bureau of Motor Carrier Safety) as a group had a bad record indeed for preventable accident frequency; 20 percent more than expected. Yet there are both quantifiable and non-quantifiable features which serve to distinguish one region as being more at risk than another. We now must try to model such features to ensure the proper allocation of resources to minimize these risks. "One question remains: how safely can hazardous materials be carried? Past research indicates that the answer to this lies in five basic areas: the use of properly constructed and maintained equipment; training of personnel; designation of hazardous materials routes; maintenance of hazardous materials routes; and, finally, effective emergency response" [13].

1.2 What Can Be Gained From Risk Assessment?

"No human activity can be conducted without risk"
-W.J. Geysen [12].

Because of the potential dangers associated with hazmat shipping, proper allocation of resources (e.g., manpower, response equipment, highway maintenance and special funding, etc.) to prevent and combat hazmat situations is sought at various government levels. "The lack of proper controls over hazardous materials transportation has created unreasonable risks to life, health, private and public property, and the natural environment--risks that can and do lead to catastrophic results," [42]. Risk assessment for hazmat shipping may be thought of as a means of quantifying these potential dangers wherever possible, in hope of providing

guidance for the allocation process. Because of the size and complexity of the modeling problem, few such models have been implemented by individual states. As of January 1988, only four states (Arizona, Colorado, Illinois, and Minnesota) had conducted “a quantitative-probabilistic risk assessment of the state’s exposure to hazardous material incidents at particular locations in the state” [7]. Planning efforts are primarily small scale projects in response to publicized occurrences, leading planners to frequently complain that they cannot get local funds for accident prevention and emergency response planning until an accident takes place [53]. Additionally, techniques to reduce the risk of hazmat shipping often meet with public opposition because of the burdens (economic, peace of mind, etc.) they can impose on select populations. As an example, trade-offs are often made between safety and truck operating costs. “Minimum risk routes may involve more circuitous travel patterns and, consequently, increased truck operating costs” [40].

Such techniques require the intelligent evaluation of alternative strategies. The interpretation of relevant data in risk assessment models is one means of intelligent evaluation. As Dr. Y.Y. Haimes observed: “Information becomes intelligence when it is processed” “...risk assessment...models...are aimed at...the processing of data into intelligence--so that elements of risks associated with policy decisions may be properly valued, evaluated, and considered in the decision-making process” [14]. So it is to the advantage of planners to be acquainted with the benefits (and limitations) of quantitative risk assessment.

The first benefit to be derived from risk assessment modeling is the ability to predict future behavior. “If there is a historical data base that is applicable to the future, distributions can be described or approximated by objective techniques” [14]. This, of course, assumes that historical data can be used for such purposes.

However, with time, actual occurrences may be compared with predictions, and help establish this relationship.

As mentioned above, some objective risk evaluation is necessary to help make politically difficult options viable. The use of risk assessment in making rules might provide a more logical and flexible basis for establishing regulations [38]. "Risk assessment methodologies provide the best means of helping community-level practitioners come to grips with local fears and perceptions" [42]. Through the understanding of risk factors, it is possible to compare risk reduction strategies and rule out those which are not relevant. "(Lautkaski found:) Risk analysis was an instructive way of going through all the factors contributing to the accident risk. In this way it was possible to suggest a number of measures by which accident risk could be reduced" "risk factors allow us to model our ability to reduce the probability of an accident by selecting routes with low vehicle accident rates" "...(and) reduce the effects of an accidental release of dangerous goods by keeping high volume/high hazard products away from sensitive areas," [48]. According to Somerhoff (proceedings from Transchem 82) [60], the ability to combat hazmat situations is enhanced by understanding the nature of the anticipated risk. The risk studies also provided a base of material for national instructions on preparedness and response to accidents involving hazardous materials [19]. If we are able to quantify the effect upon our risk factors induced by shipping regulations, then we are able to determine the level of system risk attributable to these regulations per se [38].

For all that we stand to gain from risk assessment modeling, it should be pointed out that such efforts are at best simplistic glimpses of a far more complicated picture and should not be used to replace human judgement. Among the sources of user skepticism to modeling, Dr. Haimes reminds us that models should be recognized as "means," not "ends" [14].

“Classical risk-benefit analysis often:

- * overshadows the other considerations--economic, social, aesthetic, spiritual, etc.
- * overemphasizes the ‘quantifiable’ aspects--narrows the decision-making process through concentration on easily identifiable elements amenable to quantification
- * offers only a crutch for tough political decisions
- * assumes rational decision-making vs. emotional responses
- * assumes political acceptability
- * de-emphasizes the importance of ‘process’ in decision-making”

Perhaps the most difficult obstacle to the complete acceptance of risk modeling in overall risk reduction assessment is the question of how far risk should be reduced. Given limited financial resources, state DOTs and other responsible authorities must balance their attempts at risk reduction strategies with other demands on these resources. In Dr. Haimes’ quotes from the work of Harold P. Green [1975] we find the following:

No elite group of experts, no matter how broadly constituted, has the ability to make an objective and valid determination with respect to what benefits people want, and what risks people are willing to assume in order to have these benefits [14].

Leading Dr. Haimes to conclude that it may not be possible to find a solution to the problem of acceptability of risk [14]. Complicating the matter further, no consensus has been reached as to the actual way to present the results. “Risk” itself is a very conceptual parameter, and so an appreciation of the significance of its value is difficult. Turnquist notes that “there are almost as many measures of risk as there are studies of the problem,...”[50].

Still, as models become more refined and data sets expand, it is anticipated that these issues will be addressed in an increasingly acceptable manner. With this in mind, it is widely considered to be an accepted fact that there is value in developing more sophisticated risk models. “The importance of making regionally acceptable risk-based decisions suggests that DOT could provide State and local governments with better tools for risk assessment” [52]. “(Organization for Economic Co operation

and Development - OECD) Member nations are encouraged to consider the use of risk assessment calculations as a tool to assist in route selection decisions” [29]. Primarily because of the size of the data base required, the use of computer programming to run these models is also desired. A TRB Steering Committee on the Transportation of Hazardous Materials recommended more technological innovation, information, and research related to the transportation of hazardous materials, and that the U. S. DOT continue to press for implementation of technology to improve hazardous materials transportation [5]. “In programming, the model for ranking a set of transportation strategies should have high utility” [61].

1.3 Risk Assessment Concepts

Our knowledge of the outcomes of specific hazardous material shipments is limited for we can not guarantee that events will occur. However, since we can define a comprehensive range of scenarios and determine a likelihood of each scenario occurring, we have crossed from the realm of uncertainty to that of risk. “Decision situations are often conceptually distinguished on the basis of the types of information available about the consequences associated with different courses of action. If for each alternative it is known a priori what outcome will result, the situation is one of decision under certainty. If the outcomes that may occur and their relative likelihoods are known, the situation is one of objective risk. Finally, if only possible outcomes are known, but no objective likelihoods, the case is one of uncertainty” [43]. These definitions are in substantial agreement with those put forth

by the U.S. Water Resources Council, although those definitions state our knowledge of the outcomes is in terms of “reasonably well-known probability distributions” [14].

Risk, according to the definitions above is a mathematical contrivance to be obtained from an examination of historical data trends. In contrast to this “objective risk”, there is a “perceived risk” which represents the significance of the outcome scenarios in the public eye. As is the case with other civil engineering systems, in order to instill confidence, analysis must incorporate the public’s perception of the system, be it a catwalk or a cloverleaf. To the best of the author’s knowledge, no such modifications presently exist for hazmat transportation. For now, the consideration of perceived risk is left to the judgement phase of the assessment. It should be noted that “Public concern is greatest about risks that are involuntary, uncontrolled, unfamiliar, immediate, man-made, and catastrophic” [8]. Hazardous materials transportation may possess any or all of these qualities.

...a major chemical transportation accident is a scary thing - akin to a hurricane, earthquake, or major oil spill in its potential to cause damage. And, because there are so many kinds of hazardous chemicals, each requiring its own type of special handling and capable of interacting with other chemicals to compound the hazard, chemical disasters are much harder to prepare for than are natural disasters or oil spills [35].

Within the realm of objective risk, there is also the distinction between “absolute” and “relative” risk values. Absolute risk values are those which include every necessary factor to bring about the particular scenarios. In contrast, relative risk values contain only those terms which vary from one part of the overall system to another. In the case of the highway system these parts are the different routes under consideration. Geysen refers to these terms as “system-bound” terms [12].

One concept that needs to be examined is that “...absolutely risk-free transport of dangerous products is unattainable because of failures in each of the subsystems (MTE (read:man, technology, environment))...” [12]. That is to say that there is no technology available which can guarantee the safe transport of hazardous materials

in the face of human error, Acts of God, etc. So long as the material needs to be transported, the risk of release will exist. Rather, risk reduction planning is an ongoing effort to minimize system risks under financial constraints, forming an improving environment in pursuit of the unattainable zero-risk state. "It is the national and the supranational authorities' duty to steadily increase the safety level of the entire MTE transport system by constant reduction of danger potentials and of the risk as a whole. This can be realized if, for each of the MTE subsystems, the bottlenecks are adequately analyzed. For this purpose, the available data must be systematically organized and used in the best way" [12].

The determination of risk is a function of two characteristics of an outcome scenario. The first is the likelihood of the scenario occurring (or probability). The second is the magnitude of the consequences that will result. "The consequences of accidents with dangerous products vary. They include pressure waves; fire; poisoning; toxicity; caustic action; radioactivity; and air, soil, and water pollution" [12]. In some risk analyses, consequences may reach such a level that even if the likelihood is very small, a greater importance is attached to this outcome than to other, more likely alternatives. Once this distinction is made, we leave the area of objective analysis and enter one known as "catastrophe avoidance" [14]. Because this level of consequence is arbitrary, catastrophe avoidance must be considered in the judgement phase of the risk assessment. "The risk control aimed at has not only a purely technical, but also an economic and sociological significance, especially in the field of risk acceptance of catastrophes with low frequency" [12].

1.4 The Issue of Vulnerability

There can be other controllable factors in real world situations which can increase or decrease the magnitude of consequences in the risk expression. In the case of hazardous materials transportation this usually refers to emergency response capabilities. Therefore, without this third term our risk equation presents an incomplete picture of the actual scenario outcomes. Because the relationship between response levels and the resulting levels of consequence are uncertain, there is no standardized way to incorporate response factors in the risk expression. Consequently, multiple schools of thought have evolved as to the proper treatment for these factors. The most accepted practice is to either ignore this variability or consider it as a “tie-breaking” measure when risk calculations are inconclusive. It is the author’s contention that, because of the potential extreme variability in consequences due to these factors (e.g., the Mississauga situation), these treatments are not satisfactory. Also, because of the potential for contradictory conclusions to be obtained by using different measures of response capabilities, their use as a subjective tie- breaking measure is inappropriate.

However, there is a second approach which defines a term called “vulnerability” in order to distinguish values which permit some adjustment for response capabilities from previously calculated risk values. “Vulnerability assessment refers to the determination of the level of danger that is posed to a community or area because of HM (hazardous materials) transport, and the capabilities of the community to reduce the consequences of HM releases” [30]. Inasmuch as this method is an empirical approach, it is far more appropriate for the scope of the influence of response on consequence and far more relevant as a

decision-making tool. To some extent this process is an iterative one as risk reduction strategies (e.g., hazardous materials routing, roadway improvements, curfews, etc.) will facilitate improved response [48]. One would suspect, therefore, that an increase in the data base following the implementation of such strategies will more clearly define the actual relationships, if that is possible.

1.5 Focus on Pennsylvania

There are many factors that make Pennsylvania ideal for a pilot program in risk and vulnerability modeling. These factors can be grouped into two distinct categories: the size and complexity of the hazardous materials transportation problem and the relatively extensive resources available for modeling.

In terms of the extent of the problem, Pennsylvania has traditionally been a problem area for hazmat shipping incidents (i.e., where the release of hazardous material has taken place regardless of cause). This is so much the case that, as of January 1988, "the Governor's Office of Policy Development is conducting a study of hazardous materials transportation policy in Pennsylvania" [8]. According to Research and Special Programs Administration (RSPA) data for the period 1981-85, Pennsylvania led the nation in both the total number of hazmat incidents and incidents not caused by traffic accidents [27]. This ranking has been consistent throughout recent years. According to the Hazardous Materials Incident Reporting System (RSPA) for 1971- 1984, Pennsylvania had the highest total number of hazardous material incidents and the highest percent of highway related incidents in the nation [44]. Although there has been much speculation about the cause for this

situation, it should be noted that Pennsylvania also ranks highly in various categories to measure hazmat flow levels. According to the 1982 TIUS, Pennsylvania ranks third in the nation (behind California and Texas) in its number of hazardous material trucks and truck-miles with 27,400 trucks and 810.5 million truck-miles respectively [2]. Also, Pennsylvania ranks highest in the nation in for-hire trucks, private trucks, and total trucks involved in the shipment of hazardous materials with 9.9% of the national total of trucks involved in hazmat shipping (Office of Technology Assessment statistics for the period 1976-1984) [26]. These figures, for many, provide ample cause for the high number of incidents, leading at least one authority to conclude "Pennsylvania might be the most common location for highway- related hazmat incidents for the simple reason that it has more shipments than other states..."[26]. The reason for the high flow in hazmats indicated is less apparent. One possible indicator is that Pennsylvania ranks second in the nation (behind California) in the number of petroleum terminals with 30 [2]. In any case, the high flow and high incident history as well as the large number of jurisdictions involved will be a good test for data collection and manipulation techniques.

The variety in terrain, roadways and adjoining development will serve to indicate the difference in importance of a variety of terms in the risk and vulnerability expressions. In speculating about potential risk-based routing studies, one observer noted "(one good example of a difficult routing problem) is the use of accident-prone, two-lane U.S. Route 30 over the Allegheny mountains in Pennsylvania as an alternative route for the heavily traveled Pennsylvania Turnpike with its tunnels and high-density traffic. Rerouting must include risk and consequence estimates for (the) alternative routes" [38].

As one consequence of its high incident history, Pennsylvania has developed one of the nation's finest accident record systems for hazmat study; state accident

records make distinctions about hazmat vehicle involvement. "The Pennsylvania accident data contain(s) a very complete description of the type of hazardous materials involved...including both a hazard class and a placard number" [27]. Additionally, the Pennsylvania DOT runs an economic analysis computer package which evaluates their safety improvement program [4]. This could be of some utility in performing cost/benefit analysis in future studies. It is hoped that the adoption of this modeling scheme will help in standardizing data collection practices among the states. The opportunity to utilize such an extensive data base in model formulation helps to provide both a good degree of model sophistication and a fairly comprehensive data format for other states to consider.

2. OBJECTIVES

2.1 Purposes of the Project

Every hazardous materials incident can be attributed to some failure of any MTE (man, technology, environment) sub-systems. To minimize the probability of occurrence of such incidents, we must first determine where such incidents are presently occurring and what portion(s) of the MTE subsystems are failing. When technology will allow us to correct or reduce these failings, we must do so to the maximum extent possible. It thus becomes necessary to develop models which will provide risk information on streets, counties, and municipalities in order to make such allocation distinctions. "The comparison of risks with...other similar risks in society...are best carried out at the national or regional level rather than at the local level" [38].

Because of the size of the data base involved at the state level, two options are available to generate such information. The first is to commission studies to tabulate such results as needed. The results are static, in that they cannot be updated and values can not be hypothetically changed. Also, historical trend information can get masked by the limited period covered by the study. The other alternative is to incorporate the risk model into a computer program and update the data files periodically. This not only addresses the above shortcomings but also provides the

additional capabilities of multiple output formats and the potential to interface with other computer technologies (e.g., geographic information systems and cost/benefit analysis software).

As previously mentioned, there are two problems associated with furnishing only risk values. First, they are abstractions with values and units that are not clearly understood. Any study of risk must overcome this problem in order to be of optimum value. Second, consequence levels can vary dramatically based on the effectiveness of the emergency response, especially when considering a wide variety of jurisdictions at the state level. Additionally, deficiencies in local response capabilities can be significantly reduced through timely allocation of state level funding and other resources. For these reasons, vulnerability information should be generated in the same manner as the risk information above.

In order to gain public acceptance, such a computer program must be user friendly with explanations at all points of user interaction. User guidance should be requested whenever the potential for more than one approach to the modeling may be taken. Printed output should be provided to aid in report generating. Printouts should contain listings of all user inputs and data filenames used so that assumptions may be tested and individual results reproduced. Finally, the program should be an integral part of a larger decision support system (DSS). The DSS should include a local routing program, and a mitigation information program. The latter is required to assist users in understanding which locations stand most to gain from available resources. The overall package structure should be able to integrate these three component programs such that data files and assumptions used which are common to their undertakings may be shared. The model and associated computer code presented in this work is called the "MacroRADSS" model, since it is part of the

"RADSS" (Risk Analysis Decision Support System) package, which will contain the other two programs.

2.2 Development of the Decision Support System

To date, computing applications in the field of hazardous materials transportation have, with a few notable exceptions, dealt primarily with accident and incident data storage and manipulation. Since modeling has been primarily concerned with the local routing issue, the need to perform calculations on large data sets or to perform them repeatedly over time has not been widely recognized. Computer programs currently in use which update and manipulate such data bases belong to a class of programs known as management information systems (or MISs).

In other fields, it has already been found necessary to perform rapid evaluation calculations with sizeable amounts of data so that management personnel can make informed decisions quickly. Such software packages are known as decision support systems (DSSs). For organizations familiar with MIS applications, DSSs are viewed as second generation software and may actually perform MIS functions as well. One emphasis on DSSs has been the use of the same data base by multiple users for different decision support applications. (This means that either existing data fields must be adequate for all such applications, or that new data fields must be developed for additional package requirements. The MacroRADSS package is designed to incorporate existing data fields from the Pennsylvania DOT and Department of Environmental Resources. As more refined data becomes available, these variables can be replaced in the model structure. The concept of the DSS is of interest to

transportation planners not so much for the speed it offers in processing the data but rather for its computational capabilities. "The interactive man- machine mode (or DSS) has dominated the recent active growth in the use of mathematical models and optimization methods for management decisions and risk assessment. The usefulness of the DSS as a management tool is based on the effective and convenient access that decision support systems have to (i) multiple data bases, (ii) various simulation and analytical models, and (iii) advanced optimization techniques;" [15].

Certain features are common to every DSS. These are:

- * the computer system (hardware)
- * the data base
- * the model base (the "brain")
- * the software system, comprised of three sets of capabilities -- (1) data base management software,(2) model base management software, and (3) software for managing the user/system interface
- * the user [15].

In MacroRADSS, three additional external components are required for data manipulation. The first is a program which reads select fields from the existing data bases and writes them to files on a diskette. The second is an input edit module that is a spreadsheet and/or table used to display and edit the data as needed. Third, a user option within either the main program or the input edit module will call an external program which will read from the input files in order to write to data files used by other associated programs (i.e., the local routing and mitigation programs). Since these components are external to the computerized risk and vulnerability assessment, they will receive only cursory mention in this work.

Within the context of a larger decision-making framework where engineering judgement plays a vital role, the DSS can be a powerful tool. It is part of total safety management, which includes all of the major facets of intervention and emergency planning; nuclear problems; communication difficulties; training and retraining; and all the prevention problems for labor, traffic, spare time, and environment [12]. In

studying the DSS as it pertains to similar problems, Dr. Haimes cataloged the following as 'The Usefulness of the Decision Support System...:

- * As a data-base organizer.
- * In a simulation mode...
- * In an optimization mode (for single objective models), and for the generation of noninferior solutions and their corresponding trade-offs (for multiple models)'
- * As a medium of risk assessment and management...
- * As a medium for impact analysis in a multiobjective framework, where the impact that decisions made at time k have on the options existing at time $k + 1$ can be graphically displayed and analyzed.
- * As a medium for conflict resolution...
- * As a facilitator for the coordination of decentralized subsystems...'
- * "Sensitivity relates changes in the system's performance index (or output) to possible variations in the decision variables, constraint levels, and uncontrolled parameters..." [15].

2.3 Development of a Live-On Data Base and Model

One of the potential benefits of a model using interactive software is its ability to perform the analyses on a continuing basis. To accomplish this, configuration of the data set and the model must facilitate the updating of all input parameters. In addition, in order to capture historical trends in the data, the computer program must be able to work with data files of varying length, and distinguish the most recent data from the oldest so that truncation may be possible when system limits are reached. The user is encouraged to keep historical data on routes and jurisdictions only as long as it is relevant. If a highway route undergoes reconstruction to the point where the roadway geometry or pavement performance is dramatically affected or the highway type has changed, then keeping outdated data may distort the results for the route. Similarly, if a major hazardous material producer or receiver ("source" or

“sink”) should either go into or out of business, its effect on the historical data for the immediate area should be closely examined. When this occurs for data reflecting the probability of incident occurrences, it will be necessary to either extrapolate data for the one route or jurisdiction (preferred) or to truncate the data set so that incident rates (i.e., the number of incidents/period of record) may be calculated. A third alternative may be to use default accident rates to supplement the acceptable data once a sufficient period of record is available to compute such rates. It is suspected that any dramatic changes in routes and jurisdictions which would warrant this treatment are few in number at any given time. To sacrifice any part of the remaining data set for this reason would be to reduce the precision of the model.

3. LITERATURE REVIEW

3.1 Data Bases

3.1.1 Introduction

The first step in model development was the evaluation of the available data sets at the state and national levels. To perform this task, the types of data in need of collection were stipulated in advance. These include:

1. Hazardous materials incident data
2. Hazardous materials flow data
3. Roadway lengths and highway types
4. Local population data
5. Roadway vehicle concentration and people per vehicle
6. Land use data
7. Building replacement costs (items 6 & 7 being for property damage)
8. Bridge, tunnel, and public facilities (schools, etc.) data
9. Public health concern (water supply, etc.) data.

From previous studies, it was learned at the outset that certain data deficiencies existed. "Little information exists (on) where these (hazardous material) moves occur, what vehicles are employed, and what network elements are used. Because of this deficiency, it has been difficult to monitor the activity level of hazardous materials movements and to assess the safety (i.e., accident and incident rates) of the

industry..." [21]. It was also noted that data bases did not contain all of the information necessary to perform risk analysis; information such as population statistics, route condition data such as level of maintenance, accident rates, and historic flow volumes [21]. This being the case, it became necessary to look for surrogate statistics which were believed to be indicative of the behavior of some of the missing parameters. Since it is intended that the model be as transferrable as possible between states (without modification), the use of nationally available data was preferred. These data sources were reviewed first.

3.1.2 Problems with Data Collection

One problem inherent to such data collection efforts is underreporting by shippers, which can be attributed to several causes. First, the number of shippers and volume of hazmats shipped has far outstripped the ability of state and federal officials to police the system. "The size of the community involved ... is such that inspection of every facility, manufacturer, shipper, carrier, and so on, is infeasible,..." [3]. Second, there is some amount of misunderstanding as to the size of the spill that is required to be reported. "(The Washington state) Computerized Accident System includes all truck accident reports filed by enforcement agencies... Officials suspect that many hazardous materials spills are never reported, particularly those in which quantities are below placarding requirements" [26]. This would tend to exaggerate such items as the average quantity spilled, etc.. "EPA Region 7 officials have independently estimated that only about 10 percent of reportable releases under 100 gal are reported to EPA,..." [3]. A third potential reason is that

reported information may change over time as public officials revise their reporting requirements for budgetary and other reasons.

At the federal level, the authority for collection of hazardous material shipment data is divided among a number of agencies, with no single lead agency. Consequently, “(one serious problem is) that numerous hazardous materials commodity codes are used... At least 10 exist (at the federal level)...yet few cross-reference tables have been developed...” [21]. Additionally, “It is not clear to what extent accidents reported to BMCS and not reported to RSPA, or vice versa, represent noncompliance by carriers since the reporting requirements for the two data bases differ” [26].

At the state level, funding problems and insufficient demand for data prevent most states from making collection efforts. “...(most) State forms do not...note whether or not the hazardous materials (involved in a highway accident) were released...” [24]. This, plus the lack of training of police officials in hazardous material shipping serves to make collected information less reliable.

3.1.3 Research and Special Programs Administration

(RSPA) Data

The RSPA or HMIR (Hazardous Materials Incident Reports) data base sanctioned by the Office of Hazardous Materials Transport (OHMT) “...is the only one exclusively devoted to hazardous materials transport incidents,....” [3]. Reporting requirements are very strict in that “a transportation-related incident is defined as any unintentional

release of a hazardous material during transportation, loading or unloading, or temporary storage related to transportation” and “every incident must be reported to OHMT (Office of Hazardous Materials Transport) in writing” [3]. Some small amount of consequence data can also be found in that RSPA collects figures on deaths and injuries. However, these figures pertain only to those deaths and injuries that resulted directly from the hazmat release [27].

The problem here lies in the fact that so much information is required from so many sources that the federal enforcement program does not itself provide a sufficient deterrent to violations of the reporting requirement. Although reporting spills is a requirement, in practice it is done on a voluntary basis [3]. There are additional shortcomings in RSPA data collection which serve to aggravate the underreporting problem. The General Accounting Office finds six major flaws in the OHMT reporting requirements (i.e., RSPA). “Each of these factors works to understate the overall impact of hazardous materials transportation incidents in the United States” [3]. For these reasons, RSPA has proposed a revised incident report format. Given these problems, the RSPA data base is considered unsuitable for modeling in its present form. For this reason and the lack of state level incident data bases, it has become necessary to choose a surrogate statistic for hazmat incidents.

Since non-accident related hazmat incidents (e.g., leaks due to faulty valves, shifting cargo, etc.) have not been successfully correlated with highway system features, such incidents are generally considered system independent and are modeled strictly as a function of trip length. Since route lengths are already incorporated in the data required, it is deemed reasonable to use an accident data base as a surrogate for the incident data. This is true despite the fact that “BMCS Motor Carrier Accident Reports and the Missouri Statewide Accident Reporting System, indicate that approximately 12 to 15 percent of accidents involving

hazmat-carrying trucks result in a hazmat release” [25]. In order to use an accident data base, we must recognize that not all accidents are incidents (result in releases). If some historical distinction can be made between routes as to the likelihood of a release, given that an accident has occurred, then the percentages of accidents which do release should be incorporated into the model because it has been shown that “the probability... varies substantially between highway types, primarily because different highway types have distinctly different patterns of accident types” [25]. Such data should be national default percentages because “...data on the probability of a release given an accident is simply not available in most state accident data bases” [25].

3.1.4 Bureau of Motor Carrier Safety (BMCS) Data

The BMCS data base is a national compilation of truck accident data for certain types of accidents and truck fleets. Because it indicates hazardous material vehicle involvement, it is considered to be the closest offering at present to a national hazardous material accident data base. However, underreporting is considered pervasive here as in the case of the RSPA data [26]. There are also other shortcomings to the data reporting criteria which need to be addressed. First, “...the (BMCS) data base does not include all truck accidents, but only those of regulated interstate motor carriers” [27]. In addition, data reporting criteria have changed in the past due to budgetary limitations. “The BMCS data base is incomplete for some factors for the years 1982 and 1983. In those years, selected accident factors were not entered...as an economy move” “(There are also)...some definitional problems in

identification of hazardous material cargoes (in the BMCS data)...one accident involved a motor home with a propane tank" [27]. As another example, "... some carriers may be confused about whether to report the total number of lanes on the road or the number of lanes in one direction..." [27]. Consequently, misreported or incomplete records may distort the data set. The combination of these factors make the BMCS data unsuitable for modeling.

3.1.5 Commodity Transportation Survey (CTS) Data

In an attempt to obtain flow data on the shipping industry, the Census Bureau collects data on certain types of shipments which include certain hazardous materials. By definition, "...flow data bases contain information on the movement of commodities from one place to another" and "the..CTS contains flow data for commodities shipped by manufacturing establishments selected from each of 456 industries" [21]. In the analysis of the CTS data base for hazmat flow information by List and Abkowitz, they found the following deficiencies which make the data inappropriate for direct incorporation:

It (the Commodity Transportation Survey) does not contain data on waste shipments, or agricultural or raw material shipments such as crude petroleum and natural fertilizers. The shipments that are present are only from point of manufacture to first destination, often a warehouse; they do not reflect movements in the entire distribution chain. Data submission is voluntary...the data are collected only every 5 years, the scope of the survey is heavily dependent on federal budget priorities, and the questions asked are not consistent, making trend analyses difficult. Finally, the Census Bureau typically takes at least 2 years to release the data;

In 1983, the (Commodity Transportation Survey) respondents were asked to identify their line of business... and then report the number of tons they shipped to each state and the modal shares, giving no direct indication of commodity. Thus, it is impossible to determine exactly what commodities were shipped and what percent of the tonnage constituted hazardous materials [21].

Because it is virtually the only truck flow data base available [21], it would be desirable to obtain default flow percentages if we could identify a correlation with either highway type or truck flow related data (e.g., total vehicle flow information, etc.).

3.1.6 Truck Inventory and Use Survey (TIUS) Data

The TIUS is an attempt by the Census Bureau to catalog the nature of the national truck fleet. This is accomplished by sending questionnaires to truck owners for particular trucks asking for truck type and use information [26]. This being the case, it is not possible to obtain flow information for particular routes. Other types of information may be obtained, however. "(From the Truck Inventory and Use Survey--TIUS)...it is possible to estimate various measures of transport activity, such as annual truck-miles by commodity group and carrier category" [21]. Particular year surveys may also yield particularly helpful information. "...the 1982 Truck Inventory and Use Survey (TIUS) compiled by the Bureau of the Census enables some approximate exposure estimates to be made" [27]. Limitations on the interpretation of the results lie in the number of hazardous materials studied and the overall ability of the sample set to predict parent population behavior. As with other sources, some measure of insight must be applied to the results. As an example, "...the 1982 TIUS was performed prior to the passage of the 1982 Surface Transportation Assistance Act (STAA), which has markedly increased the number of double-trailer combination trucks in use..." [27].

3.1.7 Uses of Existing National Data Bases

While poorly constructed for risk and vulnerability studies, national data bases have several uses in the area of hazmat shipping. Benefits of the existing reporting standards include: “tracking the prospective performance record of the packaging standards..., facilitating the effectiveness of compliance and inspection programs... and improving the decision making process of DOT’s operating administrations” [58]. It has also been found that “...the current reporting criteria are an important and necessary means to enable field investigators to monitor hazardous materials shippers, carriers, and package manufacturers of hazardous materials packages for compliance with the hazardous materials regulations...” [58]. Because other worthwhile applications exist for these national data sources, it may not be in the interest of the collecting administrations to provide the additional items required for risk and vulnerability modeling. Other sources of data should then be considered.

3.1.8 State Approaches

The bulk of individual state efforts at generating such data bases have been built around their statewide accident report data. “At the state level, more sophisticated applications center around the use of computerized accident record-keeping systems used in concert with flow data to determine accident rates and high-risk locations in the highway network” [3]. No states have comprehensive incident data as is attempted by RSPA. “Some states do, however, have mandatory reporting of

hazardous substance releases...” [3]. Other types of data may be included to augment these records. “New York...is computerizing the data collected by its state police during their roving truck inspections” [21].

Because data collection practices vary, it is not possible to combine state accident and flow data for the nation as is done in Canada [48]. “The most accessible state accident data bases were found to be those of Missouri, Pennsylvania, and Washington” “Missouri is one of only three states...whose accident data identifies both whether a hazmat-carrying vehicle was involved in the accident and whether a hazmat release occurred (The others are Louisiana and Wyoming)” [27]. Still, because of their specialized interests and low underreporting, state data bases have compared favorably with their national counterparts. “The Missouri STARS system has the advantage (over BMCS data in)... that it contains all accidents investigated by police agencies,” “The STARS data...include(s)...all types of carriers, not just regulated interstate carriers ” [27]. This has led to more specialized uses for state data with regard to hazmat transportation. “A data base management system for hazardous waste movements in Arizona was developed for the years 1983 and 1984” “Results of this analysis provided some insight on the distribution of origins and destinations of shipments within and outside urban areas” [33]. This includes using accident and flow data to determine rough estimates of risk. “This type of database permits the extraction of heavy-vehicle accidents in which hazardous cargo was involved (or was likely to have been involved). This information can be portrayed against movement data to determine accident rates of vehicles transporting hazardous cargo, which can subsequently be used in the computation of transport risk profiles and the identification of safer procedures for routing hazardous materials. Although the capability to do this exists in the states of Washington and New York, the fragmented location of accident and movement data and their

relationship with the offices responsible for policy analysis have served as constraints. These states are, however, moving in the direction of conducting improved analysis with those data that they collect and maintain” [3].

3.1.9 Remaining Data Needs

While it seems apparent that the federal accident and incident data bases should not be used for modeling, suitable state replacements are not available in most cases. In the past, the federal government has sought to regulate reporting. “Uniformity is a key objective in national efforts aimed at cooperative enforcement and reciprocity” [44]. However, in 1982 such federal authority was struck down by a U.S. District Court in New York [38]. Still, with adequate state data and federal incentives for uniform collection (see section 3.20), surrogate accident probabilities should be obtainable. “With trucks, it is usually necessary to examine overall road accident statistics classified according to type of vehicle (when heavy goods vehicles/trucks would be the most relevant), type of highway (motor-way, divided highway, etc.) and location (intersections, circles, tight bends, etc.)” [16].

With regard to release consequences and response capabilities, data available is comparatively less specific. “...(we find that) it is not possible to break down the available exposure data to the same level of detail as the available accident and incident data bases” [27]. To formulate the MacroRADSS model, it became necessary to identify item by item which surrogate values would be obtainable, and at which level of aggregation (street, municipality, or county) with the smallest aggregation being most favored. Here, the work of Keystone Management Systems,

Inc. became invaluable because of their familiarity with available data sources for Pennsylvania.

3.1.10 Potential Improvements in Data Bases

The advantages gained in creating a live-on risk assessment model would be diminished if better future data types were incompatible with the model's structure. With this in mind, future data sources are then examined.

As previously mentioned, RSPA is proposing to revise its incident reporting system. "(The newly proposed RSPA incident reports) would require that all hazardous materials carriers make all records and information pertaining to any incident available to an authorized representative of the Department of Transportation upon request, and provide such representative all reasonable assistance in the investigation of any incident or studies involving such incidents" [58]. Also, "... (In the proposed RSPA report form) information would be required on the number of persons killed or injured as a result of the hazardous material(s) involved. If a fatality or injury resulted from a collision...then 'none' would be entered..." Also entered would be "...the number of people evacuated and estimated loss or property damage resulting from the spill...RSPA does not expect that these numbers will be exact" [58]. However, "...the proposed report form would not require information pertaining to what party issued the shipping papers accompanying the hazardous materials shipment. Also no longer required would be the trade name of the hazardous material involved..." [58]. This means that the potential will exist for stochastic prediction of actual consequence values if the correlation with other RSPA data can

be determined. The loss of trade name information for products released means that such data should not be used to distinguish hazmat classes in the model.

In attempts to achieve uniformity of regulations, the federal government has undertaken temporary incentive programs. "In 1981, the State Hazardous Materials Enforcement Development (SHMED) Program was established to encourage states to assume a larger share of the responsibility for enforcement of regulations governing hazardous materials transportation" [44]. Approximately 25 states were in the SHMED program before its scheduled completion in 1987 [44]. Later "The federal Motor Carrier Safety Assistance Program (MCSAP)...(was) designed to encourage states to adopt not only uniform federal hazardous material regulations, but also (to) require states to adopt the...49 C.F.R....or alternatively to provide an official legal opinion from the State's Attorney General that the state embraces similar rules and regulations" [44]. This may very well mean a wider adoption of Title 49 of the Code of Federal Regulations (49 CFR). "When a commodity is defined (in 49 CFR) within a particular hazard class, such as a Poison B or an Explosive A, shippers originating the material must comply with specific requirements pertaining to shipping papers, packaging, labeling, marking, placarding, signed certifications, loading and storage specifications, blocking and bracing requirements, and so forth" [44]. Therefore, the possibility exists that commodity, placard and packaging information could be available with the flow data base. This, however, is strictly dependent on reducing underreporting.

Speculation also exists about other ways to improve the federal reporting systems. According to OTA officials, "Congress might require development of national guidelines for State information-collection programs in three areas (registration of shippers & carriers, licenses of fitness from shippers & carriers, and notification of types of shipments)..." As another option, "Congress could require DOT

to extend accident reporting requirements to all hazardous materials spills over a certain threshold whether they occur during interstate or intrastate transport... Furthermore, a coordinated national spill reporting center, with reporting procedures and common data report fields...could be designated" [54]. According to Abkowitz and List, "...recommendations... made (by the authors) to improve the quality of hazardous materials transportation incident accident information...are not resource-intensive and deserve serious consideration in light of the health threats posed by hazardous materials releases" [3]. Still, no major data revisions are posed which would change the principles of the model as have been previously put forth.

As a final note, it should be mentioned that hazmat flow data does exist at the national level for certain types of materials. This is accomplished because the material represents the combination of a small percentage of total hazmat flow which is handled by a small percentage of the carriers, and a material which is of great public concern. First, "(EPA) regulations require every hazardous waste shipment to have a manifest. Thus, in theory, a complete flow data base exists detailing hazardous waste movements" [21]. Also, "the U.S. Department of Energy (DOE) maintains a list of all high-level radioactive shipments, and it conducts surveys of the low-level radioactive shipments" [21]. Should modeling be required only for these shipment types, then available federal data bases may indeed prove satisfactory.

3.2 Models

3.2.1 Introduction

As a second step in formulating the MacroRADSS risk and vulnerability models, a thorough review has been made of existing practices in these areas. Sections 3.2.2 through 3.2.5 concern general conclusions about modeling and evaluation obtained from the literature. Sections 3.2.6 through 3.2.8 deal with general conclusions reached concerning the components of the risk and vulnerability expressions. Finally, Sections 3.2.9 through 3.2.16 describe the individual approaches of the various models studied.

3.2.2 Different Model Types

Risk assessment modeling is a diverse field with not only distinctly different approaches but also distinctly different ways of classifying (aggregating into families) such approaches. Each classification scheme proposed stipulates that there are both advantages and disadvantages to the different formats. Categorization techniques are discussed in order to more fully understand the approaches of both existing models and the MacroRADSS model.

Asbeck and Haines report on one method of classification.

Fischhoff et al discuss...three categorical approaches to acceptable risk: professional judgement, bootstrapping, and formal analysis. Professional judgement integrates facts and

technical experts' values. Bootstrapping assumes that evolutionary, adjustive processes have in the past struck a societally acceptable balance that is a useful guideline for future decisions. Formal analysis applies analytic schemes from formally defined rational principles; the central question is to determine at what point risk is 'sufficiently' reduced [62].

In this classification system, the authors are concerned with "acceptable levels" of risk; another, more subjective type of analysis. Models of these types use expert opinions or other means to determine "acceptability". Such abstractions are deemed unnecessary for model purposes.

Dr. Haimes, himself, identified the following four risk evaluation strategies:

"(a) Risk aversion. These methods are based on the aversive characteristics of human nature"

"(b) Balancing risks. The idea here is to compare various risks and to equalize the consequences which result for each risk situation"

"(c) Cost effectiveness of risk reduction. The basic questions which must be answered are: how much risk is acceptable, and how much are you willing to pay for a particular level of risk aversion?"

"(d) Benefit-risk analysis. The idea here is to balance the benefits of a particular risk aversion strategy with the actual risks involved--independent of cost factors" [14].

Since we have not discovered ways to quantify the reduction in risk for various mitigation strategies, option (d) is infeasible, and option (c) is reduced essentially to a routing exercise with multiple objectives. Since it is not necessarily our objective to make all risk levels equal on all routes (for example, we may wish to designate hazmat through routes to reduce risks elsewhere), then option (b) is an incorrect generalization. Instead, MacroRADSS, and in fact most hazmat risk studies, can be considered risk aversion methodologies.

According to MRI, the following model types were studied:

"Risk assessment models were classified into four types including: enumerative indices; regression models; network and distribution models; and probabilistic models"

"Enumerative indices: Enumerative indices are risk assessment models based on a rating or scoring scheme"

"The limitation of models based on enumerative indices is that they lack precision" "...they do not help to identify particular locations or situations of unusually high risk nor specific means to reduce these risks"

"Regression Models: ...use measurable parameters such as average daily traffic, number of heavy volume intersections,...as independent variables.

These independent variables are then related to accident probabilities per million vehicle-miles, usually for a specific vehicle type, as the dependent variable” “The values of the variables in the regression model are based on actual site-specific data... A weakness of regression models is that neither the model developer nor the model user typically has access to enough historical data on low-probability, high-consequence events...”

“Network and distribution models: ...choose routes based on specific criteria (e.g., minimum risk) through a network of routes that is usually national or regional in scope” “...these models generally use national data bases,”

“Probability risk assessment models: ...are based on the conditional probability of an accident and the magnitude of its consequences...” [26].

Enumerative indices as evidenced in the Canadian Route Screening Method were considered too indistinct for differentiating between routes and jurisdictions in a large (e.g., statewide) data set. For lack of historical data, as mentioned, and lack of ability to isolate the causal variables for all vehicle types, highway types, etc., regression models were also dismissed. Network and distribution models are used to perform the routing function based on the risk values obtained by the other methods. The MacroRADSS model itself is not concerned with routing as much as risk determination. The modeling scheme can be said to belong to the fourth category of probability risk assessment modeling.

The final risk model classification scheme found was put forth by Abkowitz, Eiger and Srinivasan. “Four general types of risk estimation methodologies have thus far evolved and been applied...these methodologies are statistical inference, fault- tree modeling, simulation modeling, and subjective estimation” [1]. Here, the MacroRADSS model can be considered a combination of the first, third and fourth methods as it relies upon historical statistics to determine future likelihoods, simulates actual release sequences to determine the threatened areas and relies on subjective interpretation of the results for final judgement of appropriate action. It should be noted that fault- tree analysis has been criticized as to whether it is sufficiently valid to be considered a basis for important decisions; and also that some

errors of omission could result in unrealistic and incorrect answers [14]. Risk models that come under the third heading are generally referred to as “operations models,” where the impacts of particular spills on particular locations are analyzed in order to predict and guard against adverse consequences. “The simulator approach...requires a large amount of (computer) calculation and, therefore, requires either easily solvable models for the risky-loss variables and/or computer packages for solution approximations of multiple integrals” [62]. Since they do not consider entire routes but rather isolated locations, their use in comparing streets and jurisdictions is extremely limited.

In judging the success of a given model in a given circumstance, it is necessary to evaluate which class(es) of models is/ are best suited for the task required. Within each class, models can be evaluated and ranked by set criteria. “Fischhoff et al. suggested seven criteria against which (a) risk- related decision-making methodology might be measured: comprehensiveness; logical soundness; practicality in relation to real problems, people, and resource constraints; openness to evaluation; political acceptability; compatibility with existing institutions; and conduciveness to learning for future risk decisions” [62]. Models of different classes can then be compared on the basis of their ability to accomplish the objectives against the associated efforts expended.

3.2.3 Computing Risk

The first issue to be resolved in the determination of risk is the unit of measurement to be obtained. Here, there is also much disagreement between

proposed models. “Even objective measurement of risk, like any intellectual endeavor, involves some elements of uncertainty. The very choice of questions to be asked, issues to be considered, and methods to be used involves judgement” [39]. The use of a risk statistic is commonplace; however, such use has the disadvantage of being an abstraction and difficult to interpret. To cope with this, “Howard proposes the concept of a micromort - one one-millionth chance of death - as a means of expressing risk” [62]. Such an artificial scale creates the fictitious appearance that all activity involving risk contains the possibility of death; normally a considered catastrophe to be avoided. “Measuring risk directly is extremely difficult, especially for rare events that happen so seldom (or never have happened) that no data can be acquired. Thus, one has to depend on ‘models’ of risk to establish a surrogate criterion” [38]. The most easily interpretable means of measuring risk is the expected value of the damage from the hazmat release based on the probability of its occurrence. “(In the risk model developed by Hubert) The risk is normally expressed in terms of the annual frequency of the number of potential fatalities...this ‘community risk’ indicator is calculated as the sum of the individual risks for the population in the zone exposed to the risk” [29]. “The most commonly used traditional measures of risk are the expected value of damage and expected utility” “...extreme events in particular become concealed during this amalgamation” [20].

The concern over extremely high damage events with low likelihood is a legitimate one under normal circumstances. There are different definitions as to what constitutes such a catastrophic event. “In the general literature...,catastrophic events have 10^{-5} or less probability of occurrence...” [62]. The problem of equating high consequence and low likelihood events with low consequence and high likelihood events has been noted in the literature (see Kaplan & Garrick in [62].). To combat

this, “risk spectrums” or “risk profiles” have been developed which are plots of likelihood versus damage furnished in addition to expected value information.

Although the total risk is an important measure, it gives only the loss that would be expected on the average during the reference time interval. The range of losses which could be experienced is not discernable. For example, the risk associated with an accident that occurs once a year and results in one fatality is the same (i.e., one fatality/year) as that from an accident which occurs once in ten years but results in ten fatalities. In a plot of the expected frequency of N or more fatalities as a function of N, these two accidents would appear as discrete points. The second measure of risk is a curve called a risk spectrum, which is generated by such points [56].

One additional advantage of the risk profile is that profiles for various hazmats or various routes can be combined [34]. That is, provided the units of damage are the same.

Even as we consider that there are cases of high consequence/low probability occurrences (i.e., catastrophes) which are markedly different from more probable events of equal risk, we must point out that there is no case of “effective zerohood” as found in other risk modeling. There is no such thing as “zero risk” (Rowe); i.e. no loss may reach a magnitude where it becomes unthinkable to allow any probability of occurrence. At the other end of the spectrum, Okrent observes that “society is not risk free and cannot be” [62]. This distinction is helpful as most hazmat risks would be considered low probability and high consequence events and subject to such considerations.

As mentioned earlier, there are different types of risk which may be modeled. In terms of “absolute” versus “relative” risk, there are advantages and disadvantages to both methods. “In the absolute mode, there is a major benefit in the ability to examine the assumptions made...so that the potential for error can be better assessed” [16]. “The risk assessment models of greatest usefulness to highway agencies are those that can be applied to compare the relative risks of alternative highway routes for hazmat transportation” [26]. Because of the greater complexity of absolute risk calculations, there are more potential sources of error and more difficulty in gathering data for these models as well.

In the case of “objective” versus “perceived” risk, the means used to predict behavioral responses would invariably fail to gain universal acceptance. Thus the acceptance of a perceived risk model will likely be less than for an objective risk model. Also, gathering behavior information is a very inexact process. “(On the use of expected utility as a model of perceived risk) as Slovic et al. remarked..., ‘Subtle changes in problem formulation can have marked effects upon risk taking and insurance decisions’. The normative implication of the context effect (of the risk question posed) observed here is that utility functions should be constructed under various contexts” [43]. Lastly, the process of determining the behavior functions themselves has not yet been completely developed. Further research must be conducted to find a systematic way to identify conditional weighting functions for probability [46].

Having resolved all of the aforementioned stipulations on the risk expression, the calculation of risk itself is a surprisingly well accepted expression for hazmat transportation. “The availability of both accident and exposure data allows the computation of measures of accident risk, expressed as the ratio of accident frequency to exposure:

$$R = A/E$$

A represents an accident frequency measure, and E represents exposure. When expressed in this form, risk measures are referred to as accident rates” [26]. In more commonly used terminology:

$$\text{Risk (R)} = \text{Probability (P)} \times \text{Total Consequences (} C_1 + C_2 + \dots C_n)$$

where consequences are of the form people, property, etc.. Thus, if two accident locations had the same probability of occurrence for an identical scenario hazmat accident, then the one with the higher level of total consequences has the higher risk.

It is disturbing to note that, while the technical community appears to be in agreement over the definition of objective risk as it applies to hazmat shipping, the larger public service community is not. The author points to a publication of the National Response Team (which draws its membership from 14 federal agencies including the Environmental Protection Agency and Department of Transportation) entitled Hazardous Materials Emergency Planning Guide [63]. Here, the definition of risk is taken to be “the probability that injury to life, or damage to property and the environment will occur”. While vulnerability is defined as “the susceptibility (read exposure) of life, property, and the environment to injury or damage if a hazard manifests its potential”. One can say that such confusing publications are acceptable in that they account for the components of risk. The difficulty is that such publications are geared to increase public awareness of hazmat emergency modeling and thus impair the technical expert with discussing such modeling with the needed officials.

It must be remembered that these models are simplistic representations of complex event scenarios, and as such have limited usefulness. “Another structural problem in truck safety research is the inability to consider the effects of all relevant independent variables.” MRI cites the work of McGee and Morganstein which lists 40 independent variables in nine categories. From a practical standpoint, however, no study can account for the effects of more than a few of these variables [26]. Factors which are not considered in the risk model are then usually considered in subjective analysis in order to make the model more comprehensive. “Whether or not the analyst chooses to select and apply subjective factors will depend in part upon the outcome of the risk calculations and how conclusive the findings are. Subjective factors are useful for tie-breaking decisions where no one alternative is clearly superior to the others” [57].

In such a situation, it is best to start from a complex model, considering all factors available and simplifying rather than to add complexity to a simple original model. This is because "...avoidance of simplification could remove the risk of accidentally eliminating some key events from the assessment" [16].

Other factors used to customize risk models may also be incorporated (e.g. it has been noted that "...transportation of nuclear wastes demands that the cost and efficiency of the transportation strategy itself, as well as the impacts of the strategy on the community, be fully considered and analyzed" [61]). Additionally, factors which are intended to refine the model in question may be employed insofar as their compound effects with other variables in the model will not distort the model. This can be seen in that "...the proportionality of releases due...to time spent on the road, indicates that the risk assessment procedure should either quantitatively or subjectively have a bias against routes where hazmat-carrying trucks are likely to be delayed in traffic" [25]. In this case, traffic delay is a function of (among other things) urban versus rural setting. If such a setting affects other parameters in the model, then use of a traffic delay parameter may cause risk to vary disproportionately with urban versus rural setting.

3.2.4 Other Models

Other types of analysis occasionally accompany risk studies because these other studies require output from the risk model. One such type, vulnerability analysis, is considered in the MacroRADSS model.

For vulnerability, Rowe cites the work of Garbor and Griffith:

The term "vulnerability"...will be used here to indicate the status of a community as a totality. Vulnerability, therefore, will refer to the threat to which a community is exposed, taking into account not only the properties of the chemical agents involved, but also the ecological situation of the community and the general state of emergency preparedness at any given point in time. Community planners should generally concern themselves with the question of vulnerability as this refers to a community's overall sensitivity, given the existing level of threat and its coping ability [38].

Put more simply, "...community vulnerability to HM (hazardous materials) accidents is defined in terms of the interaction between the level of risk and hazard preparedness" [30]. Both the choice of preparedness factors and their interaction with the risk level are not readily apparent, and so no set methodology for vulnerability studies exists. As one local planner observed, "When the St. Bernard Parish study was published in 1981, it represented only a handful of similar studies conducted by local governments around the country" [37]. In this study the results were used to develop a local emergency response plan to combat the foreseen risks. For this purpose, preparedness should not be defined in terms of the risk model, so that a community can assess its preparedness separately from the assessment of risk made by itself or some external agency [42]. It is similarly desirable to keep risk calculations separate, because they provide widely accepted values with some significance. "Risk calculations must be separated from preparedness assessments... the purpose of assessing risk is, appropriately, for the selection of corridors of transport of hazardous materials and the selection of routes within those corridors" [42]. In one study, the authors develop a "community safety assessment index" which is made up of a community preparedness index and a community risk index [42]. This is particularly confusing as safety is more commonly defined in another fashion: "risk assessment is a scientific empirical activity and is to be distinguished from judging safety, which involves determination of the acceptability of various levels of measured risk, and is a normative, subjective, or political activity" [30]. Safety is a decision-making tool to be used in the face of limited public expenditures on risk reduction.

There are two aspects to be considered in dealing with safety: the probabilistic impossibility of a total absence of hazards and the level of risk acceptability. In this context, the safety of a system should be expressed as freedom from unacceptable conditions that can cause injury or death to personnel, or damage to, or loss of, equipment or property [17].

Because of its subjectiveness, the issue of safety must be considered on a case by case basis by those with decision-making authority.

3.2.5 Effects of Risk Reduction Strategies

In previous studies of hazmat transportation risks, the efforts to reduce risks in unacceptable locations have centered on three areas: routing strategies, curfews, and improved response capabilities. Since response capabilities are addressed in vulnerability analysis, the issues of routing and curfews will be addressed here.

“It is considered that many of the risks associated with transporting hazardous materials can be substantially reduced by thoughtful routing” [28]. The impact of routing, either the designation of specific through-shipment routes or the prohibition of routes, has multiple effects on risk and vulnerability modeling. Risk is reduced because the area of exposure is less, and the hazmat permitted routes can be redesigned to minimize accident likelihood and consequences. In addition, since response can be concentrated around designated hazmat routes, vulnerability is also improved. It should be pointed out that, in the cases of consequence and response capability, these benefits are gained regardless of the cause of the release. If designated hazmat shipment routes are selected, then certain suitability exercises should be performed. “Routes selected for consideration...for designation as preferred routes should meet minimum requirements for heavy truck use. Fuel and repair stops should be available and the routes should be maintained for year- round

use...” [59]. Also, “Preferred routes in one state must...match up at the borders with preferred routes in other states” [59].

Restricted hours of shipment (curfews) of hazardous materials is based on the viewpoint that certain measures of risk and vulnerability can be improved by limiting shipments to convenient times of day. This type of control has created problems for shippers when different jurisdictions, wishing to improve different risk measures, have decided on different hours for such shipments. Any such shipments caught in transit between two jurisdictions’ differing hours of shipment remain in the system longer. Thus, it is important that adjacent jurisdictions try to adopt uniformity in curfew hours. “Most commonly, certain types of hazmat shipments are restricted from traveling on congested highways during the morning and evening peak periods” [26].

3.2.6 Probability

In the preceding evaluation of the available data bases for modeling, it was discussed that RSPA incident data was inadequate for modeling and that, for lack of suitable alternatives, accident data bases should be used to model incident rates. This is a generally accepted practice as severe releases are captured. “The emphasis on releases due to traffic accidents is reasonable since available data indicate that approximately 2/3 of serious releases from shipments on the highway result from traffic accidents” [25]. The rationale for such actions was expressed by MRI:

The probability of a release from causes other than traffic accidents could be expressed as a function of truck type or container type, but this factor would not be directly relevant to

routing evaluations since the same truck and container types would presumably be used for all alternative routes [25].

In order to determine accident probabilities, it is necessary to distinguish the various system-related features which affect accident rates. MRI notes that "...there are three primary factors whose effects on truck accident rates are critical...:

- * Highway type
- * Truck configuration
- * Cargo area configuration" [26].

Since truck and cargo area configurations are not system related, the study has been limited to highway factors. "Truck configuration is not generally considered in hazmat routing studies, because it is assumed that the same types of trucks would be used on all of the routing alternatives considered and previous research is not sufficient to provide valid estimates of how differences in accident involvement rates of truck types vary between highway types" [26]. It should be noted first that each different truck configuration may experience safety problems related to particular highway features [26]. For support in our dismissal of truck type considerations, we find that according to BMCS 1984-85 data, the differences in release rate for different truck configurations was not substantial [27]. This has led MRI to conclude "...if one examines the data for the types of trucks most commonly used in intercity trucking -- single-trailer combinations with three-axle tractors in over the road operation -- the differences in accident involvement rates between vans, flatbeds, and tankers are not large" [26]. Highway type considerations were listed in their report as:

- * "Type of development (urban/rural)
- * Access control (freeway/nonfreeway)
- * Number of lanes
- * Presence or absence of median (divided/undivided)" [26].

In terms of access control, we learn from Transport Canada that "the dominant factor in both (Urbanek and Barber, 1980 and Bercha and Associates, 1985) studies (in determining road features that influence accident probabilities) is the number of

intersections along the roadway...as the number of intersections increases in a given kilometre, the number of accidents and injuries also increases" [48]. The inclusion of all at-grade intersections is too detailed for a statewide study (especially if one considers continually updating the data base) and so this factor cannot be considered. As theoretical justification for such actions, we can cite MRI again which notes that "intersection accidents are much less likely to result in a hazmat release than accidents in general" [27]. Time of day and weather considerations which could theoretically impact different parts of the system differently (e.g., lighted versus unlighted streets), may need to be considered in the probability model. Such factors are not considered, however, because of a lack of modeling capability from existing historical data. As has been observed, "...both (RSPA and BMCS) data sets imply that there is no particular problem associated with hazmat releases resulting from ice and snow conditions" [27].

We must further approximate the hazmat incident rate by using the total truck population for flow data (hazmat flow data bases were also deemed inadequate). If the hazmat percentage of accidents is higher than the actual hazmat percentage of flow, then it is possible for the surrogate statistic to yield smaller probabilities than actually exist. The questions now posed are whether or not total truck behavior is a suitable surrogate for hazmat truck behavior and if the hazmat shipping fleet is considered safer than the trucking fleet as a whole. In the case of the first question, it has been observed that "most traffic accidents (in a global study) involving dangerous cargo...(were) dominated by a combination of 'traditional accident causes' such as human failure, vehicle defects and insufficiencies, package failure or third party causation" [29]. For the safety aspect of the questions posed, it can be said that "...empty trucks may have slightly higher accident rates than loaded trucks, primarily because of poor braking performance. (and)...nearly all of the truck studies that have

been applied to hazmat transportation include accident data for empty trucks” [26]. Thus, the presence of hazardous cargo should make the vehicle less likely to have an accident than an empty vehicle (non-hazmat). Additionally, “several states have already established special certification requirements for drivers of vehicles used to transport hazardous wastes (or materials, as in California)” “Certification requirements include a medical examination and a written test on all applicable...laws...and safe driving practices” [8]. This means that hazmat vehicle drivers in such states represent a more select population than truck drivers as a whole. Consequently, we would expect fewer hazmat accidents than total truck accidents as a percentage of their respective fleet-miles.

One recognized problem in using any truck accident rate data is that such data has random influences (such as driver judgement) affecting the values [40]. For this reason it is argued that default accident rates should be established and applied to the entire highway network. There are two fallacies to such an argument. First, if we were to incorporate the entire highway system, then we would be assigning risk to streets which carry no hazmat traffic (with the possible exception of home heating oil trucks). If we assign default risk rates to only those streets with reported hazmat accidents, then we are ignoring historic data trends which may be indicating important local conditions. The other error in proceeding with default accident rates is that default values themselves will change over time as influenced by the historic data. This means that the default accident rates will be influenced in the same manner as the individual route accident rates should nonrepresentative routes be a significant percentage. In this case, a far greater number of links would be affected (albeit to a lesser extent) than if actual route accidents were used. Thus it has been concluded that “math models that utilize local roadway accident rates should be used where possible. The best representation for most routes is the historic accident

record" [48]. Other reasons for such a conclusion have been found in the literature. "Previous investigators performing hazmat transportation risk assessments have been frustrated by the lack of definitive information on truck accident rates by highway type. Most investigators have recommended the use of actual accident data for the highway routes in question, whenever possible" [26]. Since there is no route-by-route release information for Pennsylvania, default statistics must be employed. "Because so few data are available that describe the causes and dynamics of accidents, an analysis of probabilities cannot be based on direct observation. Thus indirect models are used to simulate accidents" [60].

The use of risk analysis for routing purposes requires the consideration of additional parameters in probability modeling. It has been pointed out that "Where the amount of dangerous goods traffic is large, (dangerous goods) routes will lead to a noticeable increase in traffic on the selected roadways. The increased traffic may, in itself, increase the probability of an accident involving a dangerous goods vehicle" [48]. In the case of statewide risk ranking, it is assumed that the user will adjust accident rates (perhaps using analogous historical data) for routes which are to be designated hazmat routes. This is another advantage of the interactive computer format. In routing, it is also noted that "...there is a tradeoff between accident rate and distance traveled that needs to be considered formally to select a minimum risk route whenever the route with the lowest accident rate is not the shortest route" [26]. This leads us to the incorporation of a route length term in the probability expression.

3.2.7 Consequences

The term “consequences” may be somewhat misleading. It implies that, for a given release scenario, we can predict in advance the damage incurred in terms of death and injury. “There is no currently accepted method of estimating the consequences of hazmat releases (e.g., persons killed, persons injured, property damaged). Therefore, the FHWA Guide and other current risk assessment models assume that the consequences of a hazmat release are proportional to the number of persons or amount of property exposed to a release. This assumption should be clearly stated...” [25]. If we were to use historical death and injury figures, it could be argued that the bulk of reported deaths and injuries are unrelated to the hazmat carried. For our comparative risk calculations, the number of people killed and injured from hazmat accidents can be replaced by the total number of people in the modeled path of the hazmat release. This term is called “people exposed”. Similarly, we can develop values for property exposed, and so forth. MRI does not use the term “exposure” in the risk formulation, but instead retains the FHWA term “consequence” in the belief that future means of measuring consequence will replace the exposure measures in the equation [25]. Such a practice is misleading as it appears to empower the exposure terms with the ability to calculate consequences. Rather, it should be conspicuously noted that exposure values are surrogates for consequence values and continue to call them such.

As a first step in determining exposure, we must identify the type(s) of materials involved. As noted, the number of hazardous chemicals produced by U.S. industries is well into the thousands. “No accepted scientific and objective method is evident in the literature for rating the degree of hazard for each of the product categories”

[48]. Even so, some means of addressing the different nature of different threats is required. In previous literature, a number of different techniques have been employed to circumvent this problem. In Rowe scoping analysis, the author restricts his modeling to three principal chemicals (gasoline, chlorine, and anhydrous ammonia) as these make up the bulk of modern hazmat shipping by truck [38]. "Gasoline represents about one third of all hazardous materials shipments made by truck" [56]. Of course, to make the interactive model a live-on model, one can not presuppose that the predominance of these three chemicals in shipping will continue indefinitely. In other methods, the selectiveness of the study limits the types of hazmats (e.g., gasoline [56], radioactive materials [59], etc.) which may be considered. This technique, of course, would severely limit our study in scope and ability for general route risk comparisons. A third approach is simply to allow the user to define the hazard as it impacts the model. The argument in favor of this approach would be to provide the user with the ability to customize the analysis. However, for users with little knowledge of hazmats or their respective impacts, this would make such an interactive model highly confusing. This approach becomes useful if it is not the only one available to the user. Perhaps the most reasonable approach to modeling different hazmat types is the remaining technique of grouping the various individual hazmats into a manageable number of classes having similar properties. The use of a comprehensive hazard class or "all case" may be necessary if relative rankings are not apparent by considering various hazardous materials individually. This is a simplistic, last resort situation as it has been pointed out that "it is not sufficient for public safety purposes to lump all dangerous goods together in terms of their hazards or to expect that gross measures of product hazard can be relied upon with any confidence" [48]. The advantage here is that the degree of disaggregation is only that which is necessary to run the model. As time passes,

additional hazmat classes may have to be added; but this likelihood should diminish. Classes defined are typically based on vehicle placarding but the use of placarding alone should be discouraged. As Stough and Hoffman point out:

*“...some types of loads need not be placarded because of the quantity of the load or its packaging and some loads are not placarded that should be; (also) some placarded trucks did not have UN/NA (commodity) numbers, which made it difficult or impossible ...to determine the nature of the material...”

*“Determining if a load is adequately placarded is complicated because of the complexity of federal laws”

*“...when more than one hazardous material is present in a single load, complex and at times apparently contradictory regulations must be interpreted to determine the correct placarding” [45].

Having determined the type(s) of hazardous materials to be considered, it is then necessary to consider the various types of release scenarios which are possible for each class of hazmat considered. Certain types of release for certain types of hazardous materials can be ruled out by logic. As an example: “if a pool of gasoline does not ignite...evaporation of the gasoline forms a vapor cloud...exposure...can result in unconsciousness and eventual suffocation. The 500 ppm limit can be detected by the human sense of smell” “death by exposure to gasoline vapors is therefore discounted” [56]. However, the number of scenarios for a given hazmat type is quite large considering that multiple hazardous effects may occur during release. In one situation “...an explosion can be followed by either a shock wave, a fire ball, or fragmentation of material, each with a distinctive set of ramifications” [40]. Also, “under certain weather conditions, the instantaneous concentration of gasoline in portions of the vapor cloud can exceed the lower flammability limit at distances up to 280 meters from the edge of the pool. The primary hazard...is the formation of a fire ball” “it is expected that a fire ball would flash back to the pool, so that a pool fire would also result” [56]. Gas dispersions as well may occur in the form of sudden or continuous releases. These gas release scenarios have different modeling

characteristics making each unique. “(During an instantaneous or initial stage of pressurized gas release) one would experience a rapidly expanding vapor cloud during that time, which is not being subjected to any significant wind forces because of its relatively high expansion velocities” [16]. If we were to consider every scenario for every hazmat grouping, the options available would become very large again. For the purpose of risk and vulnerability ranking, worst case scenarios have been selected for each hazard class. The selection process as well as the impact (i.e., exposure) modeling for the MacroRADSS package is to be performed by TMS, Inc. of Burlington, Massachusetts.

The primary modeling concern of the different scenarios for the different hazmat classes is to determine impact or “exposure areas”. “A zone of impact can be obtained for each (route) in the road network by assuming a continuum of possible spill sites along its length, and a circular range of impact for each spill” “...the impact zone estimated for each road (route) tends to overestimate the area that is likely to be affected in a real spill situation” [40]. In some instances, this exposure area is dependent on wind speed and direction. “In the case of a specific site, one normally needs to use the air stability and wind statistics for the nearest meteorological station. This may be many kilometers away in perhaps totally different surroundings, so the use of such statistics may introduce some small statistical errors” [16]. On a statewide level one usually cannot afford to collect and update all such statistics for all meteorological stations in the state. We must therefore use a worst case wind scenario to be compatible with our release scenarios. “One of the important constraints in applying dispersion models to releases is the assumption that the ground, both up- and downwind, is adequately flat and unobstructed” “some estimates of risk could therefore be pessimistic, especially for areas that are

protected..." [16]. In the case of radioactive shipments, a tiered exposure area is used to reflect the dissipation of the radioactive cloud.

When radioactive material is released as the result of a traffic accident, the population in an area of approximately 25 sq mi (65 sq km) downwind of the release is generally exposed to low levels of radioactivity.

The population within a 5-mile (8-km) band is considered most critical and is given greater weight in the analysis. Economic (property damage) consequences are estimated...within 10 miles (16 km)...land uses within a 5-mile (8-km) band surrounding the highway receive greater weight in the analysis [26].

Such an empirical contrivance seems appropriate although it is completely arbitrary.

Although few studies use all of them, four possible measures of exposure have been identified in the literature. The first and most important is the threat to life. "When a substantial quantity of a lethal hazardous material is released in an accident the most important consequence is the loss of human life" [34]. Such threats are of a diverse nature. "Possible consequences include:

- * Fatalities
- * Injuries
- * Lost years of life expectancy
- * Evacuation
- * Disease
- * Long-term health effects
- * Pain, Anguish
- * Uncertainty
- * Disruption, inconvenience"

[48].

Evacuation itself is considered an impact on human life and should be considered especially important in situations where populations are difficult to move (e.g., hospitals, prisons, etc.). Since evacuation is one of the first steps taken in controlling a hazmat situation, then special consideration must be given to such facilities. The second category of exposure takes stock of the number and size of these special facilities (note that the populations themselves have already been considered). For radioactive shipments, it was stipulated that "... (special) facilities contain populations that are either large (such as stadiums), may be more sensitive to radiation (such as schools (note: children are considered more susceptible to radiation than adults)) or are difficult to evacuate (such as hospitals)" [59]. Beyond these types of facilities, damage to buildings in general must be considered. Although items stored in such buildings may be of sizeable value, it is not possible to model such fluctuating costs,

at least on a statewide level. The modeling of building damage is also in terms of potential damage (i.e., exposed buildings) since “no conclusive studies have been conducted that demonstrate the effects on buildings of dangerous goods releases” [48]. Obtaining building information on a statewide level will be a difficult project task. Current local routing techniques are based on either field investigations or land use maps. “One of the difficulties in using zoning or land use maps is that they may not distinguish between developed and undeveloped parcels...” [48]. For more distant forecasting models, “Users may want to consider the potential effects of planned or possible future expansion of high-density land uses within the hazard corridor for each route option” [48]. The fourth measure of exposure is the environmental exposure referred to as “sensitive areas”. These may include items of ecological (or, in some studies, historical) interest (wetlands, aquifers, preserves, etc.). “Part of the difficulty in identifying environmental resources is that they may be at some distance from the route” [48].

These exposure measures may be readily obtained in some instances. It is in combining them together that controversy ensues. “In general, the consequence measures (population, property, and environment) are additive...” [48]. However, we must recognize not only the different values which we ascribe to the significance of these measures but also the different units they employ. Rescher sums up this dilemma:

It is a fundamental and far-reaching fact of risk analysis that the different parameters of negativity are not necessarily commensurable. As is the case with the trio of lengths, temperatures, and weights, negativities are not measurable in terms of one common, interchangeable unit; and unlike dollars and pesetas and yen there is no “rate of exchange” that permits the automatic translation of one into the other—no “market” like that which prices apples and nails and overshoes in a common unit. Negativities cannot be adequately evaluated by a single number; their appraisal calls for a plurality of distinct and largely incomparable considerations. Any attempt to measure this ‘size’ of a negativity by a single number derived from some assumed common denominator involves the problematic oversimplification of an inherently complex picture [36].

One of the objectives of the MacroRADSS model is to develop a flexible and equitable approach to calculating total exposure.

3.2.8 Response Capabilities

Much has already been said about the difference between exposures and consequences in the risk assessment model. One of the reasons why we do not use historical consequences in the model is the varying influence of jurisdictions to respond to incidents. “Increased (response) capability does not alter the probability of an incident, but can play an important role in mitigating adverse effects in all three impact categories, population, property and environment” [48]. The incorporation of quantitative assessment of response capabilities in conjunction with traditional risk assessment is meant to help interpret such historical data, highlight such deficiencies within the state, and provide further insight into routing and other potential mitigation strategies. Within the context of hazmat incident response, different agencies have different capabilities and roles for service. In the international community, such agencies can be of many different types. “The organizational set-up and responsibility (for emergency response) in OECD (Organization for Economic Cooperation and Development) member countries differs substantially and may involve civil defense, police, gendarmery, fire brigades, civil protection services, assistance from other modes of transport, from local industries or national industry/trade organizations” [29]. In the United States, these services are traditionally provided in three forms: police departments, fire departments, and ambulance or paramedic services. Traditional roles for police departments include traffic management [26], as well as crowd control and site evacuation [37]. In Louisiana, the state police will assume command of the response effort resulting from an incident if so requested by a Parish government [37]. Fire departments are typically designated the lead agency at a site [37]. if, in fact, one is designated at all.

Depending on their available resources, fire departments will attempt to minimize property damage, free imperiled people and contain hazmat releases. Emergency medical services (ambulances and paramedics) will normally provide emergency medical attention and transportation [37].

Since we have multiple agencies for response, there are also multiple parameters for measuring response, and the way those parameters interact with the risk model have never really been examined. Sizes of various response capabilities have been already determined on a statewide basis for Virginia. In taking inventory of emergency response capabilities in Virginia, Price, Schmidt and Davis sent survey forms to police, fire and rescue crews throughout the state in order to catalog their ability to handle hazardous materials accidents [31]. One accepted measure of response capability is the time required for the first responder to reach the incident site. It has been observed that the more quickly emergency services can arrive at the site of a hazmat incident, the greater will be the mitigation of effects [48]. This is so a more rapid initial diagnosis of the size and nature of the hazard may be made, as well as more rapid initial control of the release scenario [59]. Other measures of response are in units of each response type. "A fire company is considered a more suitable measure of fire service response than a fire department because departments vary substantially in size" "Police cars are considered a more accurate measure of response than police stations because of the variance in size of police stations..." [48]. Alternately, "a qualitative estimation of response capability can be derived from the number of fire companies trained and equipped for dangerous goods response that are available on a per kilometer basis along a given route. If further information is required, the number of police cars and ambulance units available per kilometer...may be taken into consideration" [48].

Because of the wide variety in capabilities of individual fire companies, some cutoff value for “equipped companies” has to be established below which fire response is not considered. “An equipped company (in the Canadian screening method) is one with full protective clothing for all fire fighters, self-contained breathing apparatus, and immediate access to a foam extinguishing agent” [48]. Since these units are first responders with subsequent specialized teams supposedly enroute, then specialized equipment is not necessary. “The lack of fire and rescue services ownership of vital pieces of heavy equipment is not necessarily of importance. It is essential, however, that the logistics of obtaining this equipment on short order is worked out in advance to ensure its availability when needed” [32]. “Obviously it is not possible or practical for every public safety organization to be fully equipped and staffed to respond to every dangerous goods transportation occurrence” [48]. In fact, the level of sophistication of the first fire responder is based in large part on the organizational character of the state hazmat control system.

Centralized systems focus emergency response on a coordinating state organization.

In the states with decentralized systems, local public safety or public health personnel make the initial assessment of the incident. Under this approach, local personnel must be trained to handle minor incidents and to recognize incidents that are beyond their expertise. In such cases, the local officials contact appropriate state authorities and the state response system is activated [26].

Even in the case of a decentralized response network, however, it was noted that “hazardous materials emergency technical response does not have to be as immediate as other emergency response as long as local first responders have the capability to do basic hazardous materials response while technical response is on its way” [6]. In their report which suggested that Virginia develop “Special Materials Accident Response Teams (SMART)”, Price, Schmidt and Davis stipulated that it was not recommended that all stations be equipped for severe hazardous materials

transportation accidents [31]. In addition to the problem of sufficient equipment, there is the problem of training:

The first people to become involved in an accident involving hazardous chemicals are usually people from the local community-either the police or the fire department. Of all the groups that eventually may get involved, these are the people least likely to know how to handle such an emergency. And, because there are so many local police and fire departments, the task of better preparing these people to handle chemical emergencies is awesome [35].

Even so, sufficient avenues exist to provide for training [38]. and hotline information programs (such as the CHEMTREC service) help to minimize these differences.

As a final note, additional types of response unique to certain areas may be worth modeling consideration. These systems, available in select communities, are too few in number and specific in purpose to merit consideration in statewide modeling. "On high-volume freeways with frequent hazmat shipments, permanently installed response capabilities such as foam blanketing systems, could be considered" [26]. Additionally, hazmat industries may choose to operate their own response systems.

Although those industries located in the (St. Bernard, Louisiana) parish maintained fire fighting teams and a significant amount of specialized equipment, these resources could not be mobilized quickly and industry officials required 'good samaritan' protection (read: insurance) prior to committing these resources [37].

3.2.9 FHWA Guidelines and MRI revisions

The FHWA publication Guidelines for Applying Criteria to Designated Routes for Transportating Hazardous Materials represents the current accepted practice for comparative risk assessment of hazardous materials routes in the United States. Consequently, the format of this procedure has been the framework of numerous subsequent studies, each customized by the particular user. The Midwest Research Institute (MRI), is now concluding an appraisal of the Guide sponsored by FHWA.

Comments from those works which were available as of this publication date are included in this section.

Perhaps the first thing to be noted here from the MRI critique is that certain disclaimers should appear in the FHWA manual. As previously seen, MRI points out, "...in reality adequate data for developing absolute measures of risk do not exist. The (FHWA) Guide should state this clearly and should be restructured to provide the most complete assessment possible of the relative differences in risk between alternative routes" "the (FHWA) Guide should state clearly that it does not address routing procedures for shipments of radioactive materials because impact distances have not been established and because other factors (e.g., normal radiation exposure) need to be considered" [25]. Additionally, MRI notes the lack of discussion of a logical basis for the FHWA model. "User credibility and understanding of the model would be increased if the report first presented the basic equations...and explained the rationale for each term, and the method for determining its values" [25]. Although the relationships seem apparent from both the order of presentation and terminology, it is agreed that some additional discussion may be necessary in order to evaluate and modify the relationships in a logical fashion. The prompting of the call for such a logical discussion stems largely from the original model's inclusion of a "fraction of traffic accidents involving a hazmat release" (FHZ) term in the probability computations. This term, as a constant (2.3×10^{-5}) in the expression, has no bearing on relative risk (i.e., the same term appears for every route) and is based on the faulty RSPA data base [26].

"A dimensional analysis of...(FHWA probability equation) indicates that it actually determines the expected number of hazmat releases per trip over the route segment by any type of vehicle--passenger car or truck, whether carrying hazardous materials or not. Potential users...have been reluctant to use the FHWA Guide because of the awkward formulation of the FHZ (fraction of all hazmat accidents that result in release) term" [25].

If the FHZ term is considered inappropriate, then another, system-dependent term must be found to indicate the percent of all hazmat accidents resulting in a release. The observation is made that "...release probabilities vary widely with accident type, with higher release probabilities in single-vehicle accidents than in multiple-vehicle collisions. Since the proportions of these accident types are known to vary markedly between highway and area types, release probabilities will vary..." [25]. MRI recommends the following highway types be used as a minimum number for collecting such information:

- ** Rural freeways
- * Rural two-lane highways
- * Rural multilane divided highways
- * Rural multilane undivided highways
- * Urban freeways
- * Urban arterial streets" [24].

These highway types are also to be used to obtain default truck accident data to use in place of actual data in the existing FHWA model. This is because MRI claims that "if the individual route segments are very short and/or the time periods for which accident data are obtained are very short, only a few accidents will be found for each segment" "accident rates based on small numbers of accidents can be very unreliable and can result in artificial differences in accident rates between route segments that could incorrectly influence the choice of routes. A statistical test should be included in the procedure to assure that...the sample size of accidents is large enough to produce a reliable estimate of the accident rate" "users should be cautioned against using truck accident data for specific route segments unless the segment is long enough and/or enough years of accident data are included (according to Chi-squared testing)..." [25]. In their recommendations, a Chi-squared test is used to tell if the actual accident history is sufficiently different from the default values to merit replacement [24]. In opposition to this practice, MRI notes the work

of Barber and Hildebrand who urge the use of actual accident histories for route segments whenever possible. The use of actual accident data for this purpose is highly desirable, because accident rates are known to vary widely from average or expected values, even on highways that are nominally similar in design [26]. In the recommendations, the default accident rates come from the primary highway systems of two or preferably three states. Both the extrapolation of primary highway data to other system routes and the use of out of state data have the potential to introduce unwanted biases in the default data.

In the original FHWA model (also known as the Urbanek and Barber model) the accident rate used in determining the probability of an accident on a route involving a hazmat release, is based on the total vehicles on the road. This makes the parent population for the accident rates very broad and raises the question of its representativeness. It has been suggested that total truck accident data may be a better parent population because of similar truck performance characteristics and the smaller population size [25]. "Truck accident data are available from virtually every state for specific route segments and truck accident rates and patterns are likely to be closer to hazmat accident rates and patterns than data for accidents in general; however, Urbanek and Barber were concerned that no adequate predictive models for truck accidents were available" "Abkowitz et al., have developed an approach based on truck accident rates and RSPA has developed a (similar) risk assessment method for radioactive shipments" [26]. The use of total truck data rather than hazmat- only data or some other, more restrictive parent population was chosen for certain logistical reasons. First, "...it should be recognized that, while accident rates by truck type might be used to select the appropriate truck for a particular shipment, they are not generally needed for relative comparisons of routes since the same trucks would presumably be used for each route" Also, "...no attempt should be

made to determine default accident rates for hazmat-carrying trucks as a group, or for specific truck types...because adequate exposure data...for these subclasses of trucks are simply not available. The implicit assumption that hazmat-carrying truck accident rates are equal to general truck accident rates should be clearly recognized..." [25].

While avoiding distinction by truck type, another distinction is sought by MRI, that of area type (urban versus rural). While it is interesting to note the implications of such a term in risk modeling, we must guard against the inclusion of a distinct area type term, since many of the term's implications are incorporated elsewhere in the FHWA model (e.g., vehicle flow, work versus residential population, building replacement cost, etc.). Adding a distinct area type variable would be tantamount to double emphasizing such a characteristic. This term may be of little significance, however, when used in the original context of the FHWA model (i.e., routing for a single county or metropolitan area). Here such distinctions of urban versus rural areas may be made in conjunction with the level of sophistication of the analysis intended by the sponsoring community. "It would be desirable to revise the structure of the FHWA Routing Guide to address the needs of at least three types of users" (that is to say small communities, medium-sized communities, and major statewide or metropolitan areas) "the Guide should retain the flexibility for users to adopt different levels of detail for different aspects of the risk assessment method..." [25]. The current FHWA model is speculated to be optimally sized for a medium sized community [25].

The consequence (i.e. exposure) parameters in the FHWA model, both population and property, have been questioned by MRI. According to their report [25], the segment length term which is used to help determine the impact area of a hazmat release is double counting of the length parameter. In fact, this is not the

case as a dimensional analysis will indicate the length unit cancels in both expressions. What is happening is that, using the original equations, we were calculating the risk incurred by shipping a hazmat load over the entire route considered. If we divide by the route length as MRI suggests, then we obtain the risk incurred to ship a hazmat load over one (1) mile of the route considered. The latter method is useful for comparing the relative risks of routes of different lengths while the former method should be used for comparing the total risk of different routes between two points (i.e., the routing function) and for determining absolute risks should that become possible. "(MRI also argues) a single hazmat release would expose only those persons within the impact zone at the site of the release not all persons within the impact zone along the entire route segment" [26]. However, it should be kept in mind that the final objective is to obtain a measure of the comparative risks of different routes and not necessarily the damage expected from individual releases (recalling that such models are considered operations models). Consequently, it makes no difference if the unit length is one mile or the diameter of a circular impact area which represents the degree of hazmat dispersion (provided that the same impact is studied for all routes). If it was intended that dividing by both length and impact area dimension be performed, then our risk unit would be falsely expressed in terms of risk per square area.

One consideration regarding the impact or exposure area which has occurred repeatedly in the literature is the incorporation of wind speed and direction. In the original FHWA guide, conservative estimates are assumed for impact area dimensions which are assumed to be centered over the roadway. While MRI recognizes that the accumulation of wind pattern ("rose") data is highly complicated for large area assessments, they do assert that wind effects should be considered. "In the absence of wind rose data, one possible approach is to consider persons

within the impact distance on only one side of the road, but to always choose the more densely populated side of the road” [25]. It should be recognized that this approach, while valid, relies on exposure data at the census tract or similar level. For a statewide analysis, such detail presents a major data gathering and manipulating chore which mandates additional benefits to be gained before being incorporated in such a model. Similar problems are faced when attempting tiered exposure levels for large area hazards. “The use of a weighting scheme to put greater weight on population near the roadway and less weight on population near the limits of the impact area should be considered. However, it is likely that the available population data...are too aggregated...” [25].

While searching for more refined estimates of exposure area, MRI suggests the need to develop “...alternative procedures...for assessing population exposure at a lower level of detail...” [24]. This would be done through the use of default population densities [25]. The loss of detail in such a method would seem to negate the advantages of considering wind effects. At the same time, they suggest evaluating employment versus residential populations to consider the case where an employment population is higher. Also, they suggest considering outdoor populations (i.e., those at stadiums, parks, amphitheatres, etc.) more heavily, since they are thought to be “more directly susceptible to the effects of hazmat releases than indoor populations...” [25]. If population information is known for a jurisdiction, there would appear to be no reason to estimate its value. Similarly, refinements such as those mentioned above would lose significance if default values of population were used. As to the refinements chosen, every effort should be made to capture the entire population within a jurisdiction at its maximum value during a typical day. This should be accomplished in a manner which would try to avoid duplications in counting. In the case of outdoor populations, those who use such facilities typically

either reside or work in the jurisdiction considered. Another feature about open air land uses is that they feature either low temporal (e.g., stadiums and amphitheatres) or spacial (e.g., parks and golf courses) distribution of the populations involved. Such considerations, therefore, represent atypical circumstances and it would be unfair to rank routes adjacent to such outdoor facilities higher than otherwise as a result. If such an atypical situation is to be considered, then this should be accomplished through customizing the input data and using careful engineering judgement.

The populations associated with special highway facilities are also recommended for consideration. Special facilities are defined by example. In the case of highway facilities this includes bridges and tunnels (where it is difficult to avoid an impact area and also difficult to evacuate). Local special facilities are defined to be those which are difficult to evacuate (such as hospitals) or with sensitive populations (such as schools). Here, both data limitations and the unquantifiable importance of the structure(s) in the network would suggest that the lengths of bridge spans and tunnels be used as a means of deciding between similar risk routes (i.e., a tie-breaking factor).

For property damage in general, "...the FHWA Guide does not suggest any typical property values for specific land uses" [25]. The question facing MRI of finding an alternative measure for building values to the rapidly changing dollar amount was set aside by their opinion that "...it might be of greater assistance to users to provide default estimates of dollar values and warn them of the need to update them for inflation, especially since the relative values of different types of property may be stable over time" [25]. As far as building types to be replaced, MRI recommends expanding the FHWA property classifications to include the following:

- * High-density residential
- * Medium-density residential
- * Low-density residential

- * Commercial--office
- * Commercial--retail
- * Industrial
- * Institutional
- * Agricultural
- * Open land" [25].

Neither MRI nor FHWA suggest what the typical building patterns are which fall under each category. Here we must guard against double counting special facilities found under the "institutional" classification. It should be noted that property damage is only calculated for buildings which front on the route in question [26]. While this may be intended to express some measure of the shielding effects of buildings, this technique can not be employed at the statewide level because of the sophistication of the land use data required.

In combining measures of consequence to create a single measure, MRI has come to the following conclusions:

The FHWA Guide provides no specific guidance on when to consider both personal injury and property risks and how to combine or weight these risks.

The 1987 Canadian screening method suggested some specific weights for combining population, property, and environmental risks.

It is unlikely that all users could agree on a single set of weight factors appropriate for all circumstances.

Some guidance for users should be provided either by: (1) additional text discussing these issues, or (2) specific values of suggested weights presented "as an example". In either case, the final choice of which types of exposure to consider and how to combine or weight that exposure should be left to the user [25].

By providing no weighting system, we provide no means of obtaining a single risk value and so some arbitrary default weighting can be justified. With an interactive approach, user customizing is not difficult. In order to be reproducible, all such assumptions must be documented in the output.

As a final observation on the computation of consequences, we observe that the impact areas considered by FHWA refer only to individual materials. As a result, risk values obtained only apply for the material studied. In their recommendations, MRI concluded: "the (FHWA) Guide should discuss the appropriate impact distances both for routing studies for specific materials and for general hazmat routing studies on

routes carrying a variety of materials” [25]. However, the general or “all case” hazardous material properties have yet to be determined.

After the probability and consequence measures have been multiplied to determine the objective risk measure, the user must decide whether or not to entertain subjective risk measures. “If sufficient differences exist between the risks on alternative routes (e.g., 25 percent or more), it may be possible to designate the preferred hazardous materials routes on the basis of the mandatory factors and the risk calculations” “subjective factors are useful for tie-breaking decisions...typical subjective factors might include the locations of emergency response teams and their ability to respond to hazardous material releases, the locations of semi-ambulatory or pre-school populations...and the locations of sensitive ecological areas...(e.g., watersheds and reservoirs)” [28].

For a study in the Dallas-Fort Worth area, the following modifications were made:

- “* Replacing manual computations with an automated system based on data base analyses”

- “* ...the fraction of all accidents that involve a hazmat release (FHZ) was ignored, because it is constant for all alternative routes.

- * The property damage consequences of hazmat releases were not considered due to lack of data on land use. However, both population and employment were considered...”

- “* The impact area ...within 2 miles...was considered.

- Map overlays were developed ... for consistent application of the subjective factors” [28].

Portland, Oregon conducted a hazmat routing study, also based on the FHWA routing method. This study focused initially on three categories of shipments: (1) local deliveries (abandoned as being infeasible), (2) access to industrial zones, and, (3) through shipments [26]. Also, the impact area for the Portland study was only 1/2 mile in diameter. This was believed to be appropriate from a standpoint of evacuation.

A third study, also based on the FHWA routing method, was conducted in Columbus, Ohio. This study identified a need to consider additional objective and subjective factors beyond the results of the risk assessment. These included:

- * “Special populations (schools, hospitals, etc.)
- * Land usage
- * Number of highway structures
- * Operational costs to carriers” [26].

This last factor recognized that assignment of less than optimal routes can increase vehicle operating costs and driver wages for carriers [26]. For most studies sanctioned by public authorities, the costs incurred by the shippers because of rerouting are not used in the analysis, and are usually viewed as simply a cost of doing business. Otherwise, these costs may be used in cost/benefit analyses of various mitigation alternatives.

3.2.10 Canadian Route Screening Method

The most widely known variation on the FHWA model has been the Canadian Route Screening Method developed by Transport Canada. “The geographic scope of routing decisions was considered to be less than 100 kilometres” [48]. Numerous modifications have been incorporated in this method, many of which have been endorsed by MRI, either in whole or in part, for inclusion in the revised FHWA procedure. Logical presentation of the methodology is given in a consultant’s report, while computation sheets for repetitive calculations appear in a separate workbook. It is here where the practice of multiple procedures for multiple level users, subsequently endorsed by MRI, was first introduced. “Another feature that this

approach provides is the ability to conduct the evaluation in stages or rounds” “rounds continue until options are clearly identified, or until the users are satisfied with the level of confidence the results provide” [48].

One key to the correct use of all of these methods is mentioned in the consultant’s report. “Alternatives (i.e. routes) must be clearly identified and labeled...Users should be able to add or eliminate route alternatives at any time in the evaluation...each route alternative (should) be given a number and be characterized in terms of:

- * Length
 - * Roadway included
 - * Travel time
 - * Written description...
 - * Circuity
 - * Current use by DG vehicles
 - * Origin
 - * Physical constraints
 - * Destination
 - * Legal constraints”
- [48].

The Canadian method follows the FHWA method in excluding those routes which have either physical constraints or legal constraints which prohibit shipments of the type being studied. One distinction here is that the FHWA model does not consider circuity or any form of additional shipper expense incurred by rerouting traffic. “Circuity is an important factor where the final solution is not only expected to enhance public safety, but to retain the efficiency of the transportation network, as well” [48]. In situations where large circuity or other detriments make alternatives seem impractical, the Canadian method suggests retaining such routes until the final evaluation is completed. “No route will be perfect and eliminating some marginal options from evaluation reduces the opportunity for tradeoffs, which may be important in enhancing public safety” [48].

Different kinds of routes are classified in the following manner:

- “* Urban street
- * Urban expressway
- * Rural road
- * Rural freeway” [48].

In addition to different kinds of roadway, the Canadian method documentation makes the point that the procedure can compare routes which serve different parts of the highway system. "The method presented in the Workbook be used to compare routes that serve different end points. This may be desirable when researchers are, say, searching for routes within a community where dangerous goods should be prohibited" [48]. This is also necessary for our objective of comparing risk levels on a statewide basis.

As with the FHWA practices, the Canadian method employs default probability equations to predict accident rates in terms of accidents per vehicle travelling on the route. The default rates are established for each highway type recognized in the procedure. The FHWA default probabilities were adjusted as seen fit and incorporated into the Canadian screening method. At the highest level of detail, the default equations consider a number of route parameters (e.g., "average annual daily traffic (AADT)", "number of heavy volume intersections per mile", and "number of signalized intersections per mile" in the urban arterial model). These parameters should not, however, be considered comprehensive. The Canadian screening method report lists 18 separate parameters which affect the probability of a hazardous materials accident. At least ten of these parameters can be considered route characteristics.

Likewise, factors which influence the determination of levels of consequences (i.e., types of exposure) may also be developed. The Canadian screening method report lists 22 separate parameters which affect the consequence levels of a specific hazardous materials accident. For the most part, these factors pertain to specific incident information, and so are to be considered in operations modeling where such information can be stipulated. Parameter values were always to be obtained for each community (i.e., no default values were used)."(The Canadian screening method is)

a method that did not tie users to national 'norms' (such as population density)...risk assessment methods recently applied in the U.S. (which relied on default statistics) appeared to lose sensitivity at the extremes, such as in communities of very large or very small population densities" [48].

Exposure corridors are determined in the same fashion as in the FHWA method. "An appropriate hazard radius or corridor width depends on the type of product and the potential volume released" "...products, like propane, can cause death and injury more than 1,000 m from a release site" [48]. These figures represent the total exposure of the corridor (i.e., there is no dividing by the route lengths). "It is assumed that an accident could occur anywhere along a route; a band of influence is therefore possible by extending the sphere of influence radius along the entire route on both sides of the road" [48].

The measures of exposure used by FHWA are reported in the Canadian method using different means to obtain data at the three different levels of detail. To determine population exposure the Canadian screening method relies on: "general population density figures", "land use information", or "census tract information" for increasing levels of analysis sophistication. Building replacement costs are derived on a \$/linear meter basis by multiplying the cost per square meter by the average floor area and average number of floors and then dividing to obtain a building replacement cost, and then dividing by the square root of the average floor area to convert to the correct units. "(At the simplest level of detail for property exposure estimation) the user simply uses an odometer while driving in a vehicle to estimate the distance in meters of representative land uses along both sides of each route option" "(The intermediate level of detail for property exposure estimation) adds a measure of confidence by incorporating the value of route structures and special properties..." "(The highest level of detail) increases the reliability of the analysis by

allowing users to establish local representative property values for each land use type” [48].

Also the Canadian method presents a slightly more formal way of comparison for one of the FHWA subjective factors. Measures are developed for what is termed “environment” exposure. “General measures of environment exposure include hectares of marine waters, rivers, creeks, and wetlands exposed...” “...(More detailed environmental exposure measures include) information on aquifer (groundwater), wildlife and sensitive vegetation...” [48]. The highest level of detail for environmental exposure measurement includes:

- * tidal flats and estuaries,
- * sloughs and tributaries,
- * seasonal wildlife,
- * special habitat,
- * wildlife diversity,
- * unique vegetation, and
- * representative vegetation” [48].

At the highest level of detail, there is an arbitrary weighting scale to reflect the perceived importance of each environment category. Otherwise, at all levels of detail, the total number of hectares of environment (of all types) is compared. Such efforts are laudable, although completely arbitrary. The assigning of relative weights to the different kinds of environment considered is clearly a policy decision to be left to users in an interactive environment. However, the wide variety of environments with different exposure implications means that the average user will be making uninformed decisions in the regard. Also, different measures of exposure have different relative weights in different geographic regions. If users are to be able to customize the weighting system adequately, there is a corresponding potential for large amounts of input. The matter receives additional significance because of the high value attached to environment exposure in the Canadian method. “The (Canadian screening method) consultants take the view that while property may be

restored or replaced, environment, like people, often cannot be replaced and may suffer permanent damage” [48]. Also, “It is suggested that for deriving values for parks and open space the environment exposure method be utilized since the property exposure approach is concerned primarily with building replacement costs” [48].

A second FHWA subjective factor, special facilities, is given a brief, but dissimilar mention in the Canadian method. In the Canadian screening method, special facilities are considered to be those places with: “sensitive populations”, “dense concentrations of people”, or “difficult to evacuate populations” [48]. Here, special facilities are considered to be additional populations to be incorporated at the highest level of detail. In order for this assertion to be valid, our consideration of special facilities would be limited to the populations contained by the facilities, without including the facilities themselves.

Unlike the FHWA model which considers community response capabilities as a tie-breaking factor, the Canadian method incorporates quantitative response capability assessment at all levels of detail, thus making the results measures of vulnerability. The response is measured in terms of units available (fire, police, etc.) within a common period of time. Such information would have to be either gathered from officials of the various response organizations or developed through mapping for every route in the system, thus making large scale assessment with this technique virtually impossible. Also, different types of response capabilities are combined in a single measure of response using an arbitrary weighting scheme. In the Canadian screening method, fire company response is assigned four times the weight of police car response and ten times the weight of ambulance response. Further, when all contributing factors to the risk values are combined, “...the tabulated results of each risk factor are assigned abstract numbers” “This number was selected to make

comparisons easy...” [48]. It seems clear that, for a statewide analysis using interactive computer modeling, a more efficient means of incorporating response measures must be developed. It is the author’s contention that the use of arbitrary weighting systems for data inclusion or results represents an obscuring of the data and is to be avoided if possible. Such decisions should be left to the user, and should not exceed his level of expertise. The Canadian method recommends a team approach to the use of their model. “Although a single person could complete the analysis presented here, a recommended team would include representatives of the following groups:

- * Planning agency
- * Fire service
- * Emergency measures agency
- * Motor carriers
- * Chamber of Commerce

Including a number of agencies in the route selection process offers the advantage of several perspectives and increases the confidence in and acceptability of the results” [49].

3.2.12 SAFETI Computer Model

An interactive computer program for determining risks at hazmat processing plants was recently altered to consider the risks which occur during transportation. This model, called the “SAFETI” model, provides some useful insights into various aspects of the risk modeling and output format techniques. The actual SAFETI package, however, does not provide statistics for jurisdictions as a whole and loses significance for larger areas under consideration. “(In converting this package from

process plant to transportation applications) the 'cell' size can be changed to, for example, 200m by 200m, allowing the overall area to be increased to 40km by 40km. This loss of precision is relatively small, but it will increase in degree if the cell size is further increased" [16].

The objectives of the package which pertain particularly to computer modeling are generally recognized as worthwhile goals and are, for the most part, reflected in the MacroRADSS design. These include: "1. Ease of data input (it is interactive), 2. Reasonable speed of processing (dependent on machine), 3. Minimum loss of detail, 4. Variable level of data input/output to suit needs, and 5. Visibility of both intermediate and final results" [16]. It should be remembered that results should be for parameters and in units which the user can interpret. Also, the relationship between results needs to be well documented for the same reason.

In order to accomplish these objectives, certain simplifications in the modeling were necessary. "(One simplification) that is incorporated is the use of clustering, or the grouping together of events of approximately similar size into one event with a combined probability of occurrence" [16]. While it is beyond the scope of the work to consider the grouping of individual hazmats into classes, it should be noted that such groups must be dependent on material properties as well as the predicted outcomes. This is necessary in order to make classifications logical and account for degrees of variability in release outcomes.

Another simplification is that package failure rates are based on user-defined historic failure trends. "(SAFETI uses package) failure (f) rates based on the input f/km/yr" "special high (or low) risk locations can easily be identified, (e.g., grade crossings) and different failure rates input for these" [16]. These rates may or may not be available from the corresponding accident data information. Also, in order to be most useful, the user has to disaggregate the historic data by all model variables

which prove to have different failure levels. This requires an ongoing effort on the part of the user to interpret his/her incident (or, more likely, accident) data prior to objective modeling.

Simplifications may overshadow the sophistication of other portions of the model. As an example, features of the consequence analysis include: “a heavy gas dispersion model”, “probability profile(s) for certain identified levels of (acute) toxicity” “flammable effects are similarly predicted for certain levels of thermal radiation or overpressure,”, “predetermined algorithms...link human impact with dosage received...” [16]. When we use probability functions to relate exposure measures to actual effects on people, property, etc., we delve into predicting consequence levels. Such relationships are not widely accepted at present. The variety of output formats is desirable and the types used are similar to those developed for the MacroRADSS program. “The principal results can be displayed as:

1. Degrees of consequential effect (without the probability determination)
2. Individual risk rates (fatalities per person per year) displayed either geographically by a coded matrix, or as iso-risk contours derived from this; and
3. Societal risk (F-N) curves that display frequency (F) of killing N or more people...” [16].

The second and third methods reflect the probabilistic functions used to compute consequences, as stated above. If such were not the case, then curves of the third method would be reduced to points indicating the probability of exposing N people in a given jurisdiction over a given period of time. One final note, the reader should understand that the term “iso-risk” is applied here differently than as it will be presented in the MacroRADSS method. Iso-risk here refers to geographic boundaries similar to temperature divisions on a weather map.

3.2.13 U.S. Coast Guard Model

The U.S. Coast Guard has traditionally held a major role in helping communities deal with hazmat accidents. It is the Coast Guard which operates the National Response Center "...where hazardous discharges are reported..." [35]. Additionally, the Coast Guard has developed a computer based vulnerability model. "Its (the U.S. Coast Guard's) hazards assessment computer program...is available for community emergency response planning. The computer can be used to simulate the kinds of incidents that might occur in a community so ways can be developed to handle them" [35]. This model specifies a particular type of incident scenario, so it would appear to be less suited for general risk studies for streets and jurisdictions.

Here again, we have a model which seeks to provide greater detailed results through determining actual consequence levels. The approach is different in that it uses controlled test data; however, the ability to make accurate predictions is still questionable.

From 1975-1979, the U.S. Coast Guard developed a vulnerability model that includes probit equations for these gases (common toxic gases, such as ammonia and chlorine), for example, equations that indicated the probability of death for a given concentration and duration of exposure. These are really based on limited and often old animal test data [16].

3.2.14 Raj and Glickman Railroad Model

The purpose of the Raj and Glickman model is to be able to develop risk profiles for various railroad lines as a means of comparing risk levels for different sized hazmat shipments. By combining the profiles for different hazardous materials (for

the initial study, chlorine and liquefied petroleum gases were used), general measures of risk may be developed. Risk profiles are determined by plotting the frequency of a given number of rail cars releasing their contents versus the consequence of releases of that magnitude. "It is assumed conservatively that when there is a release from a car all of its contents are released" "the probability that N_x of the N_t cars contain (hazardous material of type) 'x' in a randomly selected train is assumed to follow a Poisson distribution" [34]. In the case of highway accidents, an analogous situation may be, as an example, the breaching of individual compartments in a multiple compartment tanker truck.

The probability of any certain number of cars releasing hazmats in an accident scenario is represented by a series of conditional probabilities and "can be computed sequentially from a number of other estimated constituent probability distributions that have to do with the size and makeup of the train, the severity of the derailment, and the impact of the derailment on the hazardous materials cars...this sequential approach has the advantage that sensitivity analysis can easily be performed later by varying any of the constituent probability distributions..." [34].

"The approach also relies on a number of consequence models for the various scenarios under which the hazardous materials of interest may be released...these models are combined with the population exposure estimates...in order to estimate the associated fatality levels" [34]. The consideration of loss of life as the only measure of consequence circumvents the traditionally controversial subject of the value of human life in terms of other measures. However, in doing so we neglect other measureable quantities of importance.

Calculation of risk in terms of the expected magnitude of consequences is then performed for the specific scenario. "The expected magnitude of this (loss of life) consequence may be estimated by multiplying the expected density of population in

that area by the expected size of the lethal area. To be precise, the population density factor should include any on- scene professionals (train crew, fire fighters, and related emergency personnel) and the time of day should be taken into account..." [34]. The establishment of different risk levels associated with different types of personnel (e.g., truck drivers, first response personnel, etc.) was not found in this report's survey of current risk modeling practices. The inclusion of computations to recognize such personnel was therefore not considered for the MacroRADSS model.

Having developed their model, Raj and Glickman concluded by conducting sensitivity analyses on the parameters. "Sensitivity analysis of the chlorine and LPG risk profiles were performed to evaluate (independently) the effects of reducing the release probability (Px) and conducting emergency evacuation" [34]. This was accomplished by varying input parameter amounts and observing the corresponding changes in intermediate and output variables.

3.2.15 Saccomanno Model

Apart from the Canadian Route Screening Method, a second Canadian model was developed by Saccomanno et al. to evaluate various routing considerations for the City of Toronto. Here, the attempt was made to obtain actual consequences rather than exposure values. "(For Toronto) Saccomanno et al. concluded that traditional methods of risk assessment were lacking because they considered the number of persons or the amount of property potentially exposed to a hazmat release, but not the probability that the exposed persons or property would actually

be harmed by a release” “thus the spill impact area is itself a variable whose probability distribution should be considered. Therefore, Saccomanno et al. used a fault-tree approach to try to integrate these variabilities along routes and select the minimum risk route” [26]. The use of fault trees here, as in the other methods which employ them, is meant as a means of cataloging and grouping the various release scenarios. “In general, a fault tree represents a deductive failure mechanism” [41]. The reader is referred to the previous review of general model characteristics for more discussion of fault tree usage.

In a sense, the Saccomanno model does not fit the standard definition of a risk model because the results are expressed as probabilities. “The ultimate objective of the analysis is to estimate the probability of occurrence of a system failure subject to a sequence of preconditioning or prior events” [41]. The definition of the threshold for “system failure” gives us our understanding of the level of consequences we require. Since this only considers one level of consequence, it is a less informative approach. The benefit gained in doing this is that other variables in the model may be used as the standard of comparison. “The evaluation found various paths between points in the highway network including minimum time routes, minimum truck operating cost routes, and minimum risk routes” [26]. Four routing strategies are considered: minimum truck operating cost, minimum truck accident rate, minimum spill damage potential, minimum objective risk exposure. “Comparisons against minimum- operating-cost routes indicate the trade-offs between the benefits to society and the costs to the trucking industry” [41]. These alternative measures were not required in the MacroRADSS objectives, so this approach is inappropriate. Also, as previously stated, the consideration of truck operating costs in routing is not a concern for many government-related applications.

To compute the probability portion of the risk expression, default accident rates are used. The default accident rates are disaggregated according to available classes which influence the accident rate. "Both accident likelihood and consequent damages are assumed to be affected by random environmental influences. As a result, estimates of risk exposure along specific links (routes) of the road network must account for variations induced by...these influences" "Two types of random environmental influences are considered in this (Saccomanno and Chan) paper: deterministic influences can be controlled through specific planning and design options. Stochastic influences, however... remain essentially unalterable in nature" [40]. Once disaggregated, comparison of accident rate values provides some indication of the parameter's actual influence. "Two contextual factors were found to significantly influence truck accident rates, namely, geometric design and weather" [41]. "Accident rates were estimated for different environmental conditions, including both dry pavement and wet pavement, and the minimum- risk routes were found to differ under dry and wet conditions" [26]. The use of different accident rates for different weather conditions is therefore a valid modeling approach when using default accident rates.

To compute the consequence portion of the risk expression, actual measures of consequences (e.g., fatalities, injuries, etc.) are estimated. First, the impact area is determined using specific scenario information. "For each spill, the consequent damages are estimated in terms of several impact propagation relationships. These relationships estimate the magnitude of the affected area as a function of the release rate, duration of release, wind speed, material toxicity, and concentration" [41]. Next, the exposed populations and property within the impact area are determined. "The population density employed within the model is a weighted sum of the residential and employment population in an area for a complete 24-hr day" [41].

Once the exposed populations and property are determined, the expected number of fatalities, injuries and property damaged are computed. "Analysis of 140 accident profiles from FHWA records from 1973 through 1979 provides an estimate of the proportion of accidental spills that result in fatalities, injuries, and property damage" [40]. "Essentially, in this aspect the long-term effects of dangerous goods spills, such as any carcinogenic effects, are ignored. Exposure to long-term effects is frequently correlated with immediate population impacts" [41]. Cost of the accident incurred by the shipper is not considered. "Accident costs (to shippers) occur too infrequently and too randomly to be perceived..." "a large component of the damage from specific accidents may be shared by the trucking industry as a whole through universal insurance premium increases" [40].

Although the computing of actual consequence levels is not universally accepted, the key controversy in using this model is probably the way in which the consequence measures are combined. In the Saccomanno model this is in the form of a total incurred cost. The "total cost of damage on link k from toxic impact C_k , contains variables C_i and C_f which represent the average real cost value of injuries and fatalities, respectively" [40]; thus requiring a dollar equivalent cost for personal injury and loss of life. Dollar values for bodily injuries and human life are at best complex political and philosophical questions. They can not reflect the irreplaceable nature of people relative to property. Consequently, other methods which avoid such abstractions are to be preferred.

Even so, some of the conclusions reached in the initial application of this model have far reaching implications for future model development. Results of Saccomanno's modeling:

- 1) "Accident costs are not significant in relation to either risk or truck operating costs and can thus be ignored"
- 2) "...minimum accident likelihood strategy is not cost-effective"

- 3) "...minimum accident likelihood routes consistently yield both higher risk values and, in most cases, higher operating costs"
- 4) "Environmental conditions...(dry vs. wet pavement and restricted vs. unrestricted visibility) do not generally appear to alter these cost trade-offs to any large extent" [40].

Ignoring accident (in system) costs simplifies the task of determining the property damages incurred. It would also seem from these conclusions that furnishing accident likelihood values should be prefaced by these observations with the suggestion that such concerns be kept in mind before using such data for routing. Finally, our previous consideration of weather conditions appears to have little significance in the relative ranking of multiple route segments, and so can be ignored.

3.2.16 Kansas State University (KSU) modeling

In 1986 a technique for small communities (i.e., population under 50,000 people) to evaluate their overall risk and vulnerability to hazardous materials accidents was prepared at Kansas State University. This method introduced new data gathering and interpretation techniques which will be discussed below. It should be mentioned at the outset that this model has different objectives from MacroRADSS and so modeling techniques are substantially different. The KSU model is not concerned with the calculation of different risks and vulnerabilities for streets within a jurisdiction nor for necessarily comparing multiple jurisdictions. Rather, the model is intended to give a community some idea of its degree of risk and vulnerability on an absolute scale.

Perhaps the strongest feature about the model is its exhaustive treatment of data collection techniques for municipalities. The first of the data gathering steps

requires the collection of topographic maps, aerial photographs and prevailing wind data. In the second step, this information is augmented by locating those businesses that manufacture or store hazmats in quantity. The purpose here is to identify the quantity and types of hazmats which remain for extended periods in the community. This is conducted through the moderately effective methods of mailing survey forms followed up by telephone interviews for those who don't respond. The point of including such a term must be considered cautiously as we are departing from the consideration of hazmats on the highway network. Consideration of such situations as industries that keep continuous stockpiles, additional containment afforded by stationary hazmats, etc. are necessary when our concern is not limited to the highway network. Other information regarding flow data for all hazmat types for all modes of transport is then required for final analysis.

The types of information referenced above should be available to most if not all localities in the United States and should be very easy to interpret for smaller jurisdictions. The problem here is in the size of the data required for statewide analysis and the amount of time required for data interpretation in combining the data into its final format and in the subsequent analysis. Consequently, none of the items requested can be used in the statewide approach we've chosen.

Analysis continues by physically drawing the impact areas associated with each route on land use maps of the jurisdiction. A one mile corridor width is used even though different hazmats have different areas of effect. Also, the corridor is centered over the roadway even though topographic and wind data may have been accumulated. The boundaries of one mile long segments of this corridor are arbitrarily chosen so that the limits of exposed, developed property may be determined. This is done so that a risk per unit mile term may be obtained although that fact is not explicitly stated. The approximation is a crude one in that the nearest

whole mile of route is used. For small land area jurisdictions and those with hazmat traffic routes under one mile long, this error source may yield nonrepresentative values for consequence terms. Also, the definition of “edge of a city’s growth” must be set forth in the method description so as to facilitate correct interpretation for cities with green belt zones or large parks or agricultural facilities.

Next, a “risk subfactor” is determined which, in reality, reflects the likelihood (or probability) of a certain, given level of hazmat effects of a given nature to occur for the city as a whole. It attempts to consider all modes of transport by gathering flow data on each mode and obtaining the equivalent number of trucks by an arbitrary scale. Once again, when such considerations occur within the model, we leave the realm of the highway network with the associated ramifications as previously mentioned. If a material is capable of more than one type of release, flow data for these types of hazmats are multiplied by the number of such types of release (1,2 or 3 in the present model). This does not consider the different properties of these different types of release nor does it consider the relative likelihood of each type of release occurring.

The other component of risk, the “consequence subfactor” is then computed in similar fashion to the MRI modified FHWA methodology which is the basis for the MacroRADSS technique. Here, the units are: people per mile of route, average percentage of route’s impact area covered by water, total “land use values” (an arbitrary scale for equating different types of land use) per mile of route, and a modified number representing the number of hazmat manufacturing and storage facilities per mile of route. The modification here is to equate various facilities of different size and proximity to each other. It should be pointed out that not all surface water is used as potable water supplies, nor do all support the same degree of fish and wildlife, etc.. The KSU approach is commendable for the quantitative treatment

of such a variable, however, the assumptions for this modeling approach should be spelled out for clarity's sake. By the same token, the coefficients used in the last two parameters mentioned should be recognized as completely arbitrary conventions used to combine different forms of these measures. Over and above this, these forms are added to produce a "consequence factor" thus assuming that each unit is of equal importance in the model.

Having obtained what amounts to the probability and consequence halves of the risk expression, we obtain the risk value called the "Risk Index" by multiplying the risk factor and the consequence factor together. From this we obtain what is called the "Level of Risk" (low, medium or high) as our rough indication of the community's risk from hazmat transportation. As a deciding factor between municipalities, such terms are too crude to be of use. Indeed, for the trial run conducted by the university staff, all of the communities analyzed were found to have moderate risk levels. Considering the extent of the data collection efforts required to conduct the analysis, the degree of sophistication of the output is a major shortcoming.

Continuing, the vulnerability assessment concerns an additional statistic called the "Level of Preparedness" which is obtained as the result of a survey of the leaders of the local response agencies and, perhaps, local hazmat industry officials. Questions asked are answered with either a yes or no response. From the consensus response to such questions, the total number of no responses are tallied. With an equal weight assigned to each question, this sum produces the level of preparedness value (also low, medium, or high). Knowing the risk and preparedness levels, we enter a table which determines the final "Community Vulnerability Level" (low, low to medium, medium, medium to high, or high). Such an exercise is equally crude as the previous risk level obtained. To its credit, the model does produce risk and vulnerability values which are easy to interpret but of limited worth. In obtaining

this level of preparedness value, questions were posed which were factual in nature. However, by the nature of the survey technique, we still incorporate some degree of subjectivity into our assessment. This becomes clear in the case where those responding report different values. This is also the case when we consider that all of the survey questions are weighted equally when they pertain to different response concerns.

4. MODEL DESCRIPTION

4.1 Introduction

The MacroRADSS risk and vulnerability assessment model was developed at Virginia Polytechnic Institute & State University under the sponsorship of the Pennsylvania Department of Transportation. The computer code for the model was developed using Microsoft Inc.'s QuickBASIC version 3.0 using an IBM PS/2 model 50 with one 3 1/2 inch disk drive and a 30 megabyte hard disk drive. A microcomputer was chosen as the data processing tool instead of a larger system for two reasons; accessibility of the equipment by most state agencies, and relative ease of data transferability. [33] In form and in function, MacroRADSS most resembles the FHWA model as it stands modified by MRI. The configuration of the MacroRADSS model, as seen in the overall flowchart (Figure 4-1), is in distinct modules (each module being of the type: probability, consequence, response, final calculations, or output). To simplify the presentation of the computer code, each module resides at separate locations within the main program or in separate subprograms (please see Appendix A for a listing of the computer code). To simplify the following discussion of MacroRADSS, the remainder of this chapter is divided according to the module types mentioned.

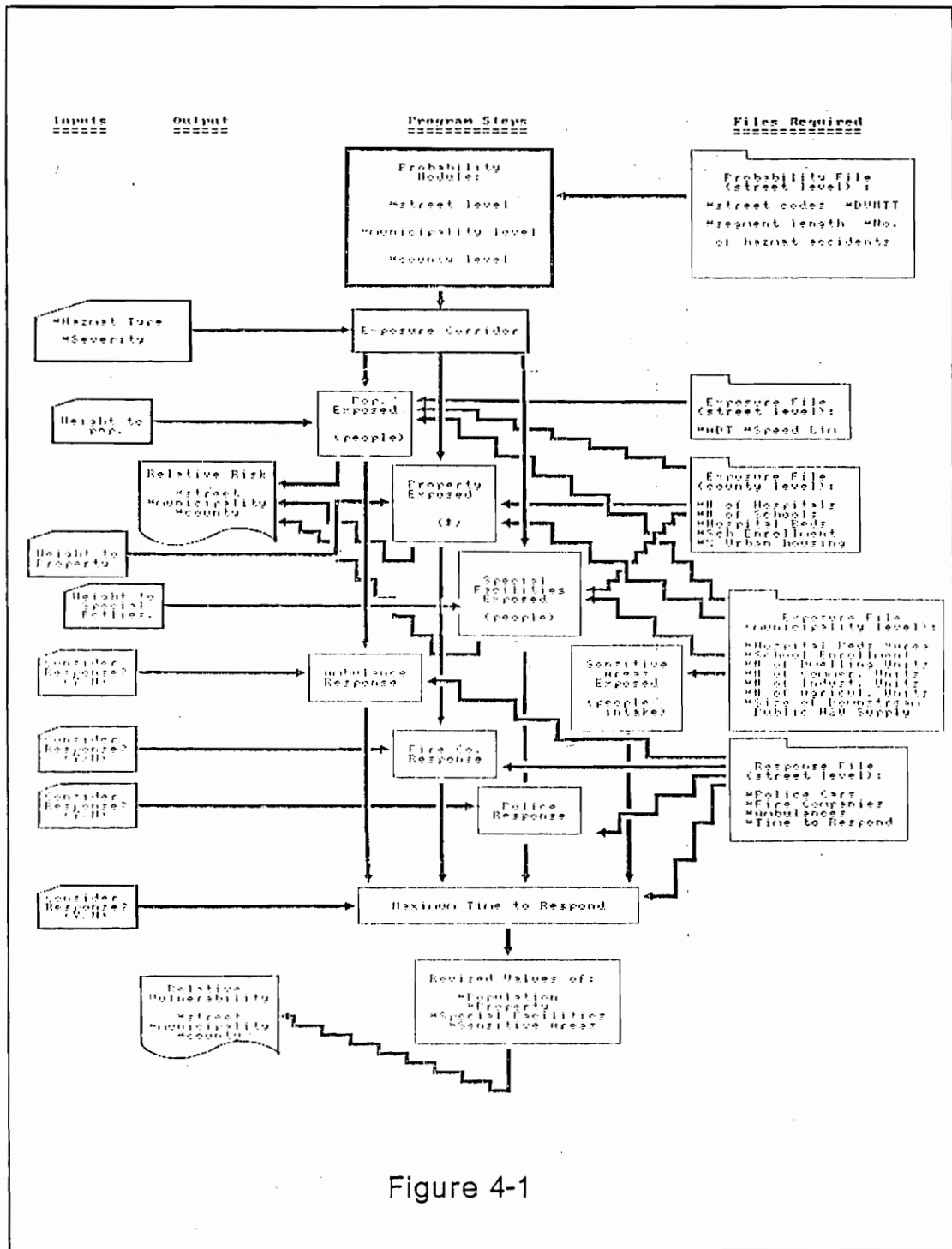


Figure 4-1

4.2 Probability

From the previous review of existing data sets available at both the national and state levels (Section 3.1), it was determined that the best approach for modeling would be to use state accident records to obtain accident probabilities. In MacroRADSS, this data is used to determine individual accident (as opposed to default) probabilities for the routes reported. In terms of route ranking, this is an important point as we here assert two fundamental observations of our approach. First, that the variation in accident rates for different routes of the same route type (due to geometric and other factors which cannot be incorporated) is sufficiently large to avoid using default accident rates for these routes. While this may mean the failure of the model to find risk in routes with no reported accidents during the period of record, a growing period of record will imply that such accidents are increasingly rare events. The use of these routes is also the only means of excluding the nonhazmat traffic routes without extensive hazmat flow information. The second point to be identified from the modeling approach is that we are using historical data to model present behavior. Here we must point out the conclusion of the Environmental Quality Council (U.S. Department of Commerce): “there does not appear to be any compelling reason to think accident occurrences will deviate substantially either up or down from the ‘best-fit’ extrapolation of the past data (but can be affected by such factors as increased speeds and changes in highway condition, etc.)” [55].

Since corresponding flow data does not exist, default flow rates based on the highway type are used to translate total truck flow into hazmat vehicle flow. Since national data is used and further aggregated to fit Pennsylvania’s road type classifications, it is doubtful that these values will change substantially over time.

As a result, these values are embedded directly in the program code and are left to be updated with subsequent releases of the program. Similar treatment is given to modeling the percent of hazmat accidents which result in a release, since Pennsylvania does not record hazmat release information. Both types of information are gathered from the 1984-1985 BMCS data (see Appendix B).

The objective of the probability module is to determine the likelihood of any hazmat-carrying vehicle traveling on a certain road to have an accident which results in a release of hazardous cargo. Because there is insufficient data to determine accident rates for each type of hazardous cargo for each route in question, the probability determined is the collective probability for all classes of hazmats. As a result, the computation of probabilities is not contingent upon input from any other part of the model and thus is performed as the first step of the model. Insufficient data also means that the probability obtained is a deterministic value (i.e., not a confidence interval of probabilities). This single value is expressed as follows:

$$PS_i = \frac{[(release)_j(\#hazmatacc.)_i(length)_i]}{[1,927,200(N)(DVMTT)_i(hazmattrucks)_j]}$$

where PS_i is the probability of an accident resulting in a release for a given street "i", $release_j$ is the percentage of hazmat accidents which result in a release for street type "j", $\#hazmatacc._i$ is the number of hazmat accidents recorded for street "i" during the period of record "N", $length_i$ is the length of segments which comprise the hazmat routes within the municipality borders (where segment end points are dictated by standardized criteria) expressed in feet, N is the period of record of the available accident data expressed in years, $DVMTT_i$ is an acronym for daily vehicle miles of truck travel for street "i" expressed in truck-miles per day, and $hazmattrucks_j$ is the percentage of hazmat trucks in the total truck flow (as

approximated by BMCS accident information) for *roadtype_j*. As one might suspect, the coefficient is used to account for the different measures of time (days vs. years) and distance (feet vs. miles). Two possible real world interpretations for our street level probability exist. First, we may say that, if a truck carrying hazardous materials is travelling on the particular street segment "i" in question, then the probability of the truck having an accident where the hazardous cargo is released based on the historic data for the segment in question is "*PS_i*". We may also consider this parameter to indicate that, for a given hazmat truck volume "*V*" during the period of record "*N*", we would expect to see *PS_i* times *V* number of hazmat release accidents (which was the case during the period of record).

In the above expression, the segment end point criteria lends this term most easily to obtaining values as they are presently available from PennDOT, and is meant to prevent the assignment of arbitrary route lengths. Of course, if it is suspected that certain portions of a route are particularly at risk or vulnerable, the route may be subdivided so long as the corresponding accident, route length, and flow (DVMTT) data are correct for each segment. By the MacroRADSS criteria, segment end points occur when (1) municipality borders are encountered, (2) an intersection/interchange occurs with an interstate, U.S., state primary, or state secondary road, (3) locations of different street names or route numbers are encountered, or (4) locations when different segment lengths are reported in the accident data set.

To read the probability portion of the computer program given in Appendix A, a few additional concepts must be introduced. First, the accident data required here (as well as exposure and response capability information) which changes over time and can be manipulated by the user, is accessed in the form of random access files read in their entirety from user-specified files on a floppy disk, while the program

itself and certain intermediate data files reside as hard disk files. This convention was chosen for smoothness and speed of operation, and may be altered by changing the program's code. Also, certain variable spaces in the random access files are left for bookkeeping parameters (e.g., street name, age of oldest data on a data line, etc.). Another item to be kept in mind is that street codes are developed within the program as 11-digit labels for individual streets. The first five digits are the municipality code, according to PennDOT, where the street is located. This follows the convention of PennDOT in that the first two digits of their municipality codes are the county code where each municipality is located. The final six digits of the code consist of the four-digit route number with a two-digit extension. The extension helps distinguish between disjointed routes (typically required for routes without route numbers reported as "0000" and "9999"). It also allows the user to subdivide routes within municipalities, as discussed earlier in this section. One final item to be kept in mind is that variables beginning with the letter P (and later with Y) are double precision variables carrying more decimal places in order to make the chances of duplicate risk or vulnerability levels less likely.

Consequences

Regardless of whether one is computing actual consequences or exposed people, property, etc., the size of the area of effect of the hazmat released is contingent upon the type of hazmat involved and the severity of the release. TMS Inc. was charged with the task of developing these type classifications for the MacroRADSS model and providing the associated areas of effect for different degrees

of release severity for each class. The results of their work are published under separate cover [63]. In considering different hazmats for risk comparisons, there is usually no stipulation of a single material or group of materials to be the basis for route comparison. Usually required is a general impact area which reflects some reasonably sized area for the most common materials. Such an area may be found by selecting one of the 26 classes developed by TMS or by stipulating a predetermined impact radius magnitude. The use of individual hazmat classes is best suited for subsequent risk comparisons to verify the reasonableness of the ranking determined by the above method.

If one of the 26 hazmat classes put forth is chosen, then the severity of the accident is requested. The term "catastrophe" indicates that we are considering the maximum potential impact area for a release of the commodity with average properties for the class chosen. The term "moderately severe" means that we are considering the average impact area size for the same commodity. The term "not severe" means that the effects of the release have been limited to the roadway and its users.

The objective of the consequence portion of the MacroRADSS program is to determine the total number of people, dollar value of property, and size of other categories of damage which are exposed to a specified release for each route under consideration.

The methodology employed is that used in the FHWA and MRI revised models. First, total values of the exposure measures are determined for each municipality in question. Then, for each route, the exposures are found by multiplying municipality totals by the ratio of its impact area to the municipality total area. Here jurisdiction exposures are simply the sum of the route exposures they contain.

Since the program determines impact areas at the statewide level, it is impossible to make such areas dependent on wind behavior or local topography without requiring excessive supporting data. It has been suggested to use only the area on one side of a street, making sure that it is always the more densely developed side. However, this would presume an extensive knowledge of land development (e.g., zoning, etc.) for all routes, and would also require excessive data. It also assumes an abstraction; that we can equate different types of land use. Instead, our choice of impact area must be centered over the roadway. Since we are comparing routes, we are comparing the total potential damage for all locations on each route. Consequently, our impact area becomes a corridor (see Figures 4-2 & 4-3) which consists of all possible impact area space within municipality borders. The semicircular ends of the corridors are omitted for computational convenience. Also, impact areas which overlap at the intersection of two routes are counted twice.

There is a logical basis for this approach in that most communities have higher levels of development at route intersections. Similarly, corridors that overlap municipal boundaries are considered in their entirety. In this case, however, there is a diagnostic step in the model which compares the size of the total impact areas for all routes in a municipality with the municipality total area. If the total impact area is larger, then the individual route areas are reduced sufficiently so that their sum equals the municipality total area. This is to prevent excessive counting of areas outside of municipality boundaries and/or redundant counting at intersections.

The first measure of exposure considered in the computer program's execution is population. The different types of population considered by MacroRADSS are the indigenous (i.e., residential, employment, and special facilities such as schools and hospitals) and "in system" (on the route). Because large commuting worker populations may gather to work in one urbanized municipality, it is conceivable that

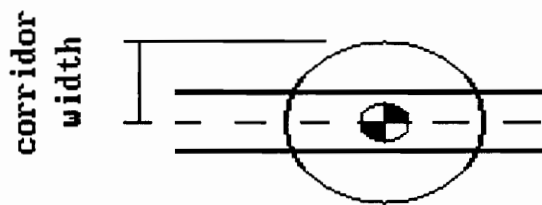


Figure 4-2

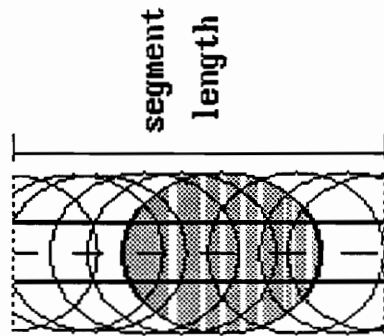


Figure 4-3

where:  denotes a particular incident location

daytime employment population could be larger than the residential population for such municipalities. The MacroRADSS program uses the larger value as it is made available from census data. To this is added the special facilities populations – schools and hospitals represent groups of people that are particularly difficult to evacuate and which also will probably include people from other municipalities. Special facilities populations are obtained by determining the fractional number of such facilities exposed for each route and multiplying by the average population density (i.e., beds/hospital and enrollment/ school) obtainable at the county level from census data.

“In system” population is approximated from the available variables in the Pennsylvania accident records used to describe the routes. These variables are: average daily traffic (ADT) in vehicles/day, speed limit in miles/hour, and segment length in feet. The objective here is to obtain a rough idea of the number of persons using the route in question at a given moment during the peak hour.

The first step is to distinguish between urban and rural roads as urban roads should experience heavier peaking, slower peak hour speeds, and a slightly higher vehicle occupancy rate. This is determined by establishing if the percent of housing in the county containing the route is greater than or less than 50 percent. If the route is considered urban, then the approximating equation for peak hour flow (PHF) in vehicles/hour becomes:

$$PHF_i = 1/10(ADT)_i$$

If, on the other hand, the route is considered rural, then the equation is:

$$PHF_i = 1/15(ADT)_i$$

where the coefficients are best guess estimates of the relationship between the peak hour and daily flows.

The second step is to use the relationship between speed, flow and concentration to obtain an approximate density of vehicles on the road. In the urban environment this equation is:

$$\text{RoadDensity}_i = \text{PHF}_i / [0.5(\text{speedlimit})_i]$$

whereas for the rural situation, it is:

$$\text{RoadDensity}_i = \text{PHF}_i / [0.8(\text{speedlimit})_i]$$

The $0.5(\text{speedlimit})$ and $0.8(\text{speedlimit})$ are best guess estimates of the average vehicle speed during the peak hour for the urban and rural routes respectively. The relationship is an intuitive one and should be refined for various locations in Pennsylvania.

The final step is to multiply the vehicle concentration by the route length to obtain the total number of vehicles on the route and multiply that by the expected number of occupants per vehicle. This equation is:

$$\text{Insystempop}_i = 1.5(\text{segmentlength})_i (\text{RoadDensity})_i$$

for the urban condition. For the rural condition, the coefficient value of 1.3 is used (both are arbitrary).

The second parameter considered by the computer program is the dollar value of buildings exposed. While some may argue that the cost of buildings is irrelevant when placed beside the exposure of human beings, this is only a convenient unit of

comparison between properties and property loss can also be measured in terms of the loss of shelter or livelihood for people, which is important indeed.

MacroRADSS recognizes four distinct types of development: residential, commercial, industrial, and agricultural. Commercial development includes both office and retail applications. The "institutional" class of buildings (common in other models) in whatever forms they are represented, are considered to be of more intrinsic value and are thus included as special facilities. These four classes are chosen since they are those which are readily available from census data. Information on commercial, industrial, and agricultural development is available at the county level. Until it is available at the municipality level, we use these values adjusted for each municipality by the ratio of the municipality's employment population (or residential population for residential development) to the county total. We subdivide these classes by considering urban versus rural counties (using percent of housing coded urban as before). For each of these eight development types, we then formulate a typical development composition (see Appendix B). This is similar to the "typical buildings" used in the Canadian Route Screening Method, however, this approach uses more than one typical building for each class. Rather than estimate cost for each development type, we consult the 1987 Dodge Assemblies Cost Data book for typical building replacement costs. Having obtained all typical building costs, we can then determine the average replacement cost for each type as a whole. Locality building cost adjustment factors, also obtained from the cost data book, highlight the difference in replacement costs between counties.

Knowing the ratio of the impact corridor size to the total municipality size, we then obtain the approximate number of each type of building exposed. Multiplying by the replacement cost per building yields the total replacement cost for each development type. Adding together all development types yields the total property

exposure at the street level. As one might suspect, municipality and county property exposure is then defined as the cumulative exposure of the streets they contain.

Next, the program considers the third category of exposure, special facilities. In MacroRADSS, we make the decision to measure the size of such facilities by the populations they contain (i.e., hospital beds and school enrollment exposed). While some may get the impression that this is double counting of such populations, we point out that we are not considering populations, but rather the facilities themselves, deeming their replacement cost as an inadequate representation. Since we have already determined the magnitude of these population representation values at the street level, the amount of additional computations required here is minimal.

The final category of exposure considered in the MacroRADSS model is called sensitive areas. This refers to the quantifiable ecological threats posed by hazmat releases. The key word here is quantifiable, since useful measures for such threats are difficult to obtain. Also, no agreed methodology exists for combining the exposures of different ecological threats. We approach the first problem and evade the second in this model's present form by considering only threats to the surface drinking water supply. As has been noted, "because of urban sprawl, the formerly isolated water supplies of many municipalities are now exposed to transportation-related hazardous material spills" "...there have been many instances in which drinking water was contaminated by hazardous material spills" [10]. Ideally, we should be able to locate the nearest downstream water supply from every reported accident location in the state. To do this, however, would require an understanding of local topography which would demand an intricate consideration of each location. This is not conducive to data file creation and maintenance. Also, routes constructed along drainage divides may affect different watersheds at the same location depending on vehicle orientation. Rather, we simply consider those

intake locations within the same municipality as the route under consideration to be exposed by such accidents. Pennsylvania Department of Environmental Resources information on the withdrawal rates at these locations is chosen as the modeling parameter. Since no calculations are performed on these values, they are not introduced in the consequence module (subprogram).

Before leaving the discussion of consequence (or exposure) estimation, we note that those measures of exposure which are dependent on the corridor area are divided by their route length as done in the MRI revised method. The reason this was performed in the MRI revised method was to avoid “double counting” (i.e., consideration) of the route length term supposedly borne out by dimensional analysis. The author takes issue with this logic, however, as the length unit in both the probability term (nullified by the DVMTT term) and the consequence term (an area divided by an area) drop out. Our reasoning instead is to perform the same operation as MRI in order to obtain measures of exposure in the unit of “exposure per unit mile”. In this way, we are able to compare the magnitude of the exposure for different length routes on an equal footing.

4.4 Response Capabilities

To make the change from risk to vulnerability assessment, we must consider measures of a community’s ability to respond to hazmat emergencies. To accomplish this, we must first develop a logical and practical solution to two questions: (1) what measure(s) can be developed that would indicate both the quantity and quality of a community’s response capability, and (2) how would such

values be used to obtain parameters of use in converting the previously obtained risk values into vulnerability terms? Because these problems are dependent on human behavior, there is a limit to the accuracy of models which include such measures. This should be reflected in restrictions on the number of significant digits in the response measures and the degree of complexity in the vulnerability relationship.

In establishing the measures of response, it was noted that the types of response which could be expected to be of interest in judging between communities would be the first-to-the-scene responders (e.g., local police, fire and ambulance services). Secondary response would be more diverse and would consequently be more quality dependent. Also, with greater time to respond, such response as necessary could be obtained in most areas. The important tasks of evacuation, rerouting of traffic, fire containment, and treatment of wounded are handled largely by these first responders. The quantity of each of these responders would therefore be useful. Some measure of quality is introduced here by stipulating that fire response is made by trained and equipped personnel (i.e., trained and equipped for first-to-the-scene response). Additional qualitative stipulations, such as trained police personnel, are of reduced significance if the fire department is designated as the lead agency (one possible product of comprehensive hazmat incident response planning). The units of response are the fire company and police and ambulance units (vehicles).

One other measure of response is reflected in the MacroRADSS model as an overall indication of the effectiveness of a community's ability to respond. This measure is the maximum time for the first responder, regardless of type, to reach the most remote location in their jurisdiction. The value of this measure is in having trained observers on the scene to describe the incident accurately, as well as applying first aid to any critically injured persons. There are, of course, limitations

to what can be done by unprotected personnel, so each type of response must focus on the areas to which they are suited. This last principle plays a very important role in the final vulnerability calculations in the MacroRADSS methodology.

The relationship between response and vulnerability, or rather, the dangers faced from hazmat releases, is constructed intuitively. It is assumed for design purposes that there exists some normative value for each measure discussed. Values above the norm (or below the norm in the case of response time) are then expected to reduce the levels of consequences measured in proportion to the amount of the improvement. The reverse is then held to be true for values of response capabilities below such norms (or above them for response time). Note, the “no response” level is not used as a base value, since absolute measures of consequence have not been developed to provide corresponding values of consequence for such comparisons (i.e., we can only compare relative levels of consequence for different levels of response). The MacroRADSS approach is to use the statewide average values as these normative values for each measure. This means that we are requiring the state average response in all categories measured so that no worse consequence levels will be obtained. Since responders for different counties are required to protect different numbers of people, it would be unfair to require, as an example, the same number of police units for Tioga County (rural) as for Allegheny County (metro Pittsburgh area). For this reason, all parameters (except response time) are divided first by their county populations.

These factors, adjusted by population and compared to their statewide norms, are our factors for converting risk to vulnerability. They are determined at the county level, since they are largely organized at the county level (also, it is conceptually easier to combine local responders in county totals than to divide up the county level forces) and are assumed to apply to all streets and municipalities in the county.

4.5 Risk and Vulnerability Determination

After probability computations, execution of the MacroRADSS program statements passes to two consecutive subprograms, appended to the end of the main program, which are responsible for determining our exposures and response capabilities for each street or jurisdiction based upon the above defined methodologies. Having accomplished that, the execution of program statements then returns to the main program where the probability, exposure, and response values are combined in some format to obtain risk and vulnerability values for the area being studied.

Typically, risk models require either some conversion factor between amounts of the different exposure types they measure, or consider only one exposure type. In the MacroRADSS approach, this dilemma is circumvented by an alternative strategy. Here we recall that we are only concerned with the relative ranking of different locations with regard to risk and vulnerability (not the amounts of those risks and vulnerabilities). As a result, we compare not the exposure types but rather the relative ranking of each location for each exposure type. This is done by dividing each measure of exposure by the statewide average exposure for each type. This accomplished, we combine the dimensionless ratios using user defined weights for each exposure type. The effect of this is to yield a term which expresses each location's ranking with respect to a normative exposure value in whatever fashion the user wishes to combine types of exposure to achieve that normative value.

This combined exposure is multiplied by our previous estimate of accident probability for the street in question in order to generate the risk statistic. These

numbers will be quite difficult to interpret. They are for this reason not made directly available to the user.

In determining vulnerability, models to date have mostly relied on subjective analysis and abstract factors which are not in keeping with our separation of objective (computer based) modeling from final, subjective judgement. For this reason, a new approach was required.

One point of departure from previous models is that previous models typically generated one modeling parameter for the response capability, regardless of the number of different types of responses considered. The author views this as an inaccurate approach, considering the nature of the modeling variables. In such an approach, changes in different types of response will affect the same kind of change in the vulnerability model. This is not reasonable, since different responders have distinct areas of responsibility. As an example, an increased ambulance response would have little effect on the amount of property damage resulting from a hazmat incident. If a particular locality had a sizeable threat to its property with only a small threat to its population, then a vulnerability model should reflect the difference in value of improvements to ambulance and fire company response. Recognizing that there is some small area of overlapping responsibility for different responders, the MacroRADSS approach associates different response types with its different measures of exposure. Here, changes in the level of fire company response are associated with property exposure. Similarly, police response is associated with special facilities exposure, because of their typical duties of evacuation (hospitals, schools, etc.) and rerouting traffic away from damaged highway structures (bridges, tunnels, etc.). Also, ambulance response is associated with population exposure as this form of response offers the most comprehensive aid to injured people. Paramedic response may be included in this category.

Having obtained our risk value, we continue by multiplying each of our exposure measures by the associated risk factor already determined (the sensitive areas measure remains, so far, unaffected). In this manner, those localities with a better than average response for a particular type of response receive a corresponding reduction in their associated exposure level. The reverse is also true if response levels are found to be below average.

The exposure measures are then recombined using the user defined weights as before. Our final response parameter, the maximum required response time factor, is then multiplied with the total exposure value. The logic in this approach is that, as mentioned before, reductions in the time needed for the first responder to reach the incident site will serve to reduce the effects of any type of consequence even if this only means faster identification of the particular threat. For example, if police respond to a hazmat accident where a critically injured person had gone undetected, they may be able to summon an ambulance in time to save a life depending on how fast they had originally arrived.

Having multiplied our final response capability factor into the model, we now recombine the probability term with the revised exposure term. This produces the MacroRADSS vulnerability statistic which is equally difficult to interpret as the aforementioned risk statistic. For this reason, it is also not furnished in the computer model's output. After all calculations have been completed, a sorting routine assigns the relative risk, and vulnerability ranks to the various streets considered.

The above calculations will yield street level risk and vulnerability values. We note that since such values are mathematical abstractions, we must determine what the correct statistic is to represent these concepts when more than one street is involved. At the direction of Dr. Hobeika, this statistic was chosen to be the sum of the individual street level risk and vulnerability statistics, respectively. This is the

case for both the municipality and county levels. Since the street level was considered too refined to be able to attribute sensitive area (read: public water supply) exposure, we incorporate it at these levels by assuming, conservatively, that each segment has the potential to impact the municipality's supply through surface runoff. That being the case, we use the same exposure level for all segments and can compute municipality level risk by multiplying the total of the segment probabilities by this exposure level. For vulnerability, this statistic is only adjusted by the response time level after the statistic has been combined with the other, adjusted exposure measures. At the county level, the risk and vulnerability statistics are the sum of the municipality level statistics.

4.6 Output Formats

Having completed the model calculations, the user is given a choice of three types of output: printed results, on screen graphs, and flashing streets on a network map. This last option has been made a part of the overall RADSS package development and is not available when using this program alone.

To obtain printed output, the user may choose from six printing formats in the format option menu. These options refer to risk or vulnerability results for any of the three levels of locality (street, municipality, and county) considered. Here a specified number of the highest ranked localities are obtained. In the printout (see sample, Figure 4-4), all of the user defined inputs are first returned. Then starting with the highest ranked locality, the street, municipality, or county numbers are displayed with their corresponding values of unadjusted exposure levels. "Risks often need to be

expressed in relation to exposure, so that different risks can be compared” “one might...compare the number of disabling injuries per passenger hour or death per rural mile...” “the task is to design the measurements so that the numbers obtained will have the greatest significance for indicating risk” [22]. By viewing these results for risk, we can determine which localities achieved high risk levels (shown). Similarly, by contrasting the risk and vulnerability printouts using the same input features, one can determine which localities have high vulnerability without high risk (because of poor or inappropriate response capabilities).

The other available option is to obtain on-screen graphical interpretation of the model for up to seven localities (this limiting number is used to avoid cluttered graphs). Here we have the option of two different formats of graphs, one for risk values and the other for vulnerability values. In both cases, the user-specified street, municipality, or county code numbers are assigned corresponding letters (A,B,...G as needed). The user then can switch back and forth between the graph chosen and a listing of the codes corresponding to each letter used by using the spacebar, in instances when he/she should forget these correlations. Also, in both risk and vulnerability plotting, the user must designate which one of the four available types of exposure (people, property, special facilities, or sensitive areas) should be considered.

In graphing risk relationships it is common to see plots of probability (dependent variable) values with respect to their corresponding levels of exposure (independent variable). Such graphs are called “risk profiles” (see Figure 4-5). In this fashion, we can see directly whether a particular risk level is due more to a high probability occurrence or a high level of exposure.

“The worksheet approaches developed under DOT sponsorship for highway routing and community planning are helpful, but insufficient because they reduce the results to a single number known as ‘expected risk’. A risk profile showing frequency in comparison to consequence is more helpful than a single number, which provides no insight into whether the

Recap of Input Parameters:

Probability File Name: A:fakprob.DAT
 Exposure File Names:
 Street Level -- A:fakests.DAT
 Municipality Level -- A:fakemun.DAT
 County Level -- A:fakecou.DAT
 Response File Name: A:fakeresp.DAT

Data Period of Record: 5

Percentage of hazmat accidents that release their contents:

State Hwy. & Mun. St.: .191
 State Hwy. Only: .102
 Mun. St. or Twshp. Rd. Only: .113
 County Rd.: .191
 Private Rd. or Area: .124
 Interstate-Urban: .145
 Interstate-Rural: .076

Percentage of all trucks carrying hazardous materials:

State Hwy. & Mun. St.: 7.3801100254058840-02
 State Hwy. Only: 3.7634398788213730-02
 Mun. St. or Twshp. Rd. Only: 4.3151099234819410-02
 County Rd.: 7.3801100254058840-02
 Private Rd. or Area: 4.7982998192310330-02
 Interstate-Urban: .0392053984105587
 Interstate-Rural: 4.0801800767448880-02

Hazmat Type:

(D) Flammable LCG

Severity of release:

(C) Catastrophic

Hazmat Release Scenario:

(A) Liquid Pool Fire

Weight to Population Exposure: .6006000238418579
 Weight to Property Exposure: .2000000629802322
 Weight to Special Facilities Exposure: .1000000014901161
 Weight to Sensitive Areas Exposure: .1000000014901161
 Level of Severity: 1

In the order of highest to lowest risk for highest streets: 78

EXPOSURE (per mile) >>>>>>			
Street Code	Population (people)	Property (\$)	Spec. Facilities (size by people)
61124008800	91.88207	47745.19	6.956411E-03
62424008800	91.88207	47745.19	6.956411E-03
63424008800	91.88207	47745.19	6.956411E-03
51217001800	44.97994	1616.02	3.864672E-04
63217001800	44.97994	1616.02	3.864672E-04
62217001800	44.97994	1616.02	3.864672E-04

Figure 4-4

concern is about frequent spills that may be of low consequence (gasoline, for example) or infrequent spills of a more dangerous substance like chlorine, and does not usually indicate the uncertainty of the risk estimate" [52].

In MacroRADSS, we do not obtain the actual mathematical relationship between different levels of probability and exposure for localities, so we cannot plot curves per se. What we obtain is a series of up to seven points which show how each locality relates to the others plotted. Since we cannot easily visualize risk levels from this form of plot, we must determine some way to clarify these points in terms of the risks they represent. To do this we introduce the concept of "isorisk" lines or "lines of equivalent risk". Each isorisk line represents all combinations of exposure and probability which, when multiplied together, yield the same risk value. Isorisk lines have their conceptual basis in the study of Gambler's Ruin based on Binomial distribution modeling. Megill [23] draws such curves for the probability of "all dry wells" for various numbers of wildcat oil wells drilled. His curves show that isorisk lines are distinguished by varying "success rates" (which is the success of striking oil for an individual well - the p term in the Binomial distribution) [23]. In constructing the on-screen graph, the program draws the isorisk lines for the highest and lowest risk points being plotted. The isorisk lines (actually curves which are asymptotic to the x and y axes) show the size of the difference in exposure (or, for that matter, probability) between two points which actually causes their different risk levels. While other modelers have avoided using equivalent risk as a sufficient basis of comparison, for fear of deemphasizing extreme events, it is the author's contention that the absolute probabilities of hazmat accidents with significant releases has been shown to be small enough to conclude that all such occurrences are extreme events.

For vulnerability, we have a third component variable and so our graph is three-dimensional. From the MacroRADSS approach, we note that our risk graph is simply a two-dimensional slice within this three-dimensional graph, which occurs at

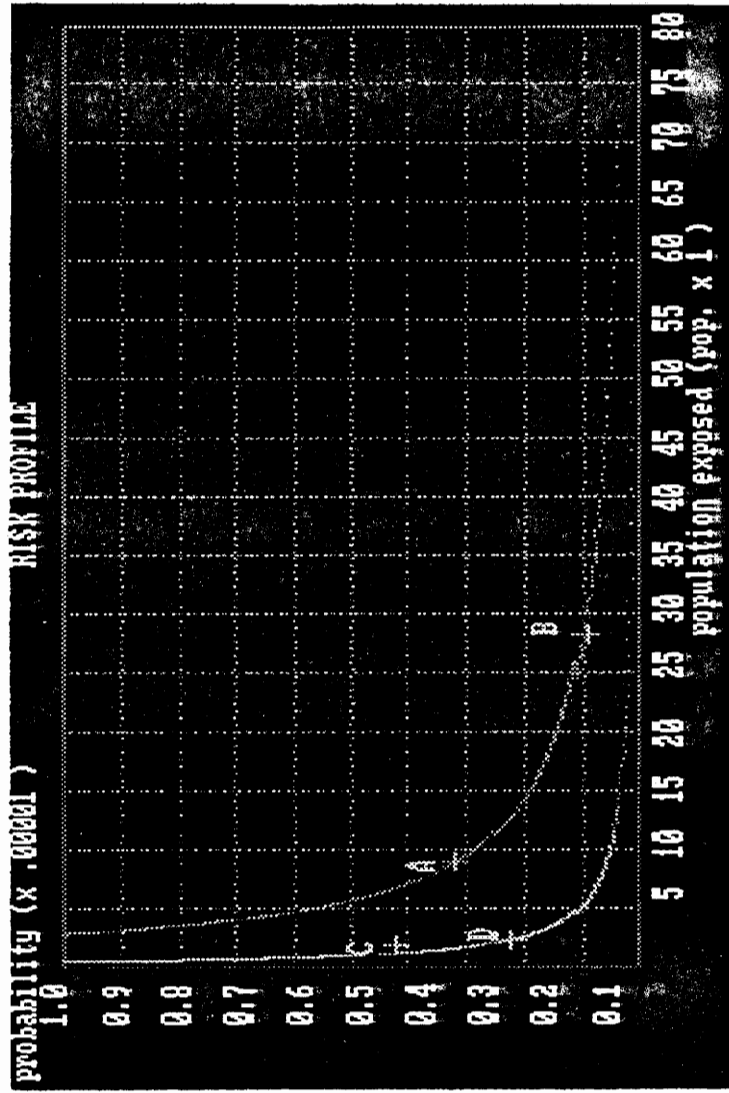


Figure 4-5

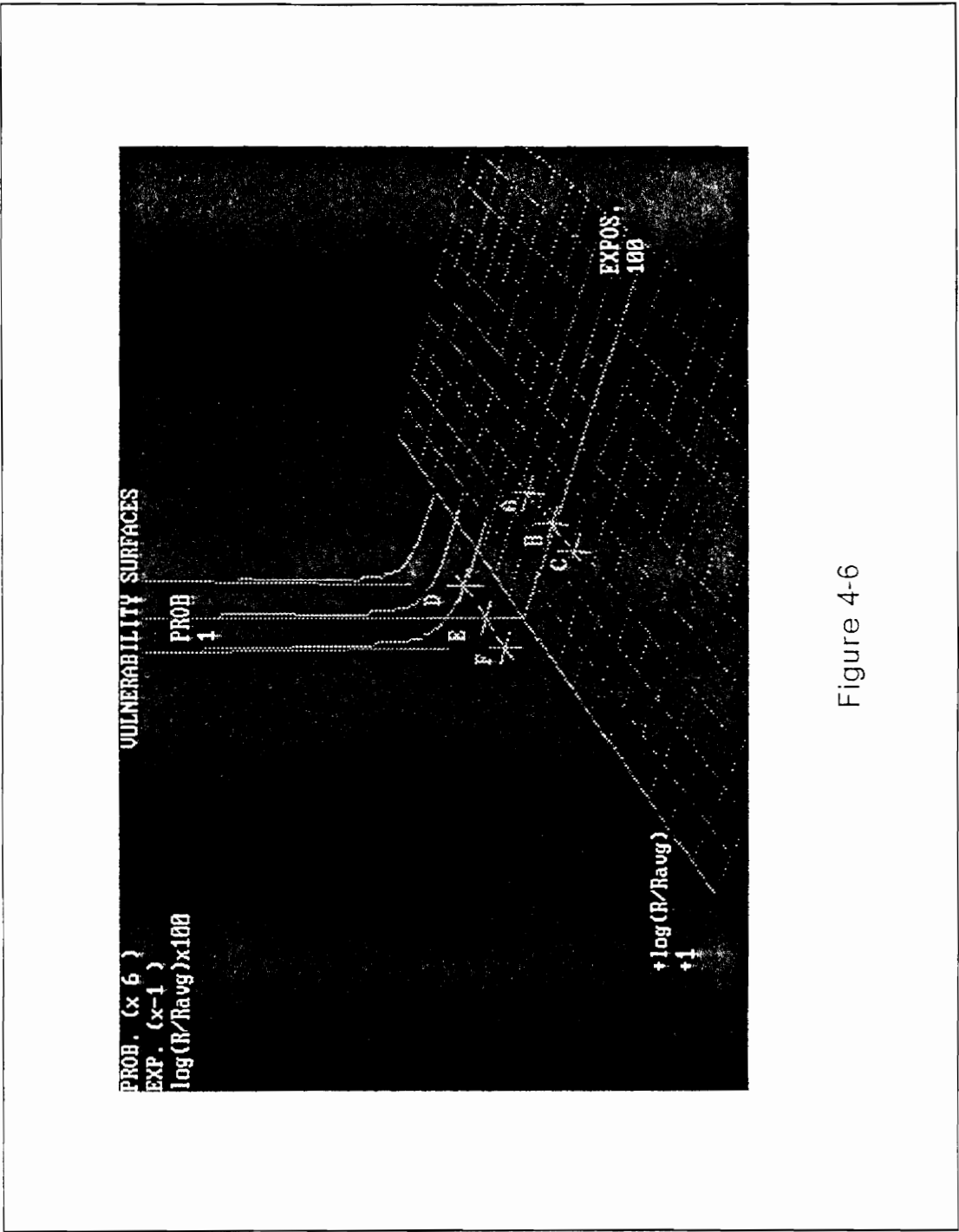


Figure 4-6

the location where the response parameter's value (corresponding to the exposure measure chosen) is one (i.e., the response of the locality equals the state average response). The sensitive area exposure factor is associated with the maximum time-to-respond response factor in this regard. We must note here that the range of bad response factors goes from 0 to 1 while the range of good response factors goes from 1 to infinity. For this reason, we must use a log scale (base 10 for our purposes) for the response factor dimension (see Figure 4-6). Points can then be plotted in all three dimensions. In this manner we can determine which of the three contributing factors (high probability, high exposure, or bad response capability) is responsible for the preponderance of the vulnerability magnitude for each locality. If we were to redraw the isorisk lines from before, we would find that the lines would be still asymptotic to the x and y axes. Yet, the lines would get closer to the axes for increasingly bad (more negative log value) response. At the same time, such isorisk lines would prove to be farther from the x and y axes for increasingly good (more positive log value) response. This is logical, since we can withstand higher damage events or more likely ones if our response capabilities are better than the average, with the reverse also true for localities with less than average response capabilities. The entire family of such lines defines what we call an "isovulnerability surface". For graphical convenience, the program draws those lines representing the highest and lowest isovulnerability surface over the locations where points are plotted on the vulnerability graph. Since the graph is three-dimensional, the user may have difficulty in determining the values represented. For this reason the user is given the ability to rotate the graph using the "left" and "right" arrow keys as well as to zoom in or out using the "up" and "down" arrow keys. The program displays the last such command on screen continuously. When the user wishes to redraw the figure, the "Enter" key is depressed.

5. COMPUTER MODELING CONVENTIONS

In developing the MacroRADSS package for interactive computer modeling, a number of modeling conventions were employed to facilitate ease of updating the data, error free running of the program, and interpretation of the results. To first acquaint the prospective user with the MacroRADSS program, these program features will now be inventoried in the order in which they are encountered.

To run MacroRADSS, the executable file MACRO.EXE as well as data files BLDCOSTS.DAT (the eight typical building replacement costs used in calculating property exposure) and FACTORS.DAT (locality cost adjustment factors also used in calculating property exposure) need to be copied onto the hard disk of an IBM style personal computer equipped with VGA or higher graphics board and monitor. In addition, the QuickBASIC library file BRUN30.EXE also must be copied to the hard disk. Five data filenames (with the .DAT extension) are searched for on the "A" disk drive at various points in the program. All of the data files are random access files, read by the computer in their entirety when the disk is accessed. Data files may be viewed and changed by the QuickBASIC editor directly or through word processing or spreadsheet programs as desired. It is also envisioned that these data files may be accessed from the overall RADSS package through a tabulation of individual street, municipality, or county data.

In looking at the data files, a number of program features should be apparent. First, dummy variable fields have been reserved on each file to provide space for

calling the entry by name (14 spaces for the county name, 15 for the municipality name, and 16 for the street name). Also, the first two spaces of every data line are reserved for a special data age parameter to keep track of the oldest item recorded on a data line. The initial data set starts off as "00" and subsequent updates change this value for lines where new data does not completely replace the previous line. In cataloging the data for computer recognition, the computer files make use of the PennDOT county and municipality codes. These codes provide a convenient means of linking the county and municipality level data as the first two digits of the five digit municipality code corresponding to the two digit county code. To reference streets, the municipality code is appended first by the four digit route number (excluding letters) found in the PennDOT accident records. An additional two digit extension is employed to assist in cataloging those locations where more than one MacroRADSS defined "segment" corresponds to the same route number. An explanation of the various fields in each data line can be found in the program listing at the points where the files are accessed by the program. An explanation of these fields is also available under separate cover.

When entering the program, the user is first presented with a decision to: run the program, write MicroRADSS files (files to be read by the software created in fulfilling Task Four), perform a What if... analysis (which changes data file variables without actually entering the data file), or to quit. Currently, the program only recognizes the first and last of these options. Choosing the first option continues execution of the program. From this point, the screen background color changes from blue to red indicating that control of the program has shifted from the "Main/Output" portion of the program to the "Probability Computation" portion. Four different background colors are employed to indicate the four distinct portions of the

program encountered during execution (Main/Output, Probability Computation, Exposure Level Determinations, and Response Capability Factors Generation).

Having entered the probability computation module, we note that on screen input prompts are preceded by plain english statements describing the requested input. The first piece of such data requested is the period of record of the accident data (i.e., the "N" term in the street level probability equation). Plain english explanations are provided at all points of user interface with the program. In addition, text explanations are included with the program's code to allow those unfamiliar with the theories involved to modify the program to meet individual needs (as may be permitted under copyright).

Before leaving the probability computation module, the program displays the default values employed in the street level equation (from the 1984-85 Bureau of Motor Carrier Safety or "BMCS" data) and provides the option for the user to change any of the values as they appear. In every instance beyond this point where the user is requested to provide specific input, default values are included with the program (simply hitting the "Enter" key accepts the default value) which are displayed as encountered. These values represent useful first guess information for unfamiliar or disinterested users and provide a means to proceed through the program more rapidly.

From here the program enters its Exposure Levels Determination module which resides as a separate subprogram appended to the end of the MacroRADSS main program. As was the case in the probability module, the computer needs to access the data files before performing its calculations. Three separate files are requested at this point, one each for county, municipality and street level data. Before the program reads these files, however, it displays a list of available hazmat classes to consider. Since it was not possible to display all 27 available user choices on one

screen, the final screen option is to display a second screen. One may similarly request a third screen and proceed from the third screen back to the original screen. The final option on the third screen is the user input option previously mentioned (where the user may input the width about the roadway he or she wishes to consider). If this option is not chosen the user may make additional specifications with regard to the release scenario and the severity of the release depending on the option chosen. Throughout this process the input programming technique of the MacroRADSS package becomes fully evident. This technique is for the user to select from a finite list of responses through the use of arrow keys, screen graphics which highlight the current entry, and use of the enter key. By using this approach, we circumvent the problem of users inputting unreasonable values where finite options are available.

The response capability factors generation program works in similar fashion to the exposures module and also resides as a separate subprogram. The only input, aside from the county level data file, requested here is types of response measures which the user would like to consider in the vulnerability analysis (risk analysis is, of course, unaffected by input here). The user makes a choice by inputting a letter value for letters corresponding to the displayed list of options. The default in this case is the "A" option of considering all types of response. Lower case values are accepted.

When the computer finishes its response capability factors determination, program execution returns to the main program and all factors needed to complete the analysis are submitted back to the main program. As was the case with accepting/rejecting the default BMCS data in the probability module, the user now has the option of accepting or rejecting the weights to be assigned to the various measures of exposure (population, property, etc.). The weights or percentages

submitted here need not add up to 100 percent as the computer compensates for other entries. These percentages are used to combine the dimensionless exposure parameter ratios in both the risk and vulnerability equations in order to arrive at a single risk and a single vulnerability statistic. As was mentioned before, the use of such single risk or vulnerability values (particularly unitless ones) is confusing to all but the most familiar users. They also do not convey all of the information about the causes of the magnitudes of their values to the user. For these reasons, the risk and vulnerability statistics generated are kept hidden from the user. The program proceeds instead to assign a rank to each street, municipality, and county based on the magnitude of each of these values. Also, the program opens an output random access file on the A drive diskette which will contain this information for access by other RADSS programs. The user has the option of writing any or all levels of output files on this diskette (to prevent disk overcrowding).

All computations of the MacroRADSS program are now complete. From here the program displays an output option menu which offers four possible choices: printouts for reports, blinking links on a network diagram (to be provided with the availability of the RADSS package shell program-that will run MacroRADSS upon completion), on screen graphics, and a quit (leave MacroRADSS) option. In all cases except exit, the output option screen is recalled following the completion of the option routine.

Selecting the printout option of the program first displays a listing of six possible output formats. While this display is being generated, the program prints out all input filenames and user specified options so that runs may be reproduced time and again. The six available options are street, municipality, or county level results from either the risk or vulnerability analyses. Next the computer asks for the number of listings desired (from most to least risky or vulnerable) and displays the total number of

listings available for the displayed level. Results in the form of all values of the unadjusted exposure measures are then printed accompanied by the corresponding county, municipality, or street level code.

The other available option produces a screen graphics output format table where the user specifies such things as the exposure parameter to consider, number of points to plot simultaneously (up to seven maximum to prevent screen clutter), level of data to consider (street, etc.), and type of analysis (risk or vulnerability). It is important at this point for the user to understand the code numbers for which he or she wishes to see output. For this reason, it is recommended that users first run the printout option to determine the streets, etc. that are of interest to them. After the requested number of code numbers is provided to the computer, the graphics generation routines provide risk or vulnerability plots using letters A through G to reference code numbers in the order of their input. It is not necessary, however, to memorize the order or the code numbers as striking the spacebar will toggle the screen back and forth between the graph requested and a listing of the code number to letter relationships. To return to the overall output option menu from this point, the user strikes the "Esc" key.

The nature of the plots produced is in the form of the previously defined "risk profiles" and their logical extension, "vulnerability surfaces" (which are three dimensional graphs using the appropriate response factor as the third axis). Since we are not comparing multiple situations for the same street, etc. but rather multiple streets, etc. at the same time, our risk profile becomes a series of points reflecting the risk or vulnerability situation for the given scenario for the given requested code numbers. In order to compare the magnitudes of these points, the program develops what will hereinafter be known as "isorisk lines" or rather lines of equivalent risk. These are, in fact, curves which are asymptotic to both the probability and exposure

axes and represent the family of all probability * exposure combinations which, when multiplied together, produce the same level of risk. In the MacroRADSS program, the plots of the individual points are followed by isorisk lines corresponding to the highest and lowest risk points displayed. These isorisk lines are of differing color and those points which coincide with these lines can be said to have the same level of risk as all of the other points which coincide with the line (and none of the points which don't). Obviously, the curve which is farther from the origin represents the highest level of risk. Similarly, the closer curve represents the lowest level. In this fashion, we can not only tell which points have the highest and lowest risk, but also by how much we are able to change probability or exposure for any given point to be as high a risk as the highest point or as low a risk as the lowest point. From any point's location to these curves, one can also gather whether the bulk of a given risk level is attributable to high probability or high exposure levels.

In order to plot vulnerability, we need to show how the risk profile changes when the ratio of the statewide average response level to the local response level does not equal one. Since this ratio for jurisdictions with worse than average response levels can range from 0 to 1 while those which are better than the statewide average can, instead, range from 1 to infinity, the display convention was adopted to use the \log_{10} of the response value so that response levels equally below and above the statewide average would plot an equal distance from the exposure and probability axes. In the case of vulnerability plotting, the different colored isorisk lines become similarly colored three dimensional "isovulnerability surfaces" where the same level of vulnerability is achieved by all sets of probability, exposure, and response capability factors contained on the surface. Our previous isorisk line was merely a slice through this surface at the location where the \log_{10} (response capability factor) is equal to 0. As our ratio becomes more and more negative (i.e., response levels

progressively worse than the statewide average), the slice through the surface for the given response level becomes closer and closer to the other two axes. The reverse is also true for response levels above the statewide average. This stands to reason as higher response levels will allow us to withstand more hazmat release while lower ones will serve to reduce that ability.

Since three dimensional plotting is often difficult to interpret, the program provides additional graphic enhancements to help in this regard. First a coordinate grid is superimposed in the exposure/response capability plane. The poor response half (i.e., ratios in the range from 0 to 1) is color coded red while the better half (i.e., ratios in the range from 1 to infinity) is color coded blue. Second, through the use of the arrow and enter keys, the user can redraw the plot through a full 360 degree rotation about its probability axis in increments of $\pi/16$ as well as zoom in or out as seen fit. Using the spacebar toggle with the code number display provides a rather simple way to refresh the screen in its original format. Lastly, in order to avoid a cluttered screen, the isovulnerability surfaces are drawn over only the response levels which correspond to the factor levels on one of the points requested for plotting so that high and low vulnerability points may be identified.

6. COMPUTER TESTING - Washington County, Pa.

6.1 Input File Information

In order to provide some understanding of the significance of the results from the MacroRADSS computer model as well as to provide some real world problem for testing of the model formulation, a sample data file was created using Washington County, Pennsylvania data. Washington County was selected for a variety of reasons. It has a wide variety of population and commercial/industrial densities thanks to its fairly large area and proximity to the Pittsburgh metropolitan area. It is at the confluence of multiple interstate and other through routes making it a likely location for significant hazmat traffic. It is also made up of a wide variety of municipalities both in size and in type. Lastly, PennDOT's Roadway Management Information System (RMIS) data file showing properties of the highway network was readily available for Washington County which would help with output interpretation.

Information from the PennDOT accident record system on Washington County was obtained from a magnetic tape dump of the accidents stored for the period 1984 to 1988 (five year inclusive). During this period, accidents were noted on 26 distinct highway segments (according to the MacroRADSS definition of such segments) within 15 municipalities. The following streets in the following municipalities were identified:

Table 6-1

Street	Municipality	Shafer
Highway (I-79) Amwell		
I-70	Buffalo	
I-70 (2 segments)	Canton	
I-70 (2 segments)	Donegal	
Highway 844	Independence	
Highway 18	Mt. Pleasant	
Shafer Highway (I-79, 2 segments)	N. Strabane	
Highway 519	N. Strabane	
Local Route 4009	Robinson	
I-70	Somerset	
I-70 (6 segments)	S. Strabane	
Shafer Highway (I-79)	S. Strabane	
Route 316 (name unknown)	W. Finley	
Local Route 2041	W. Pike Run	
I-70	Washington	
Highway 837	Donora	
Route 1077 (name unknown)	Donora	
Route 0088 (name unknown)	New Eagle	

Variations in the accident records for the individual streets allowed the model to be tested under the following conditions:

- * Maximum no. of accidents on a segment = 2
- * Maximum DVMTT = 1702 truck miles/day
- * Maximum ADT = 24986 vehicles/day
- * Speed Limit Range = 25 to 55 mph
- * Segment Length Range = 111 to 3960 ft

Variations in the municipality level data as reported by the Pennsylvania State Data Center, Pennsylvania Department of Environmental Resources, and other sources included the following range of conditions:

- * Range of area = 1 (New Eagle) to 44 (Amwell) sq mi
- * Maximum of 1 Hospital, 8 Schools
- * W. Finley had lowest work population (323), residential population (1040), no. of dwelling units (341), no. of commercial businesses (4), no. of industries (17), and lowest no. of agricultural units (6)

- * Washington had the highest work population (6843), residential population (17730), no. of dwelling units (7115), commercial businesses (89), and no. of industries (355)

- * N. Strabane had the highest no. of agricultural units (167), and public drinking water supply (2720 mgd)

Figures for the county as a whole with regard to the calculation of the total exposures are as follows:

- * No. of Hospitals = 3
- * Total no. of hospital beds = 733
- * Total no. of schools = 99
- * Total enrollment of schools = 34631
- * Percent of housing coded urban = 60.5

Figures for the county as a whole with regard to the calculation of the response capability factors (as achieved from telephone survey - population is from Data Center) are as follows:

- * Total no. of police units = 42
- * Total no. of trained and equipped fire companies = 52
- * Total no. of emergency medical units = 36
- * Maximum time to respond = 15 minutes
- * County population = 210,600

6.2 Additions to Input File Information

Since the analysis is to be performed using the data from only one county, all response factors would be equal to unity. We know this ahead of time because our factors are determined based on the ratio of the county level measures of response

capability for each county to the average value of these statistics for all of the counties being considered (which in this case is only Washington County). In this situation, vulnerability analysis would yield street and municipality rankings which would be identical to the risk analysis rankings if we chose to obtain printed output. Similarly, our three dimensional plot of vulnerability would yield points only on the plane defined by the log of response factor equal to 0 (i.e., response factor equals 1) for whichever set of points we supplied.

In order to provide a relevant test of the vulnerability analysis portion of the program, two fictitious counties were created by duplicating all of the probability and exposure information for Washington County and assigning different county numbers. We then distinguish between the counties by varying the level of the response parameters. Since the PennDOT County Code for Washington County is 62, we will create the fictitious counties no.s 61 and 63 (not to be confused with the real PennDOT County Code No.s 61 and 63 which are Warren and Wayne counties respectively). Our fictitious county no. 61 will have worse response levels while the fictitious county no. 63 will enjoy better response levels. The following response capabilities files were generated:

FAKERESP.DAT: variation of all measures of response

* County No. 61 had 5 fewer police cars. County No. 63 had 5 more. (88.1% and 111.9% of actual)

* County No. 61 had 5 fewer fire companies. County No. 63 had 5 more. (90.4% and 109.6% of actual)

* County No. 61 had 5 fewer emergency medical units. County No. 63 had 5 more. (86.1% and 113.9% of actual)

* County No. 61 takes 5 minutes longer to respond. County No. 63 takes 5 minutes less. (66.7% and 133.3% of actual)

FAKEAMBU.DAT: variations of ambulance response alone. Ambulance response was chosen for two reasons. First, it fluctuates by the highest percentage of its original level. Second, the relative weight ascribed to population exposure (impacted by ambulance response) is high.

FAKETIME.DAT: variations of response time only. Response time was chosen because of the different nature of the parameter and the differing way it appears in the vulnerability expression.

7. COMPARATIVE ANALYSIS

7.1 Testing Procedure

Since we have maintained up to this point that actual values of risk and vulnerability are theoretical abstractions and that our output should reflect values of significance to the user, our method of testing such output is not readily apparent. That is to say that our job of testing becomes harder without the actual risk and vulnerability values to inspect. In order for the chosen output form to be acceptable, it should be within our means to check the reasonableness of our results. The original intent of the model testing portion of this work was to perform a sensitivity analysis on the data by varying the levels of the input parameters and viewing the changes in the levels of risk and vulnerability produced. This approach is not possible in that those output levels aren't normally accessible. What we can do instead is to view the output as it is presented to the user and intuitively check for the reasonableness of the results. Recall here that the objective of the macro level model is not to indicate the magnitude of the risk/vulnerability (which, as has been stated, is much too complex to determine here) but rather to give an indication of the size of such values for one location relative to all other locations considered. We shall perform this "comparative analysis" at the street level in order to provide the maximum number of points for comparison as well to recognize the fact that it is

easier to understand jurisdictional trends from street level information than to identify street level trends from jurisdictional level output.

Our job now becomes to design a testing procedure utilizing our three county data file from Chapter 6 to lend sufficient insight into the various portions of the model. We must be judicious here because of another concern. One of our primary objectives in developing the MacroRADSS model was to allow the user maximum opportunity to customize the analysis. As a result, all program variables are available for alteration in some fashion. Without considering variations in the input files or different numbers of output streets/ jurisdictions to be requested, the user can achieve 721,280 unique combinations of input (excluding different values at the same locations). Consequently, were we to test every possible combination, this report may be years in the making. Rather, by identifying the various portions of the computations to inspect individually, we test critical locations and conclude that similar locations (such as population exposure and property exposure) will vary in similar fashions. The following test runs were performed:

I. Comparative Risk Analysis

A. Basic Risk - use of all default values except uses a custom corridor width of 1 mile impact diameter.

B. Variations on Risk by Highway Type Parameters - same as basic risk except we alter our assumptions with regard to the default values of hazmat flow percentage and hazmat accident release rate for specific highway types represented in the sample data.

C. Variations on Risk by Size of Impact Area - one portion of the exposure computation subprogram curtails the impact area when it exceeds the municipality total area. If this is performed correctly, then we will begin to see progressively lower ranking for municipalities with small land areas as we increase our corridor width.

II. Comparative Vulnerability Analysis

A. Basic Vulnerability - same as basic risk in input values, this run shows vulnerability ranking considering all forms of response and using the file FAKERESP.DAT (with variations to all measures of response capabilities) in order to show the cumulative effect of all response factors.

B. Variations on Vulnerability by Size of Response Parameters - using the files FAKEAMBU.DAT and FAKETIME.DAT, we obtain the direct effect of considering incremental changes to single measures of response capabilities.

7.2 Risk Output for Washington County, Pa.

7.2.1 Basic Risk

Using the above file information as generated for each street and municipality shown above, the MacroRADSS program was run for the default settings of input information for the customized width hazmat class with a corridor width (diameter of circles shown in Figure 4-3) of one mile.

The following information was reported at the street level:

- * Range of population exposed = 1×10^{-2} (W. Finley) to 170 (S. Strabane - Shafer Highway). Recall here that W. Finley had the lowest populations and that S. Strabane had a high combination of population density (high population, moderate land area) and large segment length (2423 ft).

- * Range of property exposure = \$3720 (W. Finley) to \$1,087,980 (Washington). Recall here that these two jurisdictions had the highest and the lowest number of dwelling units, commercial businesses, and industries.

- * Range of Special Facilities exposure = 0 (no schools or hospitals) to 0.192 people (Washington). Washington had the highest reported number of such facilities. The reason for the magnitude is that the relatively low number of beds and schools involved is multiplied by the ratio of the corridor size to the municipality area and Washington happened to have one of the smallest land areas (3 sq mi).

The following information was at the municipality level:

- * Range of population exposed = 1×10^{-2} (W. Finley) to 783 (S. Strabane) for the same reasons as above.

- * Range of property exposed = \$3720 (W. Finley) to \$1,416,950 (Donora). W. Finley is lowest because it was lowest at the street level. Donora is the highest

because it had a high level of property damage at the street level and more than one street.

* Range of special facilities exposed = 0 to 0.20 people (Donora) for the same reason as the high value of property exposure above.

* Range of Sensitive Area exposed = 0 (no public drinking water supplies within the municipality borders) to .3602172 mgd (N. Strabane). Recall here that N. Strabane had by far the highest public drinking water supply at 2720 mgd.

County total figures:

- * Population exposed = 1885 (roughly 0.9% of total county)
- * Property exposed = \$3,878,387
- * Special facilities exposed = 0.61 people
- * Sensitive areas exposed = 0.54 mgd

The ranking results indicate that the following streets and municipalities are most to least at risk:

Table 7-1

Street Code:	Street Name:	Municipality:
62424008800	Unknown New Eagle	
62217001800	Highway 18	Mt. Pleasant
62220051900	Highway 519	N. Strabane
62231204100	Local Rte. 2041	W. Pike Run
62223400900	Local Rte. 4009	Robinson
62214084400	Highway 844	Independence
62413083700	Highway 837	Donora
62227007900	Shafer Highway	S. Strabane
62413107700	Unknown	Donora
62220007900	Shafer Highway	N. Strabane
62302007000	I-70	Washington
62201007900	Shafer Highway	Anwell
62227007002	I-70	S. Strabane
62220007901	Shafer Highway	N. Strabane
62209007001	I-70	Donegal
62204007001	I-70	Canton
62204007000	I-70	Canton
62225007000	I-70	Somerset
62227007005	I-70	S. Strabane
62227007004	I-70	S. Strabane
62227007000	I-70	S. Strabane
62227007001	I-70	S. Strabane
62227007003	I-70	S. Strabane
62203007000	I-70	Buffalo

62209007000	I-70	Donegal
62230031600	Unknown	W. Finley

Table 7-2

	Municipality Code:	Municipality Name:	62424	New
Eagle	62217	Mt. Pleasant		
	62220	N. Strabane		
	62231	W. Pike Run		
	62223	Robinson		
	62214	Independence		
	62227	S. Strabane		
	62413	Donora		
	62204	Canton		
	62209	Donegal		
	62302	Washington		
	62201	Amwell		
	62225	Somerset		
	62203	Buffalo		
	62230	W. Finley		

Please note here that streets and municipalities are ranked differently than we would be lead to believe based upon their exposure values alone. The highest risk street, Route 88 in New Eagle Borough, ranks 13th in population exposure, 4th in property exposure, and 4th in social facilities exposure This is our means of showing in printed fashion which jurisdictions attribute more of their risk levels to their high probabilities and which attribute them to the high levels of damage they may sustain. Please note also that, in all risk output requested, the actual street or jurisdiction number can be found next to the numbers for their ficticious counterparts (in the ficticious counties no.s 61 and 63). This is to be expected as the risk values for all three counties should be identical (only change is in the level of response provided).

7.2.2 Variations on Risk by Highway Type Parameters

Certain parameters which remain uncollected at the street level are approximated by default values using BMCS data. These parameters, used in the probability computation portion of the risk calculations, are grouped according to a modified PennDOT highway classification scheme in order to facilitate the assignment of highway classes to individual segments from information provided in the statewide accident record file. In Washington County there are four of the possible seven classes represented: State Highway & Municipal Street, State Highway only, Municipal Street or Township Road only, and Interstate - Urban. These are highway types no.s 1, 2, 3, and 8 respectively. There are four segments of highway type no. 1, four of type no. 2, one of type no. 3, with the remaining 20 of type no. 8.

We wish to investigate the magnitude of the change in risk (and, consequently, vulnerability) ranking due to large changes in the level of these default values. Since we have more than two classes of highway, we can get an understanding of the individual effects in one run by varying different parameters for two different classes. In this attempt, we increased the default accident release percentage for highway type no. 2 from 10.2% to 75%. Likewise, we increased the hazmat percentage of total truck flow for highway type no. 3 from roughly 4.3% to 75%.

In the output, we first notice that no change has taken place in the exposure levels which is to be expected as our new values only appear in the probability computations. Referring back to Table 7-1, our new results show that the unknown street in New Eagle Borough fell from highest to third highest in risk. Also, Local Route 2041 in West Pike Run Township fell from fourth highest in risk to sixth highest.

This is because the originally second, third, fifth and sixth highest risk segments were of type no. 2. Since the unknown street in New Eagle Borough remains higher in risk than the Robinson and Independence Township segments, we can conclude that such variations are quite noticeable but, sufficient differences exist in the original risk levels to avoid being overwhelmed by wide fluctuations in these levels. As a final note, no change was observed in the rank of the type no. 3 segment in West Finley. This is probably due to the fact that this segment had unquestionably the lowest exposure levels in all categories.

7.2.3 Variations on Risk by Size of Impact Area

The effect of impact area can be seen in the determination of all measures of exposure except sensitive areas, which is not observed at the street level. Consequently, we would expect a high sensitivity of the risk model to this parameter. We recognize at this point that, assuming a uniform distribution of people, property, etc. in all municipalities, simply varying the impact area size (read corridor width) will not change our rankings. The exception to this observation can be found when our impact area size exceeds the municipality total area at which point, if our program is working correctly, the impact area is truncated to that value and individual street areas are reassigned. What we would expect to see as impact areas continue to increase is growing levels of exposure parameters up to the municipality maximum with a continued downward trend in the ranking for streets in municipalities above this level (due to a combination of small total land area and large corridor width).

Our testing methodology is straightforward. Knowing the total land area and the sum of the segment lengths, we can determine the maximum corridor width which

will not exceed the total area for each municipality. We then group these widths by size to determine threshold values for corridor width just above these levels. Four such thresholds have been chosen:

Table 7-3

Threshold Width (miles)	Exceeds Total Area for:
7	Donora Borough New Eagle Borough South Strabane Township Washington City
19	Canton Township North Strabane Township
44	Buffalo Township Donegal Township Robinson Township Somerset Township
90	West Pike Run Township (All remaining except West Finley Township)

Results from the various runs confirm these trends when compared to the basic risk run. As an example, results from the 7 mile width run indicate a drop in rank from 13th highest to 14th highest for South Strabane’s third segment of I-70 relative to North Strabane’s second segment of Shafer Highway (I-79). From Table 7-3 it is apparent that the reason for this is due to the fact that South Strabane’s threshold width has been reached whereas North Strabane’s hasn’t. Also, the increasing trend in exposure levels is observed for those municipalities that haven’t reached their threshold level of corridor width. Property exposure for the West Finley Township, originally estimated at \$3720 is increased for a 90 mile corridor width to \$334,790 or 90 times as much.

7.2.4 Basic Vulnerability

In obtaining the basic vulnerability run, the county level response information file FAKERESP.DAT was used. The reader is referred to Chapter 6 for a discussion of this file. Since we are considering response factors now, it is safe to assume that identical streets for the three counties tested will no longer be grouped in the rankings. The degree of dispersion of the individual streets for the individual counties depends on how close the risk values were between the group of three in question and its adjacent groups. It is possible that some of the groups may remain intact even if the group itself appears at a different location in the ranking. These effects are attributable to a wide variation in risk values coupled with the fact that different jurisdictions have different high measures of exposure (which are impacted by the response factors in the vulnerability calculations).

The resulting run will be difficult to interpret because of these possible occurrences. What we would wish to avoid seeing is a dramatic dispersion of the original groups of three identical segments from one end of the ranking to the other. Since we've already noted a fairly wide range of risk values in Section 7.2.2, this kind of behavior would indicate that the response factors are causing dramatic changes in the rankings owing to their own magnitude. Additionally, since the actual magnitude of exposure which is lessened or increased for various response levels isn't known, the exposure levels printed should remain the unadjusted values. Consequently, we should expect the levels printed to be identical to those in the basic risk run.

In comparing the basic vulnerability run to the basic risk run, we notice first that our exposure levels reported are indeed identical to those in the basic risk run. This is useful information to the policy maker as it indicates the size of the various threats

to be prepared for with his/her response crews. No matter how good or bad the response capability is at present, this is the average magnitude of exposure that an average responder must serve in a stipulated hazmat emergency. Upon further inspection, we note that limited swapping of ranks has taken place. The highest level of swapping (that is to say the largest change in rank) occurs in the center region of the list with no changes in rank at either the high risk or low risk extremes. This leads us to conclude that the majority of our original risk values were clustered about a mean value so that the response factors will more easily cause rank changes in this region. As far as avoiding dramatic changes in rank is concerned, there appears to be no such problem. The vast majority of rank changes (which are considered to be changes between the original risk groups of three for any segment in this situation) consist of swapping of segment ranks between one of the original risk groups and an adjacent risk group. The highest such change occurred between the originally 23rd highest risk group and the current 15th highest group which is an increase in rank of eight positions out of a possible 25. This magnitude of change, considering that all measures of response were altered for their cumulative effect on the outcome, would indicate that normal vulnerability ranks would likely differ from risk ranks but not dramatically.

7.2.5 Variations on Vulnerability by Size of the Response Parameters

These runs are similar to the basic vulnerability run with the exception being that the response files used are FAKEAMBU.DAT (where the ambulance response is the only one varied) on the first run and FAKETIME.DAT (where the maximum time to respond is the only varied parameter) on the second run. In both cases the

discrepancies between the rankings of the new vulnerability runs and the basic vulnerability run should be explainable in terms of the exposure levels as shown in the printouts. Since ambulance response only impacts population exposure, we would expect that basic vulnerability ranks would be different for segments where the primary threat is to the property or special facilities category. We also know that since changes in the response time factor are presumed to affect all measures of exposure equally, we can say that this run will (when compared to the basic risk run) only serve to distinguish between the different counties whereas the basic vulnerability run will also highlight differences in exposures between segments within the same county (because of the varying effect of the different response factors on the varying levels of the different exposure measures for each segment). This trend may be masked, however, due to potentially offsetting high and low exposure values for a single segment.

In looking at the actual run results for the response time variations, it is apparent that some of the aforementioned dampened effects took place in the basic vulnerability run. The same type of rank swapping as was observed in the basic vulnerability run occurred except that it was more pronounced. The largest swap that took place was for a segment that was originally in the 25th highest group and now appears in the 15th highest group. Still, the majority of swapping occurs between groups and their adjacent groups. In the case of variations to the level of ambulance response, no change was observed when compared to the original risk groups. This would indicate one of two possibilities. First, that the exposed population variation was not of sufficient magnitude to produce rank changes when ambulance response variations were introduced. This possibility can be virtually discounted because of the large default weight given to population exposure (60%). The second and more plausible explanation is that the original risk ranks were already in order from high

to low population risk (the combination of probability and population exposure). In such an event, lending additional emphasis to population exposure would not change the run's outcome.

Having completed our comparative analysis of the model, we find that the behavior of the MacroRADSS model lends readily to interpretation without requiring the publishing of actual risk and vulnerability values. The behavior of the data set was explainable and the format of the output was of utility to the transportation and overall public service community. This data set was, of course, representative of only one county but it is believed to represent a wide variety of jurisdictions and thus is a good test suitability of the model for larger data sets.

8. RECOMMENDATIONS

8.1 Introduction

There are many suitable avenues available to either refine or extend the work of the MacroRADSS model. In order to provide an orderly account of these potential improvements, this chapter is divided into distinct subsections. The first subsection applies to refinements which affect the model as a whole as well as possible alterations in the objectives of the model. The next three subsections deal with improvements within parts of the model (probability, consequences [exposure], and response capabilities). Lastly, a section is provided to document needs for information which can be obtained from hazmat vehicle surveys and investigations.

8.2 Overall Improvements

So long as the MacroRADSS model remains within the framework of the larger decision support system it was envisioned to serve, the primary purpose for the model must remain in keeping with the needs of the rest of the model. Currently, the need for state- wide analysis has been limited to providing a ranking system to

identify problem risk and vulnerability areas within the state to be targeted for closer scrutiny by other parts of the system.

Because of the large quantities of hazmats being shipped by other modes, particularly by shipping and rail services, it follows that comprehensive hazmat risk and vulnerability modeling should include all viable modes with particular attention to modal interface points. "As far as is known, there have been no analytical studies concerning intermodal routing. Such routing has been discussed, however, such as the EPA's suggestion that barges, as an alternative to trucks, be used for transporting radioactive wastes..." "Studies should be undertaken to address analytically the relative risks of intermodal hazardous material transport" [38]. In preparation for such an endeavor, however, studies should be undertaken which would: identify different types of accident or incident scenarios and forms of exposure which are peculiar to the different modes, the available and proposed databases which are suitable for modeling, and the particular prevention, alleviation, and response needs for each mode.

Public perception of the specific risks involved in hazmat transportation does not necessarily agree with the risk values obtained from objective analysis. For this reason, government agencies (which must answer to public concerns) should try to anticipate these discrepancies between perceived and actual risk. In this way, a program of education can be undertaken to reduce the potential for public concern. As Wright and Glickman observe, "...despite the relevance of public opinion toward decisions made to enhance public safety, little research has been done to predict public response to such decisions." "Although the public may object that they are kept in ignorance of the risks they face, Benwell observed that programs for public education often cause alarm rather than lesson it" [60].

For similar reasons and to insure program cost effectiveness, decision-making authorities should strive to keep track of the success of their risk and vulnerability reduction strategies. "A study is needed to define the benefits, problems, and costs of using risk analysis criteria for decision making..." [38]. A comparison can then be drawn between the cost of the reduction strategy and the actual amounts of risk and vulnerability reduced as well as the nature of accidents or incidents before and after the improvements.

Improvements which are exogenous to the model and its implementation will be addressed within the specific chapter subsections in which they are relevant. Here, however, there is one such improvement which needs mention. As pointed out in Section 3.12, lack of uniformity in hazmat classification, even at the federal level has led to confusion in reporting. "United Parcel Service recognizes the need for a more simplified Guide to assist the shipper in meeting his obligations under Title 49 of the Code of Federal Regulations in shipping of Hazardous Materials" [51]. Regardless of whether or not a single classification system is universally adopted, federal and state authorities must coordinate their efforts to integrate the classification schemes as well as their enforcement strategies. It is hoped that adoption of the MacroRADSS model will lead to greater uniformity in reporting practices. It is also hoped that the TMS, Inc. hazmat classification scheme will prove to be a reasonably sized and logically sound beginning for integration of such schemes to take place.

8.3 Probability

Improvements to data collection practices appear to be the way to improve model accuracy as long as probability is computed in the existing format (i.e., by using historic data). “The most difficult data-gathering problem in State and local studies has been obtaining reliable information on past hazardous materials incidents” “State and local planners usually must rely on outside sources, some of which may be unreliable or contradictory” [53]. Currently, few states distinguish hazmat vehicle involvement in accidents and almost no states report on quantities released. The use of default accident rates would also be improved by using more well-defined data as well as by using state, rather than national, default rates. In either case, “...accident rates by truck type and cargo area configuration...could be incorporated in the risk assessment procedure. Data on differences, if any, between general truck accident rates and hazardous materials truck accident rates would also be desirable. However, these improvements...will only be possible if the quality of exposure data...improves in the future” [24].

To improve flow data, the surrogate population of total trucks must be reduced. This can be done in a number of ways. One possibility is to improve our understanding of the percentages of truck flow attributable to hazmats through random sampling (for further discussion of this see the truck survey subsection 8.6 below). A second approach might be to require separate traffic counts, particularly for high risk or vulnerability routes. Traffic counts would simply distinguish between placarded and nonplacarded trucks. For this reason steps should be taken to either account for or prevent misplacarding. A third alternative would be for the state or other agency to require all shippers of placardable quantities of hazmats to file route

and schedule information. It is recognized that the initial effort in handling such data would be difficult. However, since a large percentage of shipments travel by regular routes and schedules, updating and maintenance of the data would be far less difficult. The benefits of the approach are: enforceability (as a mandatory practice at the state level, this may be a requirement for licensing of shippers); separate data defined by the individual commodity, if desired; verification that the decision support system is considering all the hazmat traveled routes; and flow data which stays current.

8.4 Consequences

The first item which needs to be recognized is that our measure of consequence is an indirect one. "(On relating exposure to effect - or actual consequences:) Although the concept underlying this step is intuitively straightforward - if a little bit causes a little effect, more should cause a larger effect, and a lot should cause a very large effect - the actual business of quantifying the relationship can be quite complicated" [22]. Refinements in this regard should be concerned with producing stochastic measures of actual consequences based on past performance of the hazmat in question. This can be derived either from a sufficiently large population of actual release results or from controlled testing. "In the future, from the results of tests of hazmat damage to structures, it may be possible to consider the susceptibility of different structures, particularly wooden ones, to the effects of dangerous goods. In doing so, it may be assumed that the total replacement cost for some buildings such as barns and old warehouses be incorporated into the method, while only a

partial replacement cost be used for other structures such as bridges.” “...behaviour (of different classes of hazardous materials) in the environment should be studied...Exposure areas should be considered for air, water, ground-surface and sub-surface environments” [48]. In any event, the model would then have to be refined to accept such a stochastic variable with both different degrees of magnitude and variability.

Another area where the MacroRADSS model measures indirectly is in using accident data to represent incident data. This is a faulty surrogate measure, since not all releases are accident related nor do all accidents result in releases. Since we are interested in the effects of the presence of hazmats upon the highway system, the use of incident data is to be preferred. “Future research should consider the feasibility of considering releases from causes other than traffic accidents...” [25]. In order for incident data to be useful, it must be comprehensive. This means that underreporting problems associated with existing incident databases (e.g., RSPA) must be addressed. Problems with the existing collection practices lie in misunderstanding of reporting requirements by shippers as well as the lack of enforcement capabilities. Both of these problems may be remedied but only at considerable expense. One alternative is to shift the requirement for reporting from the shipper to the lead agency responder with the added manpower expense to be borne by the shippers. The responder can have other benefits from such reporting as well (e.g., high efficiency ratings for good report histories, increased resources if judged necessary, case histories to aid in future similar hazmat situations, etc.). Using mandatory lead responder reporting, comprehensive data may be collected on all incidents where response was necessary.

In terms of the existing model, the greatest improvements in sophistication can be made by incorporating more complete measures for special facility and sensitive

area exposure. One of the research needs identified in the MRI report was the ability to evaluate risks “at special facilities such as elevated freeways, depressed freeways, bridges, and tunnels...” “the comparison should consider...the experiences of emergency response personnel at such facilities...” “...priority issues for future research were developed jointly by the MRI/KSU research team and a study review panel... Those responding included: four State highway agency representatives; one State police agency representative; one metropolitan planning organization representative; one consultant; one NTSB representative; and three FHWA representatives” [24]. Eighteen priority topics for research were identified. [24] In the case of sensitive areas, a more refined estimate of the existing parameter can be obtained. It is envisioned that such a parameter would consider not only the size of the demand for water but also the: type of demand (potable or nonpotable), the size of the supply (in millions of gallons per day for rivers, acre-feet for reservoirs, etc.), and the downstream distance from the incident site to the public water intake (or rather time to reach the intake facility). Other measures of sensitive areas, as have been suggested in the Canadian Route Screening Method, should be incorporated once logical, quantitative modeling of such exposures is developed. As is the case with exposure measures in general, a user defined weighting system for these measures would be required. The Canadian report suggests that “Wildlife surveys should be carried out to determine the numbers of birds, mammals and other wildlife in a given area” “Such surveys should begin with available information in support of biological maps” [48].

Other measures of exposure, which are now left to be considered solely by engineering judgement, may also be considered in a separate package after the objective analysis is completed. MRI suggests “An expert system...to consider the role of subjective factors...could make available...the opinions of a panel of experts

concerning the relative risks..." [25]. This would be of most help to users, unfamiliar with the implications of these subjective factors, who are placed in tie breaking decision situations.

8.5 Response Capabilities

The areas of improved modeling for response capabilities would not deal with other types of responders (unless industry sponsored response or first response hazmat specialty teams became commonplace), but rather with the quality of first-to-the- scene response. "Communities may want to consider (modeling) the availability of heavy equipment, booms, skimmers, absorbent materials, gas masks and acid suits to fire companies" [48]. MRI feels that "...it is vital that the rating of emergency response abilities include consideration of more qualitative factors, such as the level of training and experience of emergency responders" [25]. In this regard we observe that jurisdictions which are unaware of the nature of the hazmat threats they face are at a disadvantage in their planning efforts. In situations where inadequate planning exists, it is possible that well trained crews or specialized equipment may be misdirected within the organization. Here the true benefit of vulnerability modeling is realized as jurisdictions organize their resources to counter the identified threats.

The process is hopefully an iterative one. As jurisdictions become aware of new hazmat threats, they not only provide comprehensive system planning (e.g., evacuation, response, road improvement, etc.) but also become more aware of their best management strategies. Specific ways to apply MacroRADSS output would

include: comprehensive highway plan creation, interception patrol route planning, evacuation planning, responder drills, and streamlined communication through lead agency designation. Planning agencies within highway departments or similar organizations may be able to improve community planning on their own. "It would not be difficult to undertake contingency planning... In many cases relatively inexpensive road drainage reconstruction projects could provide temporary containment of hazardous material spills" [10]. MRI also notes that "...highway agencies may support emergency response capabilities through training and through prepositioning of emergency response supplies at highway agency maintenance yards" [26]. Once these improvements have been identified, information on community problem areas would then be furnished to the local jurisdictions. "Installations with hazardous commodities and the hazardous material shipping routes should be indicated on a map to be distributed to all responding (fire) companies, appropriate chiefs, and fire alarm dispatchers" [18]. Police departments could benefit from this information by training for the specific classes of materials which threaten, and by using risk results to help design interception patrol routes in areas where first response time may be excessive. Interception patrols are situations where police patrol specific areas in order to detect threatening activity. They are costly to run and are usually restricted to hours of darkness or a slightly larger number of hours per week for small cities. "The major function of the (interception police) patrol during the daytime is to provide a reaction force..." "In a test with the Syracuse, New York, police force, the use of computer-designed routes increased the interception probability by 50 per cent" [11]. This is not to say that hazmat release detection should outweigh criminal activity detection, but rather that police on patrol may be made aware of the possibility of hazmat releases in their area.

Response planning of a more general nature should be conducted by a designated lead agency with input from all other potential responders. "Although planning initiated by a single (fire) company or shift will greatly improve their ability to cope..., the preferred method of planning is one that is organized through and endorsed by the administrators of the entire emergency response delivery system" [18]. This planning may require evacuation planning. "Detailed plans for the evacuation of special facilities are essential to the minimization of injuries and confusion" [59]. Also, drills conducted by any or all responders may be appropriate. "These (accident and response capability) data can be used to develop realistic hazardous materials drills to sites and for hazardous materials known to be at risk in a given locality" [31]. Finally, even though the model will not mandate such, lead agencies may wish to predetermine available specialized equipment. Price, Schmidt, and Davis hold that "...responders in the most dangerous localities need to inventory their hazardous materials accident equipment or make arrangements to borrow needed equipment on a demand basis" [31].

8.6 Need for Roadway Surveys

There is a need to improve the (flow) measurement methodology if hazardous materials risk on highways is to be more accurately estimated [45].

The weakest link in the MacroRADSS model is its reliance on the surrogate populations of total trucks for hazmat flow levels and accident data for incident data. While the second surrogate deals with two distinct sets of data, the first deals with data that includes the parameter we are really interested in as a subset. Consequently, it is possible to refine our estimate of hazmat flow data using the total

truck surrogate with better correlation values. “Communities may wish to conduct an inventory of the dangerous goods that are currently being transported by truck through the region to gain an appreciation for the extent of the problem.” “...it may be very helpful to prepare...an inventory to assess the need for dangerous goods routes” [48]. By collecting such data for specific conditions (e.g., road type, terrain, etc.), we may be able to redefine national default values continuously, based on observed characteristics for multiple states. This would help alleviate a genuine lack of data as observed by List and Abkowitz: “Although a national reporting system for hazardous materials transport incidents exists, a companion data base on hazardous materials movements does not” [21].

One other form of in-the-field measurement may prove useful to refine the existing modeling parameters. “MRI recommends that the distribution of accident types on each highway be determined in...(a truck accident survey)” [25]. Since different accident types may have different release probability distributions, it follows that distinguishing these patterns periodically for different highway types, will improve our estimate of release probability in its present format. What is required is on-site investigation of selected accidents by trained observers to determine the nature of the accidents and the extent of the release.

BIBLIOGRAPHY

- [1] Abkowitz, M., Eiger, A. and Srinivasan, S. "Estimating the Release Rates and Costs of Transporting Hazardous Waste" Transportation Research Record #977: Transportation of Hazardous Materials: Planning and Accident Analysis (Washington, DC: Transportation Research Board, 1984) pp. 22-30.
- [2] Abkowitz, M. and List, G. "Estimates of Current Hazardous Materials Flow Patterns" Transportation Quarterly, Vol. 40, no. 4, October 1986 pp. 483-502.
- [3] Abkowitz, M. and List, G. "Hazardous Materials Transportation Incident-Accident Information Systems" Transportation Research Record #1148: Hazardous Materials Transportation, Work-zone Traffic Control, and Traffic Marking Materials (Washington, DC: Transportation Research Board, 1987) pp.1-8.
- [4] American Association of State Highway and Transportation Officials: Administrative Subcommittee on Computer Technology Computer Systems Index 1985 (Washington, DC: AASHTO, 1985).
- [5] Anonymous "Transportation of Hazardous Materials: Toward a National Strategy" TR News No. 107, July-August 1983 pp.7-10.
- [6] Bowman, G. M. A Study of Optimal Siting of Hazardous Materials Response Teams in the Commonwealth of Virginia (Charlottesville, VA: Virginia Transportation Research Council, May 1987).
- [7] Bowman, G. M. Hazardous Materials Programs in the Fifty States (Charlottesville, VA: Virginia Transportation Research Council, January 1988).
- [8] Bowman, G. M. Hazardous Materials Regulation in Virginia (Charlottesville, VA: Virginia Transportation Research Council, February 1987).
- [9] Brogan, J. D. and Cashwell, J. W. "Routing Models for the Transportation of Hazardous Materials-State Level Enhancements and Modifications" Transportation Research Record #1020: Improving Transportation of Hazardous Materials through Risk Assessment and Routing (Washington, DC: Transportation Research Board, 1985) pp. 19-22.
- [10] Crusberg, T. C., Hoffman, A. H., Murray, B. E., Cull, B. D. and Barnes, C. E. "Planning for a Transportation- related Hazardous Material Spill in a Municipal Watershed" Transportation Research Record #977: Transportation of Hazardous

Materials: Planning and Accident Analysis (Washington, DC: Transportation Research Board, 1984) pp. 1-6.

- [11] Elliott, J. F. Ph.D. Interception Patrol: An Examination of the Theory of Random Patrol as a Municipal Police Tactic (Springfield, IL: Charles C. Thomas-Publisher, 1973).
- [12] Geysen, W. J. "The Transport System of Dangerous Products as a Risk Factor for the Future: The Computer-Aided Information Program on Hazardous Materials" Transportation Research Board State of the Art Report #3: Addendum , 1987 pp. 10-16.
- [13] Haddow, G. D. "The Safe Transportation of Hazardous Materials" Transportation Quarterly , Vol. 41, no. 3, July 1987 pp. 309-322.
- [14] Haimes, Y. Y. "Risk-Benefit Analysis in a Multiobjective Framework" Risk/Benefit Analysis in Water Resources Planning and Management (Plenum Publishing Corporation, 1981) pp. 89-122.
- [15] Haimes, Y. Y. "Risk and Impact Analyses in a Multiobjective Framework" Risk-based Decision Making in Water Resources (New York: American Society of Civil Engineers, 1986) pp.46-64.
- [16] Harris, N. C., Roodbol, G. G. and Ale, B. J. M. "Risk Assessment of Alternative Transport Modes for Hazardous Materials" Transportation Research Board State of the Art Report #3 pp.47-52.
- [17] Horodiniceanu, M. and Cantilli, E. J. Transportation System Safety (Lexington, MA: D.C. Heath and Company, 1979).
- [18] Isman, W. E. and Carlson, G. P. Hazardous Materials (Encino, CA: Glencoe Publishing Co., Inc., 1980).
- [19] Lautkaski, R. "Use of Risk Analysis in Enhancing the Safety of Transporting Hazardous Liquefied Gases" Transportation Research Board State of the Art Report #3 , 1986 pp. 59-63.
- [20] Li, D. and Haimes, Y. Y. "Risk Management in a Hierarchical Multiobjective Framework" Lecture Notes in Economics and Mathematical Systems #286: Toward Interactive and Intelligent Decision Support Systems , Vol. 2 Berlin: Springer-Verlag, 1987) pp. 180-189.
- [21] List, G., Abkowitz, M. A. and Page, E. "Information Sources for Flow Analyses of Hazardous Materials" Transportation Research Record #1063: Transportation of Hazardous Materials (Washington, DC: Transportation Research Board, 1986) pp. 15-20.
- [22] Lowrance, W. W. Of Acceptable Risk: Science and the Determination of Safety (Los Altos, CA: William Kaufmann, Inc., 1976).

- [23] Megill, R. E. An Introduction to Risk Analysis , 2nd ed. (Tulsa: PennWell Publishing Co., 1984).
- [24] Midwest Research Institute Present Practices of Highway Transportation of Hazardous Materials: Draft Final Report Contract No. DTFH61-86-C-00039 (McLean, VA: Federal Highway Administration, February 28, 1989).
- [25] Midwest Research Institute Present Practices of Highway Transportation of Hazardous Materials: Recommended Revisions to the 1980 FHWA Hazardous Materials Routing Guide Contract No. DTFH61-86-C-00039 (McLean, VA: Federal Highway Administration, January 22, 1988).
- [26] Midwest Research Institute Present Practices of Highway Transportation of Hazardous Materials: Task B Interim Report, Literature Review Contract No. DTFH61-86-C-00039 (McLean, VA: Federal Highway Administration, January 30, 1987).
- [27] Midwest Research Institute Present Practices of Highway Transportation of Hazardous Materials: Task C Interim Report, Analysis of Existing Data Bases Contract No. DTFH61-86-C-00039 (McLean, VA: Federal Highway Administration, May 19, 1987).
- [28] Nemmers, C. and William, W. L. "Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials" Civil Engineering for Practicing and Design Engineers , Vol. 2, 1983 pp. 447-456.
- [29] Organization for Economic Co-operation and Development Road Transport Research: Transporting Hazardous Goods by Road (Paris: OECD Publications, 1988).
- [30] Pijawka, K. D., Foote, S. and Soesilo, A. "Risk Assessment of Transporting Hazardous Material: Route Analysis and Hazard Management" Transportation Research Record #1020: Improving Transportation of Hazardous Materials through Risk Assessment and Routing (Washington, DC: Transportation Research Board, 1985) pp.1-5.
- [31] Price, D. L., Schmidt, J. W. and Davis, R. P. "Hazardous Materials Highway Transportation Accident Potentials in Virginia" Accident Analysis & Prevention , Vol. 14, no. 4, 1982 pp. 257-265.
- [32] Price, D. L., Schmidt, J. W. and Kates, R. W. Multi Modal Hazardous Materials Transportation in Virginia (Blacksburg, VA: Virginia Polytechnic Institute and State University, September 1981).
- [33] Radwan, A. E., Pijawka, K. D., Soesilo, A. and Shieh, F. "Transportation of Hazardous Wastes in Arizona: Development of a Data Base Management System for Basic Analysis" Transportation Research Record #1063: Transportation of Hazardous Materials (Washington, DC: Transportation Research Board, 1986) pp. 1-7.

- [34] Raj, P. K. and Glickman, T. S. "Generating Hazardous Material Risk Profiles on Railroad Routes" Transportation Research Board State of the Art Report #3 , 1986 pp.53-59.
- [35] Rawls, R. L. "Chemical Transport-coping with disasters" Chemical & Engineering News , November 24, 1980 pp. 20-30.
- [36] Rescher, N. Risk: A Philosophical Introduction to the Theory of Risk Evaluation and Management (Washington, DC: University Press of America, 1983).
- [37] Rittvo, S. M. and Haddow, G. D. "Transportation of Hazardous Materials: A Case Study" Transportation Quarterly , Vol. 38, no. 1, January 1984 pp. 137-151.
- [38] Rowe, W. D. National Cooperative Highway Research Program Synthesis of Highway Practice #103: Risk Assessment Processes for Hazardous Materials Transportation (Washington, DC: Transportation Research Board, November 1983).
- [39] Sabey, B. E. and Taylor, H. "The Known Risks We Run: the Highway" Societal Risk Assessment: How Safe is Safe Enough? (New York: Plenum Press, 1980) pp. 43-70.
- [40] Saccomanno, F. F. and Chan, A. Y.-W. "Economic Evaluation of Routing Strategies for Hazardous Road Shipments" Transportation Research Record #1020: Improving Transportation of Hazardous Materials through Risk Assessment and Routing (Washington, DC: Transportation Research Board, 1985) pp. 12-18.
- [41] Saccomanno, F. F., Van Aerde, M. and Queen, D. "Interactive Selection of Minimum-Risk Routes for Dangerous Goods Shipments" Transportation Research Record #1148: Hazardous Materials Transportation, Work-zone Traffic Control, and Traffic Marking Materials (Washington, DC: Transportation Research Board, 1987) pp. 9-17.
- [42] Scanlon, R. D. and Cantilli, E. J. "Assessing the Risk and Safety in the Transportation of Hazardous Materials" Transportation Research Record #1020: Improving Transportation of Hazardous Materials through Risk Assessment and Routing (Washington, DC: Transportation Research Board, 1985) pp. 6-11.
- [43] Shoemaker, P. J. H. Experiments on Decisions under Risk: the Expected Utility Hypothesis (Boston: Martinus Nijhoff Publishing, 1980).
- [44] Soeteber, P. K. "Incidence, Regulation, and Movement of Hazardous Materials in New Jersey" Transportation Research Record #1063: Transportation of Hazardous Materials (Washington, DC: Transportation Research Board, 1986) pp. 8-14.
- [45] Stough, R. R. and Hoffman, J. "Assessing the Risk of Hazardous Materials Flows: Implications for Incidence Response and Enforcement Training" Transportation Research Record #1063: Transportation of Hazardous Materials (Washington, DC: Transportation Research Board, 1986) pp. 27-32.

- [46] Tamura, H., Mori, Y. and Nakamura, Y. "On a Measurable Value Function under Risk" Lecture Notes in Economics and Mathematical Systems #286: Toward Interactive and Intelligent Decision Support Systems , Vol. 2 (Berlin: Springer-Verlag, 1987) pp. 210-219.
- [47] Tomachevsky, E. G., Ringot, C., Pages P. and Hubert, P. "A Validation Study of the INTERTRAN Model for Assessing Risks of Transportation Accidents: Road Transport of Uranium Hexafluoride" Transportation Research Board State of the Art Report #3: Addendum , 1987 pp. 17-23.
- [48] Transport Canada: Transport Dangerous Goods Directorate Dangerous Goods Truck Route Screening Method for Canadian Municipalities-Consultant's Report (Vancouver, 1987).
- [49] Transport Canada: Transport Dangerous Goods Directorate Dangerous Goods Truck Route Screening Method for Canadian Municipalities-Workbook (Vancouver, 1987).
- [50] Turnquist, M. A. "Research Opportunities in Transportation System Characteristics and Operations" Transportation Research. Part A: General , Vol. 19A, no. 5/6, September 1985 pp. 357-366.
- [51] UPS Guide for Shipping Hazardous Materials (Greenwich, CT: June 1981).
- [52] U.S. Congress, Office of Technology Assessment Transportation of Hazardous Materials , OTA-SET-304 (Washington, DC: U.S. Government Printing Office, July 1986).
- [53] U.S. Congress, Office of Technology Assessment Transportation of Hazardous Materials: State and Local Activities , OTA-SET-301 (Washington, DC: U.S. Government Printing Office, March 1986).
- [54] U.S. Congress, Office of Technology Assessment Transportation of Hazardous Materials: Summary , OTA-SET-305 (Washington, DC: U.S. Government Print Office, July 1986).
- [55] U.S. Department of Commerce: Environmental Quality Council An Appraisal of the Problem of the Handling, Transportation, and Disposal of Toxic and other Hazardous Materials (Springfield, VA: National Technical Information Service, January 1970).
- [56] U.S. Department of Energy An Assessment of the Risk of Transporting Gasoline by Truck , Contract # EY-76-C-06-1830 (Richland, WA: Pacific Northwest Laboratory, November 1978).
- [57] U.S. Department of Transportation: Federal Highway Administration Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials , FHWA-IP-80-15 Implementation Package (Washington, DC: U.S. Government Printing Office, November 1980).

- [58] U.S. Department of Transportation: Research and Special Programs Administration "Detailed Hazardous Materials Incident Reports" Federal Register , Vol. 52, no. 59, March 27, 1987 pp.9996-10004.
- [59] U.S. Department of Transportation: Research and Special Programs Administration Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials , DOT/RSPA/MTB-84/22 (Washington, DC: June 1984).
- [60] Wright, M. E. and Glickman, T. S. "A Survey of Foreign Hazardous Materials Transportation Safety Research since 1978" Transportation Research Record #977: Transportation of Hazardous Materials: Planning and Accident Analysis (Washington, DC: Transportation Research Board, 1984) pp. 39-43.
- [61] Yu, J. C. and Judd, C. A. "Cost-effectiveness Analysis of Transportation Strategies for Nuclear Waste Repository Sites" Transportation Research Record #1020: Improving Transportation of Hazardous Materials through Risk Assessment and Routing (Washington, DC: Transportation Research Board, 1985) pp. 23-30.
- [62] Asbeck, E. L and Haines, Y. Y "The Partitioned Multiobjective Risk Method (PMRM)" Large Scale Systems 6 (North Holland: Elsevier Science Publishers B.V.,1984) pp. 13-38.
- [63] National Response Team of the National Oil and Hazardous Substances Contingency Plan Hazardous Materials Emergency Planning Guide , NRT-1 (Washington, DC: March 1987).

Appendix A.

1. Default Hazmat Flows and Release Rates

Table A-1: Excerpts from BMCS-Reported Truck Accidents by Highway Type and Area Type, 1984-1985

Highway Type/ Area Type	All Truck Accidents	Hazmat Accidents	% Hazmat acc. with Release
Rural Areas/ 2-lane	16,829	1242	19.1
4-lane (or more) undivided	1302	49	10.2
4-lane (or more) divided	17,268	677	14.5
Business Areas/ 2-lane	8925	342	10.2
4-lane (or more) divided	8513	368	7.6
Residential Areas/ 2-lane	2355	113	12.4

Table A-2: PennDOT Highway Classes

Code Number	Road Type
1	State Highway and also a Municipal Street
2	State Highway but not a Municipal Street
3	Municipal Street/Township Road, not a State Road
4	County Road
5	Private Road or Area
6	Pennsylvania Turnpike - Main Branch
7	Pennsylvania Turnpike - NE Extension

Table A-3: MacroRADSS default values

Road Type	PennDOT code (mod.)	% Release	Hazmat Accident % of Total Truck
State Hwy. & Mun. St.	1	19.1	1242/16,829
State Hwy.	2	10.2	49/1302
Mun. St.	3	(10.2 + 12.4)/2	(113/2355 + 342/8925)/2
County Rd.	4	19.1	1242/16,829
Private Rd.	5	12.4	113/2355
Interstate (Rural*)	8	14.5	677/17,268
Interstate (Urban*)	9	7.6	1036/25,391

* Urban vs. Rural depending on the URBANRURAL variable field on the PennDOT accident record system

2. Building Replacement Costs and Locality Cost

Adjustment Factors

Table A-4:

The following is a list of building types and associated average costs to construct such buildings within the United States as reported in the 1987 Dodge Assemblies Cost Data book (see p. 27):

	sq. ft.	\$/sq. ft.	Total \$
For Residential Buildings:			
* Apt. Buildings-Low Rise	100,000	38.55	3,855,000
* Apt. Building-High Rise	100,000	52.15	5,215,000
* Apartment for Handicapped	24,000	66.25	1,590,000
* Multi-Story Houses	65,000	42.54	2,765,000
* Nursing Homes	30,000	61.31	1,839,000
* Parish House	4,000	63.50	254,000
For Commercial Buildings:			
	sq. ft.	\$/sq. ft.	Total \$

* Auto Dealers Building	14,000	42.55	596,000
* Banks (Branch)	30,000	90.30	2,709,000
* Cinema, Six Screen	25,000	31.67	792,000
* Convenience Store	2,000	72.88	146,000
* Department Store	125,000	54.10	6,763,000
* Dining Restaurants	6,000	88.10	529,000
* Office-Atrium	180,000	75.63	13,613,000
* Office Buildings	20,000	71.53	1,431,000
* Restaurant (Fast Food)	1,450	94.53	137,000
* Service/Gas Stations	950	44.63	2,000
* Shopping Center	175,000	43.26	7,571,000
* Stores, Shops	12,000	47.45	569,000
* Supermarkets, Foodstores	25,000	47.44	1,186,000

For Industrial Buildings:	sq. ft.	\$/sq. ft.	Total \$
* Manufacturing (Light)	20,000	40.99	820,000
* Manufacturing (Heavy)	30,000	60.85	1,826,000
* Mini-Warehouse	20,000	17.29	346,000
* Office & Warehouse	25,000	39.30	983,000
* Process Plants (Chemical)	40,000	50.87	2,035,000
* Process Plants (Food)	100,000	61.28	6,128,000
* Research Development	10,000	71.00	710,000
* Warehouses (Refrig.)	40,000	61.30	2,452,000

For Agricultural Buildings, assume:

	sq. ft.	\$/sq. ft.	Total \$
* 1/2 Parish House	2,000	63.50	
+ 1/4 Mini-Warehouse	5,000	17.29	213,000

Table A-5: From the above building types, we obtain the average building replacement costs for given, generalized categories shown below using the assumed mix of building types indicated in parentheses:

For Residential Buildings:	sq. ft.	\$/sq. ft.	Total \$
I. Low Density (1/2 Parish House)	2,000	63.50	127,000
II. Medium Density (1 Apt. Building-Low Rise, 1 Multi-Story House, 1 Nursing Home)	65,000	47.47	3,086,000
III. High Density (2 Apt. Buildings-High Rise, 1 Apartment for Handicapped)	74,667	56.85	4,245,000
For Commercial Buildings:	sq. ft.	\$/sq. ft.	Total \$
I. Retail Commercial- Rural Mix (1 Auto Dealer Building, 3 Banks (Branch), 1 Cinema, Six Screen, 5 Convenience Stores, 1 Dining	17,175	64.29	1,104,000

Restaurant, 3 Restaurants (Fast Food), 3 Service/Gas Stations, 1 Shopping Center, 5 Stores, Shops, 1 Supermarket, Foodstore)			
II. Office Commercial	73,333	72.90	5,346,000
(1 Office-Atrium, 2 Office Buildings)			
III. Retail Commercial-	33,783	65.47	2,212,000
Urban Mix (3 Auto Dealers Buildings, 9 Banks (Branch), 1 Cinema, Six Screen, 5 Convenience Stores, 3 Department Stores, 3 Dining Restaurants, 3 Restaurants (Fast Food), 5 Service Stations/Gas Stations, 3 Shopping Centers, 3 Stores, Shops, 3 Super- markets, Foodstores)			
For Industrial Buildings:	sq. ft.	\$/sq. ft.	Total \$
I. Light Industrial	21,667	32.53	705,000
(1 Manufacturing Light, 1 Mini-Warehouse, 1 Office & Warehouse)			
II. Heavy Industrial	29,250	46.00	1,346,000
(5 Manufacturing Light, 3 Manufacturing Heavy, 3 Mini-Warehouses, 5 Office & Warehouse, 1 Process Plant (Chemical), 1 Process Plant (Food), 1 Research Development, 1 Warehouse (Refrig.))			
For Agricultural Buildings: (see Table A-4)			

Table A-6: From the above generalized categories, we obtain the average replacement cost for each type of building, indicated below, using the accompanying assumptions about rural and urban patterns for development of each type:

RURAL

Assumption Used:	Average Replacement Cost
Residential (2/3 Low, 1/3 Medium)	\$1,113,000
Commercial (Retail-Rural Mix)	\$1,104,000
Industrial (Light)	\$705,000
Agricultural	\$213,000

URBAN:

Assumption Used:	Average Replacement Cost
Residential (1/3 Low, 1/3 Medium, 1/3 High)	\$2,486,000
Commercial (1/2 Office, 1/2 Retail- Urban Mix)	\$3,779,000
Industrial (Heavy)	\$1,346,000

Adjustment Factors Table (see Figure A-1)

Locality	Location Factors Considered	Factor Used
A	Erie, Erie Co. (0.92) Waterford, Erie Co. (0.92)	0.92
B	DuBois, Clearfield Co. (0.91)	0.91
C	Williamsport, Lycoming Co. (0.88)	0.88
D	Scranton, Lackawanna Co. (0.90)	0.90
E	Ellwood City, Lawrence Co. (1.01) New Castle, Lawrence Co. (0.98)	0.995
F	Dayton, Armstrong Co. (0.95) Sagamore, Armstrong Co. (0.95) Johnstown, Cambria Co. (0.95) Indiana, Indiana Co. (0.95) Jennerstown, Somerset Co. (0.95) Somerset, Somerset Co. (0.95) Ursina, Somerset Co. (0.95)	0.95
G	Wilkes-Barre, Luzerne Co. (0.89)	0.89
H	Altoona, Blair Co. (0.85)	0.85
I	Lancaster, Lancaster Co. (0.81) New Holland, Lancaster Co. (0.81) Quarryville, Lancaster Co. (0.81) Bartonsville, Monroe Co. (0.81)	0.81
J	Reading, Berks Co. (0.96)	0.96
K	Allentown, Lehigh Co. (0.97)	0.97
L	Pittsburgh, Allegheny Co. (1.01)	1.01
M	Greensburg, Westmoreland Co. (1.01) Murrysville, Westmoreland Co. (0.98) Vandergrift, Westmoreland Co. (1.01)	1.00
N	Harrisburg, Dauphin Co. (0.87) Middletown, Dauphin Co. (0.94)	0.905
O	Levittown, Bucks Co. (1.08) King of Prussia, Montgomery Co. (1.08) Pottstown, Montgomery Co. (1.08) Philadelphia, Philadelphia Co. (1.08)	1.08
P	Washington, Washington Co. (0.93)	0.93
Q	Camp Hill, Cumberland Co. (0.87)	0.87
R	Coatesville, Chester Co. (1.08) Oxford, Chester Co. (0.81) West Chester, Chester Co. (1.08)	0.99

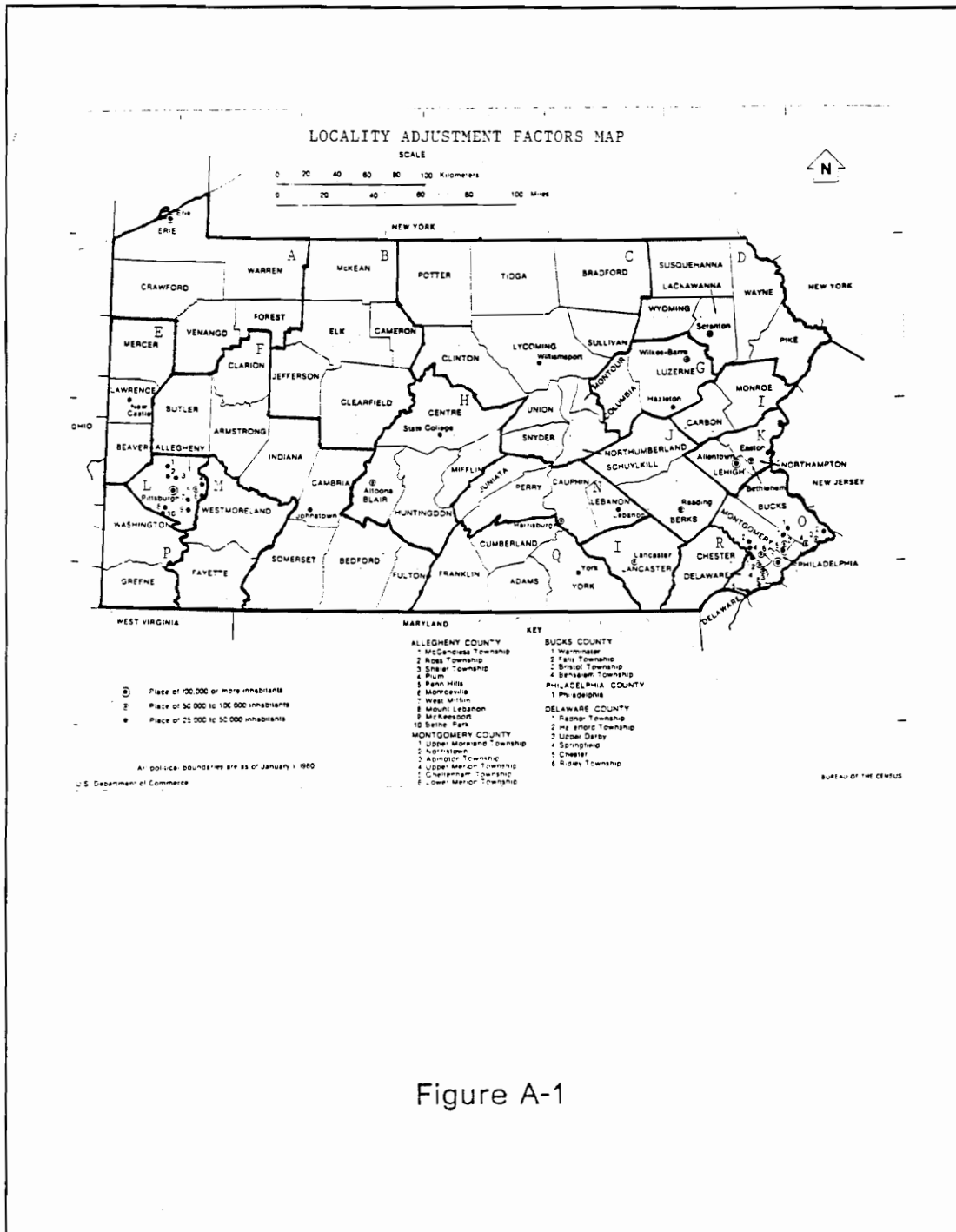


Figure A-1

Appendix B.

```

*****
** MacroRADSS Version 1.0 **
** developed by **
** Charles E. Taylor for **
** University Center for **
** Transportation Research **
** at Virginia Tech **
** 106 Faculty Street **
** Blacksburg, VA 24061 **
** (703) 231-7740 **
*****

Begin Main Program
DEFDBL Y,P
COMMON SHARED J,B,F
10 CALL SCRNMKR4 "Main program's screen generator"
LOCATE 6,17
PRINT "(County and Municipality Vulnerability Assessment)"
COLOR 15
LOCATE 8,36
PRINT "MAIN MENU"
DRAW "BM 275,118"
DRAW "M 355,118"
DRAW "BM 355,120"
DRAW "M 275,120"
B% = 1
-----
DO "First screen asks user to choose
which operation to perform some
operations are unavailable.
LOCATE 13,25
COLOR 15
IF B% = 1 THEN COLOR 9
PRINT "(A) EXECUTE ANALYSIS FOR GIVEN FILES"
LOCATE 15,25
COLOR 15
IF B% = 2 THEN COLOR 9
PRINT "(B) What if..."
LOCATE 17,25
COLOR 15
IF B% = 3 THEN COLOR 9
PRINT "(C) WRITE MicroRADSS FILES"
LOCATE 19,25
COLOR 15
IF B% = 4 THEN COLOR 9
PRINT "(D) EXIT MacroRADSS"
DO
AS=""
AS=INKEY$
LOOP UNTIL AS<>" "
IF LEN(AS)=2 THEN AS=MID$(AS,2,1)
IF ASC(MID$(AS,1,1))=13 THEN EXIT DO
IF ASC(MID$(AS,1,1))=80 THEN B%=B%+1
IF ASC(MID$(AS,1,1))=72 THEN B%=B%-1
IF B%>=5 THEN B%=1
IF B%<=0 THEN B%=4
LOOP
IF B%=1 GOTO 20
IF B%=2 THEN B%=3
IF B%=3 THEN LOCATE 22,10 : PRINT "PACKAGE UNAVAILABLE" ;
FOR I=1 TO 15000 : NEXT I : GO TO 10
IF B%=4 THEN END
-----
This is the beginning of the Probability Calcula-
tion module. Here the program obtains link data from
a user specified filename on the A drive and performs
calculations to obtain individual link probabilities
and then averages these values over link lengths for
each municipality and county in question.
20 FILES="PROB"
CALL SCREENMKR "Probability task screen generator"
LOCATE 4,9
PRINT "***** Now entering the Risk/Vulnerability Analysis_
Package *****"
LOCATE 8,14
PRINT "PLEASE INPUT YOUR DATA SET'S PERIOD OF RECORD (years): "
INPUT N
LOCATE 10,14
PRINT "Thank you."
LOCATE 15,10
PRINT "PLEASE ENTER YOUR PROBABILITY DATA FILE NAME FOR FILE_
IN DRIVE A."
LOCATE 16,10
PRINT "DO NOT ENTER THE EXTENSION (.DAT IS ASSUMED). DEFAULT_
FILENAME IS"

```

```

LOCATE 17,10
PRINT "PROB:"
LOCATE 20,32
INPUT "N = >" FILES
FILENAME$="A:" + FILES + ".DAT"
LOCATE 21,32
PRINT "Thank you."
CALL SCREENMKR
LOCATE 8,15
PRINT "Now reading probability data..."
OPEN FILENAMES FOR RANDOM AS #1 LEN = 238
  Read in the string variables from the specified
  random access file. STR'S refers to the street no.,
  RDTYPE'S refers to the ROADTYPE field from the Penn-
  DOT accident data base, HAZNO'S refers to the number
  of hazmat accidents on the link during the period of
  record, AD'S refers to the average daily truck traf-
  fic on the link, SEGM'S is the link length in feet,
  CNAMES is the county name, MNAMES is the municipality
  name, AGES is the age of the oldest data on the data
  line in the file, MUNICS is the municipality code and
  NOOFST$ is the no. of streets on the data line.
  FIELD #1,2 AS AGES,5 AS MUNICS,2 AS NOOFST$,
  6 AS STR1$,1 AS RDTYPE1$,2 AS HAZNO1$,7 AS AD1$,6 AS SEGM1$,
  6 AS STR2$,1 AS RDTYPE2$,2 AS HAZNO2$,7 AS AD2$,6 AS SEGM2$,
  6 AS STR3$,1 AS RDTYPE3$,2 AS HAZNO3$,7 AS AD3$,6 AS SEGM3$,
  6 AS STR4$,1 AS RDTYPE4$,2 AS HAZNO4$,7 AS AD4$,6 AS SEGM4$,
  6 AS STR5$,1 AS RDTYPE5$,2 AS HAZNO5$,7 AS AD5$,6 AS SEGM5$,
  6 AS STR6$,1 AS RDTYPE6$,2 AS HAZNO6$,7 AS AD6$,6 AS SEGM6$,
  6 AS STR7$,1 AS RDTYPE7$,2 AS HAZNO7$,7 AS AD7$,6 AS SEGM7$,
  6 AS STR8$,1 AS RDTYPE8$,2 AS HAZNO8$,7 AS AD8$,6 AS SEGM8$,
  6 AS STR9$,1 AS RDTYPE9$,2 AS HAZNO9$,7 AS AD9$,6 AS SEGM9$,
  14 AS CNAMES,15 AS MNAMES
A = LOF(1)/238
DIM MUNICI(A),NOOFSTR(A)
FOR I = 1 TO A
  GET #1, I
  MUNICI(I) = VAL(MUNICS)
  NOOFSTR(I) = VAL(NOOFST$)
NEXT I
B = 1
APRIME = A-1
FOR I = 1 TO APRIME
IF (MUNICI(I) = MUNICI(I + 1)) GOTO 30
B = B + 1
30 NEXT I
DIM MUN(B),NOHAZ(B)
C = 1
D = NOOFSTR(1)
MUNIC = MUNICI(C)
FOR I = 1 TO A
IF (MUNICI(I) = MUN(C)) GOTO 40
C = C + 1
MUNIC = MUNICI(I)
40 IF (NOOFSTR(I) <= D) GOTO 50
D = NOOFSTR(I)
50 NEXT I
DPRIME = A-9
DIM STRT1(A),STTYPE1(A),HAZ1(A),ADM1(A),SEGL1(A)
DIM STRT2(A),STTYPE2(A),HAZ2(A),ADM2(A),SEGL2(A)
DIM STRT3(A),STTYPE3(A),HAZ3(A),ADM3(A),SEGL3(A)
DIM STRT4(A),STTYPE4(A),HAZ4(A),ADM4(A),SEGL4(A)
DIM STRT5(A),STTYPE5(A),HAZ5(A),ADM5(A),SEGL5(A)
DIM STRT6(A),STTYPE6(A),HAZ6(A),ADM6(A),SEGL6(A)
DIM STRT7(A),STTYPE7(A),HAZ7(A),ADM7(A),SEGL7(A)
DIM STRT8(A),STTYPE8(A),HAZ8(A),ADM8(A),SEGL8(A)
DIM STRT9(A),STTYPE9(A),HAZ9(A),ADM9(A),SEGL9(A)
DIM YSTREET(DPRIME)
V = 0
FOR I = 1 TO A
COUNT = (I-1)*9
GET #1, I
  GAPS = MUNICS + STR1$ 'Assemble street codes from
  'municipality codes and
  'street numbers.
  YSTREET(COUNT + 1) = VAL(GAPS)
  GAPS = MUNICS + STR2$
  YSTREET(COUNT + 2) = VAL(GAPS)
  GAPS = MUNICS + STR3$
  YSTREET(COUNT + 3) = VAL(GAPS)
  GAPS = MUNICS + STR4$
  YSTREET(COUNT + 4) = VAL(GAPS)
  GAPS = MUNICS + STR5$
  YSTREET(COUNT + 5) = VAL(GAPS)
  GAPS = MUNICS + STR6$
  YSTREET(COUNT + 6) = VAL(GAPS)
  GAPS = MUNICS + STR7$
  YSTREET(COUNT + 7) = VAL(GAPS)
  GAPS = MUNICS + STR8$
  YSTREET(COUNT + 8) = VAL(GAPS)
  GAPS = MUNICS + STR9$
  YSTREET(COUNT + 9) = VAL(GAPS)
IF MUNICI(I) = MUNICI(I-1) GOTO 60
V = V + 1
NOHAZ(V) = VAL(HAZNO1$)
GO TO 70

```

```

60 NOHAZ(V) = NOHAZ(V) + VAL(HAZNO1$)
70 STRT1(I) = VAL(STR1$)
STTYPE1(I) = VAL(RDTYPE1$)
HAZ1(I) = VAL(HAZNO1$)
ADM1(I) = VAL(AD1$)
SEGL1(I) = VAL(SEGM1$)
STRT2(I) = VAL(STR2$)
STTYPE2(I) = VAL(RDTYPE2$)
HAZ2(I) = VAL(HAZNO2$)
NOHAZ(V) = NOHAZ(V) + HAZ2(I)
ADM2(I) = VAL(AD2$)
SEGL2(I) = VAL(SEGM2$)
STRT3(I) = VAL(STR3$)
STTYPE3(I) = VAL(RDTYPE3$)
HAZ3(I) = VAL(HAZNO3$)
NOHAZ(V) = NOHAZ(V) + HAZ3(I)
ADM3(I) = VAL(AD3$)
SEGL3(I) = VAL(SEGM3$)
STRT4(I) = VAL(STR4$)
STTYPE4(I) = VAL(RDTYPE4$)
HAZ4(I) = VAL(HAZNO4$)
NOHAZ(V) = NOHAZ(V) + HAZ4(I)
ADM4(I) = VAL(AD4$)
SEGL4(I) = VAL(SEGM4$)
STRT5(I) = VAL(STR5$)
STTYPE5(I) = VAL(RDTYPE5$)
HAZ5(I) = VAL(HAZNO5$)
NOHAZ(V) = NOHAZ(V) + HAZ5(I)
ADM5(I) = VAL(AD5$)
SEGL5(I) = VAL(SEGM5$)
STRT6(I) = VAL(STR6$)
STTYPE6(I) = VAL(RDTYPE6$)
HAZ6(I) = VAL(HAZNO6$)
NOHAZ(V) = NOHAZ(V) + HAZ6(I)
ADM6(I) = VAL(AD6$)
SEGL6(I) = VAL(SEGM6$)
STRT7(I) = VAL(STR7$)
STTYPE7(I) = VAL(RDTYPE7$)
HAZ7(I) = VAL(HAZNO7$)
NOHAZ(V) = NOHAZ(V) + HAZ7(I)
ADM7(I) = VAL(AD7$)
SEGL7(I) = VAL(SEGM7$)
STRT8(I) = VAL(STR8$)
STTYPE8(I) = VAL(RDTYPE8$)
HAZ8(I) = VAL(HAZNO8$)
NOHAZ(V) = NOHAZ(V) + HAZ8(I)
ADM8(I) = VAL(AD8$)
SEGL8(I) = VAL(SEGM8$)
STRT9(I) = VAL(STR9$)
STTYPE9(I) = VAL(RDTYPE9$)
HAZ9(I) = VAL(HAZNO9$)
NOHAZ(V) = NOHAZ(V) + HAZ9(I)
ADM9(I) = VAL(AD9$)
SEGL9(I) = VAL(SEGM9$)
NEXT I
DIM STRTYPE(DPRIME),HAZACCS(DPRIME),ADVMTT(DPRIME),SEGMENT(DPRIME),_
STMUN(DPRIME)
FOR I = 1 TO A 'place all street information from
'all data lines in matrices.
COUNTER = (I-1)*9
STMUN(COUNTER + 1) = MUNIC(I)
STRTYPE(COUNTER + 1) = STTYPE1(I)
HAZACCS(COUNTER + 1) = HAZ1(I)
ADVMTT(COUNTER + 1) = ADM1(I)
SEGMENT(COUNTER + 1) = SEGL1(I)
STMUN(COUNTER + 2) = MUNIC(I)
STRTYPE(COUNTER + 2) = STTYPE2(I)
HAZACCS(COUNTER + 2) = HAZ2(I)
ADVMTT(COUNTER + 2) = ADM2(I)
SEGMENT(COUNTER + 2) = SEGL2(I)
STMUN(COUNTER + 3) = MUNIC(I)
STRTYPE(COUNTER + 3) = STTYPE3(I)
HAZACCS(COUNTER + 3) = HAZ3(I)
ADVMTT(COUNTER + 3) = ADM3(I)
SEGMENT(COUNTER + 3) = SEGL3(I)
STMUN(COUNTER + 4) = MUNIC(I)
STRTYPE(COUNTER + 4) = STTYPE4(I)
HAZACCS(COUNTER + 4) = HAZ4(I)
ADVMTT(COUNTER + 4) = ADM4(I)
SEGMENT(COUNTER + 4) = SEGL4(I)
STMUN(COUNTER + 5) = MUNIC(I)
STRTYPE(COUNTER + 5) = STTYPE5(I)
HAZACCS(COUNTER + 5) = HAZ5(I)
ADVMTT(COUNTER + 5) = ADM5(I)
SEGMENT(COUNTER + 5) = SEGL5(I)
STMUN(COUNTER + 6) = MUNIC(I)
STRTYPE(COUNTER + 6) = STTYPE6(I)
HAZACCS(COUNTER + 6) = HAZ6(I)
ADVMTT(COUNTER + 6) = ADM6(I)
SEGMENT(COUNTER + 6) = SEGL6(I)
STMUN(COUNTER + 7) = MUNIC(I)
STRTYPE(COUNTER + 7) = STTYPE7(I)
HAZACCS(COUNTER + 7) = HAZ7(I)
ADVMTT(COUNTER + 7) = ADM7(I)
SEGMENT(COUNTER + 7) = SEGL7(I)
STMUN(COUNTER + 8) = MUNIC(I)

```

```

STRTYPE(COUNTER + 8) = STTYPE8(I)
HAZACCS(COUNTER + 8) = HAZ8(I)
ADVMTT(COUNTER + 8) = ADM8(I)
SEGMENT(COUNTER + 8) = SEGL8(I)
  STMUN(COUNTER + 8) = MUNIC(I)
STRTYPE(COUNTER + 9) = STTYPE9(I)
HAZACCS(COUNTER + 9) = HAZ9(I)
ADVMTT(COUNTER + 9) = ADM9(I)
SEGMENT(COUNTER + 9) = SEGL9(I)
NEXT I
ERASE STRT1,STRT2,STRT3,STRT4,STRT5,STRT6,STRT7,STRT8,STRT9,
STTYPE1,STTYPE2,STTYPE3,STTYPE4,STTYPE5,STTYPE6,STTYPE7,STTYPE8,
STTYPE9,HAZ1,HAZ2,HAZ3,HAZ4,HAZ5,HAZ6,HAZ7,HAZ8,HAZ9,
ADM1,ADM2,ADM3,ADM4,ADM5,ADM6,ADM7,ADM8,ADM9,
SEGL1,SEGL2,SEGL3,SEGL4,SEGL5,SEGL6,SEGL7,SEGL8,SEGL9
E = DPRIME-1
F = 0
FOR I = 1 TO E 'Evaluate if street information is
'for different municipalities or
'is a zero field on a data line.
IF (YSTREET(I) = YSTREET(I + 1)) GOTO 80
IF (ADVMTT(I) <= 0.0) GOTO 80
F = F + 1
80 NEXT I
DIM YSTS(F),MSEGS(B),SEGLTH(F),PS(F),HAZARD(F)
DIM DVMTT(F),MNUMBER(B)
G = 0
YSTS(1) = YSTREET(1)
HAZARD(1) = HAZACCS(1)
DVMTT(1) = ADVMTT(1)
SEGLTH(1) = SEGMENT(1)
H = 1
MSEGS(1) = SEGLTH(1)
MFLAG = STMUN(1)
SPILL1 = 0.191:PCTFLOW1 = 0.0738011
SPILL2 = 0.102:PCTFLOW2 = 0.0376344
SPILL3 = 0.113:PCTFLOW3 = 0.0431511
SPILL4 = 0.191:PCTFLOW4 = 0.0738011
SPILL5 = 0.124:PCTFLOW5 = 0.047983
SPILL8 = 0.145:PCTFLOW8 = 0.0392054
SPILL9 = 0.076:PCTFLOW9 = 0.0408018
CALL SCREENMKR
LOCATE 7,10
PRINT "As an assumption, what percentage of hazmat accidents_
release their"
LOCATE 8,10
PRINT "contents for the following road types (default values_
shown):"
LOCATE 10,10
INPUT "State Hwy. & Mun. St. (19.1%)-----"askspil$
IF ASKSPILS < > "" THEN SPILL1 = VAL(ASKSPILS)/100
LOCATE 12,10
INPUT "State Hwy. Only (10.2%)-----"askspil$
IF ASKSPILS < > "" THEN SPILL2 = VAL(ASKSPILS)/100
LOCATE 14,10
INPUT "Mun. St. or Twshp. Rd. Only (11.3%)-----"askspil$
IF ASKSPILS < > "" THEN SPILL3 = VAL(ASKSPILS)/100
LOCATE 16,10
INPUT "County Rd. (19.1%)-----"askspil$
IF ASKSPILS < > "" THEN SPILL4 = VAL(ASKSPILS)/100
LOCATE 18,10
INPUT "Private Rd. or Area (12.4%)-----"askspil$
IF ASKSPILS < > "" THEN SPILL5 = VAL(ASKSPILS)/100
LOCATE 20,10
INPUT "Interstate-Urban (14.5%)-----"askspil$
IF ASKSPILS < > "" THEN SPILL8 = VAL(ASKSPILS)/100
LOCATE 22,10
INPUT "Interstate-Rural (7.6%)-----"askspil$
IF ASKSPILS < > "" THEN SPILL9 = VAL(ASKSPILS)/100
CALL SCREENMKR
LOCATE 7,10
PRINT "As an assumption, what percentage of all trucks on these_
road"
LOCATE 8,10
PRINT "types carry hazardous materials (default values shown):"
LOCATE 10,10
INPUT "State Hwy. & Mun. St. (7.38011%)-----"ASKFLOWS
IF ASKFLOWS < > "" THEN PCTFLOW1 = VAL(ASKFLOWS)/100
LOCATE 12,10
INPUT "State Hwy. Only (3.76344%)-----"ASKFLOWS
IF ASKFLOWS < > "" THEN PCTFLOW2 = VAL(ASKFLOWS)/100
LOCATE 14,10
INPUT "Mun. St. or Twshp. Rd. Only (4.31511%)-----"ASKFLOWS
IF ASKFLOWS < > "" THEN PCTFLOW3 = VAL(ASKFLOWS)/100
LOCATE 16,10
INPUT "County Rd. (7.38011%)-----"ASKFLOWS
IF ASKFLOWS < > "" THEN PCTFLOW4 = VAL(ASKFLOWS)/100
LOCATE 18,10
INPUT "Private Rd. or Area (4.7983%)-----"ASKFLOWS
IF ASKFLOWS < > "" THEN PCTFLOW5 = VAL(ASKFLOWS)/100
LOCATE 20,10
INPUT "Interstate-Urban (3.92054%)-----"ASKFLOWS
IF ASKFLOWS < > "" THEN PCTFLOW8 = VAL(ASKFLOWS)/100
LOCATE 22,10
INPUT "Interstate-Rural (4.08018%)-----"ASKFLOWS
IF ASKFLOWS < > "" THEN PCTFLOW9 = VAL(ASKFLOWS)/100

```

```

FOR I=1 TO DPRIME
IF (YSTREET(I)=YSTS(G)) GOTO 120 'compare for
IF (ADVMTT(I) <= 0.0) GOTO 120 'identical street
                                codes and zero
                                fields to ignore
G=G+1
YSTREET(I)=YSTREET(I)
HAZARD(G)=HAZACCS(I)
DVMTT(G)=ADVMTT(I)
SEGLTH(G)=SEGMENT(I)
' Embedded matrix of release rates and ratio of
' hazamat traffic to total truck traffic for different
' highway types:
IF STRTYPE(I)=1 THEN RELEASE=SPILL1:HAZRATIO=PCTFLOW1
IF STRTYPE(I)=2 THEN RELEASE=SPILL2:HAZRATIO=PCTFLOW2
IF STRTYPE(I)=3 THEN RELEASE=SPILL3:HAZRATIO=PCTFLOW3
IF STRTYPE(I)=4 THEN RELEASE=SPILL4:HAZRATIO=PCTFLOW4
IF STRTYPE(I)=5 THEN RELEASE=SPILL5:HAZRATIO=PCTFLOW5
IF STRTYPE(I)=8 THEN RELEASE=SPILL8:HAZRATIO=PCTFLOW8
IF STRTYPE(I)=9 THEN RELEASE=SPILL9:HAZRATIO=PCTFLOW9
' Compute street probability:
PS(G)=RELEASE*HAZARD(G)*SEGLTH(G)/(1927200*N*DVMTT(G)*HAZRATIO)
' Identify if street is in the same municipality
' as the previous street.
IF (STMUN(I) <> MFLAG) GOTO 90
' If so, then add the weighted probabilities and
' the segment lengths.
MNUMER(H)=MNUMER(H)+PS(G)*SEGLTH(G)
MSEGS(H)=MSEGS(H)+SEGLTH(G)
GO TO 120
90 H=H+1
IF (H > B) GOTO 110
' If not, then begin a new summation of the weigh-
' ted probabilities and lengths for the new municipality
100 MSEGS(H)=SEGLTH(G)
MNUMER(H)=PS(G)*SEGLTH(G)
MFLAG=STMUN(I)
GO TO 120
110 LOCATE 10,15
PRINT "WARNING ERROR: Program has assigned streets to too many_
municipalities."
PRINT "Please check street and municipality codes."
H=B
GO TO 100
120 NEXT I
ERASE YSTREET,ADVMTT,SEGMENT,STMUN
IF (H >= B) GOTO 130
LOCATE 10,15
PRINT "FATAL ERROR: Program has assigned streets to too few_
municipalities."
PRINT "Please check street and municipality codes. Program_
terminates."
END
130 DIM PM(B)
LOCATE 12,15
PRINT "Now computing municipality probabilities..."
DIM CNUMER(67),CDENOM(67),COUNTY(67)
CNUMER(1)=0.0
CDENOM(1)=0.0
CFLAG=FIX(MUN(1)/1000)
COUNTY(1)=CFLAG
J=1
FOR I=1 TO B
' Compute municipality probabilities and determine
' if municipalities are within the same county.
PM(I)=MNUMER(I)/MSEGS(I)
CTEST=FIX(MUN(I)/1000)
IF (CTEST=CFLAG) GOTO 140
J=J+1
CFLAG=CTEST
COUNTY(J)=CFLAG
' Add the weighted probabilities and the segment
' lengths for municipalities within a county.
140 CNUMER(J)=CNUMER(J)+(PM(I)*MSEGS(I))
CDENOM(J)=CDENOM(J)+MSEGS(I)
NEXT I
DIM PC(J)
LOCATE 16,15
PRINT "Now computing county probabilities. Please stand by..."
FOR I=1 TO J
' Compute county probabilities
PC(I)=CNUMER(I)/CDENOM(I)
NEXT I
ERASE CNUMER,CDENOM
-----End of Probability Computation Module-----
' Potential Output Variables:
' I. County Level
' A) J -- no. of counties with hazmat accidents (highest
' c' value)
' B) COUNTY(c) -- county codes
' C) PC(c) -- county's relative probability
' II. Municipality Level
' A) B -- no. of municipalities with hazmat accidents
' (highest m' value)
' B) MUN(m) -- municipality codes
' C) MSEGS(m) -- total length of exposed roads in the

```

```

      municipality (ft)
      D) PM(m) -- municipality's relative probability
III. Street Level
      A) F -- no. of streets with hazmat accidents
      B) YSTS(s) -- "street codes" (incl. municipality codes)
      C) DVMTT(s) -- daily truck vehicle miles (truck mi/day)
      D) SEGLTH(s) -- length of street (ft)
      E) PS(s) -- street's relative probability
      F) HAZARD(s) -- no. of hazmat accidents on the street
IV. Additional Information
      A) A -- no. of lines in the random access file
      B) D -- largest no. of streets on a data line
-----
DIM SHARED RDSEGLTH(F), YSTREET(F), COU#(J), MUN#(B), STR#(F)
DIM SHARED EXPOP(F), MEXPOP(B), TTLCOST(F), MTLFCOST(B), SPECTTL(F)
DIM SHARED MSPECTTL(B), INTAKE(F), MINTAKE(B), MRDSEGLTH(B)
DIM SHARED FACTOR1(J), FACTOR2(J), FACTOR3(J), FACTOR4(J)
FOR I = 1 TO F      'create variable to pass
      'to subprograms.
RDSEGLTH(I) = SEGLTH(I)
YSTREET(I) = YSTS(I)
NEXT I
FOR I = 1 TO B      'create variable to pass
      'to subprograms.
MRDSEGLTH(I) = MSEG(S(I))
NEXT I
-----
CALL CONSSUB      'access the consequence subpro-
gram
-----
CALL RESPSUB      'access the response subprogram
-----
      This is the beginning of the Risk and Vulnerabil-
ity calculation module. Here the program combines the
probability, exposure and response terms from other
parts of the program for evaluation.
CALL SCRNMKR4
WT1 = 60.0      'default weights for the combi-
WT2 = 20.0      'ning of the various measures
WT3 = 10.0      'of consequence into the risk &
WT4 = 10.0      'vulnerability expressions.
LOCATE 8,10
PRINT "Please input the relative weighting factors you wish to use"
LOCATE 9,10
PRINT "in determining risk based on the following categories:"
LOCATE 12,20
IF HAZTYPE% = 7 GOTO 150
PRINT "(A) Population (default is 60%)-----"
LOCATE 14,20
PRINT "(B) Property (default is 20%)-----"
LOCATE 16,20
PRINT "(C) Special Facilities (default is 10%)----"
LOCATE 18,20
PRINT "(D) Sensitive Areas (default is 10%)-----"
LOCATE 12,64
INPUT "VALUE1$
IF VALUE1$ < >" THEN WT1 = VAL(VALUE1$)
LOCATE 14,64
INPUT "VALUE2$
IF VALUE2$ < >" THEN WT2 = VAL(VALUE2$)
LOCATE 16,64
INPUT "VALUE3$
IF VALUE3$ < >" THEN WT3 = VAL(VALUE3$)
LOCATE 18,64
INPUT "VALUE4$
IF VALUE4$ < >" THEN WT4 = VAL(VALUE4$)
GO TO 160
      150 WT1 = 70.0      'default weighting factors if the
WT2 = 0.0      'hazmat type does not consider
WT3 = 15.0      'property damage.
WT4 = 15.0
PRINT "(A) Population (default is 70%)-----"
LOCATE 14,20
PRINT "(B) (Note: Property is 0%)"
LOCATE 16,20
PRINT "(C) Special Facilities (default is 15%)----"
LOCATE 18,20
PRINT "(D) Sensitive Areas (default is 15%)-----"
LOCATE 12,64
INPUT "VALUE1$
IF VALUE1$ < >" THEN WT1 = VAL(VALUE1$)
LOCATE 16,64
INPUT "VALUE3$
IF VALUE3$ < >" THEN WT3 = VAL(VALUE3$)
LOCATE 18,64
INPUT "VALUE4$
IF VALUE4$ < >" THEN WT4 = VAL(VALUE4$)
      160 WTSUM = WT1 + WT2 + WT3 + WT4      'normalize the weighting
PART1 = WTSUM / WTSUM      'factors.
PART2 = WT2 / WTSUM
PART3 = WT3 / WTSUM
PART4 = WT4 / WTSUM
LOCATE 22,10
PRINT "Thank you..."
      The user is given the option of obtaining out-
put for only certain levels if it appears that the

```

```

' output is too large for the storage requirements.
CALL SCRNMKR4
LOCATE 8,10
PRINT "For which levels do you wish to obtain output?"
COUFLAG=0.0
MUNFLAG=0.0
STFLAG=0.0
E%=1
DO
LOCATE 12,15
COLOR 15
IF E%=1 THEN COLOR 9
PRINT "(A) ALL"
LOCATE 14,15
COLOR 15
IF E%=2 THEN COLOR 9
PRINT "(B) COUNTY ONLY"
LOCATE 16,15
COLOR 15
IF E%=3 THEN COLOR 9
PRINT "(C) MUNICIPALITY ONLY"
LOCATE 18,15
COLOR 15
IF E%=4 THEN COLOR 9
PRINT "(D) STREET ONLY"
LOCATE 12,42
COLOR 15
IF E%=5 THEN COLOR 9
PRINT "(E) COUNTY & MUNICIPALITY"
LOCATE 14,42
COLOR 15
IF E%=6 THEN COLOR 9
PRINT "(F) COUNTY & STREET"
LOCATE 16,42
COLOR 15
IF E%=7 THEN COLOR 9
PRINT "(G) MUNICIPALITY & STREET"
LOCATE 18,42
COLOR 15
IF E%=8 THEN COLOR 9
PRINT "(H) NONE--Quit"
DO
AS=""
AS=INKEYS
LOOP UNTIL AS < > ""
IF LEN(AS)=2 THEN AS=MID$(AS,2,1)
IF ASC(MID$(AS,1,1))=13 THEN EXIT DO
IF ASC(MID$(AS,1,1))=80 THEN E%=E%+1
IF ASC(MID$(AS,1,1))=72 THEN E%=E%-1
IF E% > 9 THEN E%=1
IF E% < 0 THEN E%=8
LOOP
IF E%=1 THEN COUFLAG=1.0 : MUNFLAG=1.0 : STFLAG=1.0
IF E%=2 THEN COUFLAG=1.0
IF E%=3 THEN MUNFLAG=1.0
IF E%=4 THEN STFLAG=1.0
IF E%=5 THEN COUFLAG=1.0 : MUNFLAG=1.0
IF E%=6 THEN COUFLAG=1.0 : STFLAG=1.0
IF E%=7 THEN MUNFLAG=1.0 : STFLAG=1.0
IF E%=8 GOTO 605
DIM POPEXP(F),PROPEXP(F),FACILEXP(F),MSSENSI(B),EXPOS(F),YRISK(F)
DIM YVULNER(F),EXPOS2(F)
SUMEXPOP=0
SUMCOST=0
SUMSPEC=0
SUMINTKE=0
' Add all consequence values for all streets in
' the system for each measure of consequence. Find
' average values.
FOR I=1 TO F
SUMEXPOP=EXPOP(I)+SUMEXPOP
SUMCOST=TTLTTL(I)+SUMCOST
SUMSPEC=SPECTTL(I)+SUMSPEC
NEXT I
SUMEXPOP=SUMEXPOP/F
SUMCOST=SUMCOST/F
SUMSPEC=SUMSPEC/F
ACHECK=0.0
BCHECK=0.0
CCHECK=0.0
IF SUMEXPOP <= 0.0 THEN ACHECK=1 : GOTO 162
IF SUMCOST <= 0.0 THEN BCHECK=1 : GOTO 162
IF SUMSPEC <= 0.0 THEN CCHECK=1 : GOTO 162
GO TO 163
162 CALL SCRNMKR4
LOCATE 8,10
PRINT "WARNING ERROR : One or more measures of exposure have zero_
or negative"
LOCATE 9,10
PRINT "values for the statewide total value. The following_
values are to be"
LOCATE 10,10
PRINT "addressed : "
IF ACHECK > 0.5 THEN LOCATE 12,05 : PRINT "A Population"
IF CCHECK > 0.5 THEN LOCATE 12,20 : PRINT "C Special Facilities"
IF BCHECK > 0.5 THEN LOCATE 14,05 : PRINT "B Property--Note : " : _

```



```

LOCATE 16,10 : PRINT "Before proceeding, be sure that FACTORS.DAT_
and BLD COST.DAT"
LOCATE 16,10 : PRINT "are residing on the C: disk drive with the_
program."
LOCATE 18,10
PRINT "If you wish to proceed, then please assign a 0% weight_
to these"
LOCATE 19,10
PRINT "variables when the appropriate screen is reached."
LOCATE 20,10
HALTER% = 1
DO
LOCATE 21,25 : COLOR 15 : PRINT "PROCEED"
IF HALTER% = 1 THEN LOCATE 21,25 : COLOR 4 : PRINT "PROCEED"
LOCATE 20,35 : COLOR 15 : PRINT "HALT"
IF HALTER% = 2 THEN LOCATE 21,35 : COLOR 4 : PRINT "HALT"
DO
AS = ""
AS = INKEYS
LOOP UNTIL AS < > ""
IF LEN(AS) = 2 THEN AS = MIDS(AS,2,1)
IF ASC(MIDS(AS,1,1)) = 13 THEN
IF HALTER% = 1 GOTO 163
IF HALTER% = 2 THEN EXIT DO
END IF
LOOP
END 163 FOR I = 1 TO F
COUTEST1 = FIX(YSTS(I)/1000000000)
FOR U = 1 TO J Find the county code which matches
with the county in the street code
IF (COU#(U) = COUTEST1) GOTO 165
NEXT U
Determine the size of the exposures of each
street against the size of the total exposure stu-
died (normalize each measure).
165 POPEXP(I) = PART1*(EXPOP(I)/SUMEXPOP)
IF (SEVERITY = 0) GOTO 170 If the corridor
width is zero, buildings are not
in jeopardy
IF (DA% = 2) GOTO 170 Dispersion of vapor
PROPEXP(I) = PART2*(TTLFCOST(I)/SUMFCOST)
FACILEXP(I) = PART3*(SPECTTL(I)/SUMSPEC)
Add the weighted, normalized exposures for each
street to determine total street exposure.
170 EXPOS(I) = POPEXP(I) + PROPEXP(I) + FACILEXP(I)
Calculate street risk.
YRISK(I) = PS(I)*EXPOS(I)
If we are considering any of the response fac-
tors in computing vulnerability, we use them here to
adjust the corresponding measures of exposure.
IF FLAG1 = 0 THEN FACILEXP(I) = FACILEXP(I)*FACTOR1(U)
IF FLAG2 = 0 THEN PROPEXP(I) = PROPEXP(I)*FACTOR2(U)
IF FLAG3 = 0 THEN POPEXP(I) = POPEXP(I)*FACTOR3(U)
EXPOS2(I) = POPEXP(I) + PROPEXP(I) + FACILEXP(I)
Since response time is considered to affect all
exposure values, we multiply FACTOR4 with the total
recomputed exposure value (recomputed since response
time has a direct bearing on the effectiveness of
the first responders.
IF FLAG4 = 0 THEN EXPOS(I) = EXPOS(I)*FACTOR4(U)
Calculate street vulnerability.
YVULNER(I) = PS(I)*EXPOS(I)
NEXT I
IF STFLAG < 0.5 GOTO 180
OPEN "street.out" FOR OUTPUT AS #30
FOR I = 1 TO F
PRINT #30, YSTS(I), YRISK(I), YVULNER(I)
NEXT I
CLOSE #30
Add all risk and vulnerability values for each
street in each municipality in order to represent
the risk and vulnerability at the municipality level.
180 DIM YMRISK(B), YMVULNER(B), MEXPOS(B), MEXPOS2(B)
SUMINTKE = 0.0
FOR I = 1 TO B
SUMINTKE = MINTAKE(I) + SUMINTKE
NEXT I
SUMINTKE = SUMINTKE/B
FOR I = 1 TO B
MSENS(I) = PART4*(MINTAKE(I)/SUMINTKE)
NEXT I
FOR I = 1 TO F
RIG1 = FIX(YSTS(I)/1000000)
FOR U = 1 TO B
IF (RIG1 = MUN(U)) GOTO 175
NEXT U
175 YMRISK(U) = YRISK(I) + YMRISK(U)
YMVULNER(U) = YVULNER(I) + PS(I)*YMVULNER(U)
MEXPOP(U) = EXPOP(I) + MEXPOP(U)
MTTLCOST(U) = TTLFCOST(I) + MTTLCOST(U)
MSPECTTL(U) = SPECTTL(I) + MSPECTTL(U)
MEXPOS(U) = EXPOS(I) + MEXPOS(U)
MEXPOS2(U) = EXPOS2(I) + MEXPOS2(U)
NEXT I
Incorporate sensitive area exposure at the mun-
icipality level by breaking apart and recombining

```

```

' probability and exposure (times response factors for
' vulnerability) in the risk and vulnerability values.
FOR I = 1 TO B
  RIG2 = FIX(MUN(I)/1000)
  FOR U = 1 TO J
IF (RIG2 = COUNTY(U)) GOTO 176
  NEXT U
176 IF MEXPOS(I) <= 0.0 THEN MPROB = 0.0 : GO TO 178
  MPROB = YMRISK(I)/MEXPOS(I)
178 MEXPOS2(I) = MEXPOS(I) + MPROB*MSENSI(I)
  YMRISK(I) = MPROB*MEXPOS(I)
  IF MEXPOS2(I) <= 0.0 THEN MPROB = 0.0 : GO TO 179
  MPROB = YMVULNER(I)/MEXPOS2(I)
179 MEXPOS2(I) = (MEXPOS2(I)/FACTOR4(U) + MPROB*MSENSI(I))*FACTOR4(U)
  YMVULNER(I) = MPROB*MEXPOS2(I)
  NEXT I
  IF MUNFLAG < 0.5 GOTO 211
  OPEN "municip out" FOR OUTPUT AS #31
  FOR I = 1 TO J
PRINT #31,MUN(I),YMRISK(I),YMVULNER(I)
  NEXT I
  CLOSE #31
' Add all risk and vulnerability values for each
' municipality in each county in order to represent
' the risk and vulnerability at the county level.
DIM YCRISK(J),YCVULNER(J),CINTAKE(J)
DIM CEXPOP(J),CTTLCOST(J),CSPECTTL(U)
FOR I = 1 TO B
  RIG3 = FIX(MUN(I)/1000)
  FOR U = 1 TO J
IF (RIG3 = COUNTY(U)) GOTO 177
  NEXT U
177 YCRISK(U) = YMRISK(I) + YCRISK(U)
  YCVULNER(U) = YMVULNER(I) + YCVULNER(U)
  CEXPOP(U) = MEXPOP(I) + CEXPOP(U)
  CTTLCOST(U) = MTTLCOST(I) + CTTLCOST(U)
  CSPECTTL(U) = MSPECTTL(I) + CSPECTTL(U)
  CINTAKE(U) = MINTAKE(I) + CINTAKE(U)
  NEXT I
  IF COUFLAG < 0.5 GOTO 211
  OPEN "county out" FOR OUTPUT AS #32
  FOR I = 1 TO J
PRINT #32,COUNTY(I),YCRISK(I),YCVULNER(I)
  NEXT I
  CLOSE #32
'---End of Risk and Vulnerability Calculation Module---
' Potential Output Variables :
' I. County Level
' A) YCRISK(c) -- County relative risk
' B) YCVULNER(c) -- County relative vulnerability
' II. Municipality Level
' A) YMRISK(m) -- Municipality relative risk
' B) YMVULNER(m) -- Municipality relative vulnerability
' C) MINTAKE(m) --Total municipality exposed sensitive
' areas (avg. annual withdrawal in 1000 gal./day)
' III. Street Level
' A) YRISK(s) -- Street relative risk
' B) YVULNER(s) -- Street relative vulnerability
' C) EXPOP(s) -- Total street exposed people/mi.
' D) TITLCOST(s) -- Total street exposed property ($/mi.)
' E) SPECTTL(s) -- Total street exposed special
' facilities (people/mi.)
' IV. Additional Information
' A) PART1 -- User defined weight of value to give to
' population exposure measure
' B) PART2 -- User defined weight of value to give to
' property exposure measure
' C) PART3 -- User defined weight of value to give to
' special facilities exposure measure
' D) PART4 -- User defined weight of value to give to
' sensitive areas exposure measure
'-----
' This is the beginning of the Risk and Vulnerabil-
' ity ranking module. Here the program sorts the codes
' (all levels) in the order from the highest to lowest
' probability, risk and vulnerability.
DIM PRANK(F),RRANK(F),VRANK(F)
DIM RMRANK(B),VMRANK(B),RCRANK(J),VCRANK(J)
211 FOR I = 1 TO F 'Initialize street level ranking
PRANK(I) = 1 'vectors
RRANK(I) = 1
VRANK(I) = 1
NEXT I
FOR I = 1 TO B 'Initialize municipality level
RMRANK(I) = 1 'ranking vectors
VMRANK(I) = 1
NEXT I
FOR I = 1 TO J 'Initialize county level ranking
RCRANK(I) = 1 'vectors
VCRANK(I) = 1
NEXT I
IF STFLAG < 0.5 GOTO 220
' Street Level Sort : initial vector assumes that
' probability, risk and vulnerability decrease with
' increasing street code vector subscripts. The fol-
' lowing routines sort for the correct high to low

```

```

' order (i.e., PRANK(14) = 1 means that the street with
' YSTS(14) code has the highest probability).
DO
  BADGE = 0.0
  FOR I = 1 TO F
    FOR U = 1 TO F      'Street Level Probability
  IF PS(I) <= PS(U) GOTO 212
  IF PRANK(I) <= PRANK(U) GOTO 212
  BADGE = 1.0
  FIXPRANK = PRANK(I) : PRANK(I) = PRANK(U) : PRANK(U) = FIXPRANK : FIXPRANK = 0.0
  212 NEXT U
  NEXT I
  FOR I = 1 TO F
    FOR U = 1 TO F      'Street Level Risk
  IF YRISK(I) <= YRISK(U) GOTO 214
  IF RRANK(I) <= RRANK(U) GOTO 214
  BADGE = 1.0
  FIXRRANK = RRANK(I) : RRANK(I) = RRANK(U) : RRANK(U) = FIXRRANK : FIXRRANK = 0.0
  214 NEXT U
  NEXT I
  FOR I = 1 TO F
    FOR U = 1 TO F      'Street Level Vulnerability
  IF YVULNER(I) <= YVULNER(U) GOTO 216
  IF VRANK(I) <= VRANK(U) GOTO 216
  BADGE = 1.0
  FIXVRANK = VRANK(I) : VRANK(I) = VRANK(U) : VRANK(U) = FIXVRANK : FIXVRANK = 0.0
  216 NEXT U
  NEXT I
  IF BADGE < 0.5 THEN EXIT DO
  LOOP
220 IF MUNFLAG < 0.5 GOTO 230
' Municipality Level Sort : see Street Level Sort
' above for explanation.
DO
  BADGE = 0.0
  FOR I = 1 TO B
    FOR U = 1 TO B      'Municipality Level Risk
  IF YMRISK(I) <= YMRISK(U) GOTO 224
  IF RMRANK(I) <= RMRANK(U) GOTO 224
  BADGE = 1.0
  FIXRRANK = RMRANK(I) : RMRANK(I) = RMRANK(U) : RMRANK(U) = FIXRRANK
  FIXRRANK = 0.0
  224 NEXT U
  NEXT I
  FOR I = 1 TO B
    FOR U = 1 TO B      'Municipality Level Vulnerability
  IF YMVULNER(I) <= YMVULNER(U) GOTO 226
  IF VMRANK(I) <= VMRANK(U) GOTO 226
  BADGE = 1.0
  FIXVRANK = VMRANK(I) : VMRANK(I) = VMRANK(U) : VMRANK(U) = FIXVRANK
  FIXVRANK = 0.0
  226 NEXT U
  NEXT I
  IF BADGE < 0.5 THEN EXIT DO
  LOOP
230 IF COUFLAG < 0.5 GOTO 250
' County Level Sort : see Street Level Sort above
' for explanation.
DO
  BADGE = 0.0
  FOR I = 1 TO J
    FOR U = 1 TO J      'County Level Risk
  IF YCRISK(I) <= YCRISK(U) GOTO 234
  IF RCRANK(I) <= RCRANK(U) GOTO 234
  BADGE = 1.0
  FIXRRANK = RCRANK(I) : RCRANK(I) = RCRANK(U) : RCRANK(U) = FIXRRANK
  FIXRRANK = 0.0
  234 NEXT U
  NEXT I
  FOR I = 1 TO J
    FOR U = 1 TO J      'County Level Vulnerability
  IF YCVULNER(I) <= YCVULNER(U) GOTO 236
  IF VCRANK(I) <= VCRANK(U) GOTO 236
  BADGE = 1.0
  FIXVRANK = VCRANK(I) : VCRANK(I) = VCRANK(U) : VCRANK(U) = FIXVRANK
  FIXVRANK = 0.0
  236 NEXT U
  NEXT I
  IF BADGE < 0.5 THEN EXIT DO
  LOOP
'-----End of Risk and Vulnerability Ranking Module-----
' Potential Output Variables :
' I. County Level
' A) PCRANK(c) -- County relative probability rank
' B) RCRANK(c) -- County relative risk rank
' C) VCRANK(c) -- County relative vulnerability rank
' II. Municipality Level
' A) RMRANK(m) -- Municipality relative risk rank
' B) VMRANK(m) -- Municipality relative vulnerability rank
' III. Street Level
' A) RRANK(s) -- Street relative risk rank
' B) VRANK(s) -- Street relative vulnerability rank
'-----
' This is the beginning of the Output module. The
' user is provided a variety of formats for viewing
' the results depending on their needs. Please note

```

```

' that if certain levels of ranking are not performed,
' then these levels of printout are disabled.
DIM YCODE(7),RISKO(7),PROBI(7),CON(7),NUM(7),PLOT(7),PLOT(7)
250 CALL SCRNMKR4
LOCATE 8,31
PRINT "OUTPUT OPTION MENU"
B% = 1
DO
LOCATE 13,22
COLOR 15
IF B% = 1 THEN COLOR 9
PRINT "(A) REPORTS (printed copy)"
LOCATE 15,22
COLOR 15
IF B% = 2 THEN COLOR 9
PRINT "(B) ON NETWORK (on screen)"
' Writes files that are read by the main RADSS
' package. Blinks streets, municipalities and count-
' ies in that package by referencing rank and code #s
LOCATE 17,22
COLOR 15
IF B% = 3 THEN COLOR 9
PRINT "(C) SCALED PLOTS (on screen)"
' Isorisk lines and isovulnerability surfaces are
' plotted on screen. No print capability yet.
LOCATE 19,22
COLOR 15
IF B% = 4 THEN COLOR 9
PRINT "(D) EXIT MacroRADSS (supressed)"
DO
AS=""
AS=INKEY$
LOOP UNTIL AS<>" "
IF LEN(AS)=2 THEN AS=MID$(AS,2,1)
IF ASC(MID$(AS,1,1))=13 THEN EXIT DO
IF ASC(MID$(AS,1,1))=80 THEN B%=B%+1
IF ASC(MID$(AS,1,1))=72 THEN B%=B%-1
IF B%>=5 THEN B%=1
IF B%<=0 THEN B%=4
LOOP
IF B%=1 GOTO 260
IF B%=2 THEN LOCATE 22,10 : PRINT "PACKAGE UNAVAILABLE" : _
FOR I=1 TO 15000 : NEXT I : GO TO 250
IF B%=3 GOTO 390
IF B%=4 THEN END
' If the print option is chosen then the follow-
' ing screen is displayed
260 CALL SCRNMKR4
LOCATE 4,31
PRINT "FORMAT OPTION MENU"
B% = 1
DO
LOCATE 10,18 : COLOR 15 : PRINT "(A) COUNTY--RISK"
IF B% = 1 THEN LOCATE 10,18 : COLOR 4 : PRINT "(A) COUNTY--RISK" : _
BS="risky" : CS="counties" : MAXASK=J
LOCATE 12,18 : COLOR 15 : PRINT "(B) COUNTY--VULNERABILITY"
IF B% = 2 THEN LOCATE 12,18 : COLOR 4 : _
PRINT "(B) COUNTY--VULNERABILITY" : _
BS="vulnerable" : CS="counties" : MAXASK=J
LOCATE 14,18 : COLOR 15 : PRINT "(C) MUNICIPALITY--RISK"
IF B% = 3 THEN LOCATE 14,18 : COLOR 4 : _
PRINT "(C) MUNICIPALITY--RISK" : _
BS="risky" : CS="municipalities" : MAXASK=B
LOCATE 16,18 : COLOR 15 : PRINT "(D) MUNICIPALITY--VULNERABILITY"
IF B% = 4 THEN LOCATE 16,18 : COLOR 4 : PRINT "(D) MUNICIPALITY--
VULNERABILITY" : _
BS="vulnerable" : CS="municipalities" : MAXASK=B
LOCATE 18,18 : COLOR 15 : PRINT "(E) STREET--RISK"
IF B% = 5 THEN LOCATE 18,18 : COLOR 4 : PRINT "(E) STREET--RISK" : _
BS="risky" : CS="streets" : MAXASK=F
LOCATE 20,18 : COLOR 15 : PRINT "(F) STREET--VULNERABILITY"
IF B% = 6 THEN LOCATE 20,18 : COLOR 4 : _
PRINT "(F) STREET--VULNERABILITY" : _
BS="vulnerable" : CS="streets" : MAXASK=F
LOCATE 22,18 : COLOR 15 : PRINT "(G) RETURN TO OUTPUT OPTION MENU"
IF B% = 7 THEN LOCATE 22,18 : COLOR 4 : PRINT "(G) RETURN TO OUTPUT
OPTION MENU"
DO
AS=""
AS=INKEY$
LOOP UNTIL AS<>" "
IF LEN(AS)=2 THEN AS=MID$(AS,2,1)
IF ASC(MID$(AS,1,1))=13 THEN EXIT DO
IF ASC(MID$(AS,1,1))=80 THEN B%=B%+1
IF ASC(MID$(AS,1,1))=72 THEN B%=B%-1
IF B%>=8 THEN B%=1
IF B%<=0 THEN B%=7
LOOP
IF B%=7 GOTO 250
LPRINT
LPRINT
LPRINT "Recap of Input Parameters : "
LPRINT
LPRINT "Probability File Name : "FILENAME$
LPRINT "Exposure File Names : "
LPRINT " Street Level -- "STRNAMES

```

```

LPRINT " Municipality Level -- "MUNNAMES
LPRINT " County Level -- "COUNAMES
LPRINT "Response File Name : "RAFNAMES
LPRINT
LPRINT "Data Period of Record : "N
LPRINT
LPRINT "Percentage of hazmat accidents that release their contents : "
LPRINT "State Hwy. & Mun. St. : "SPILL1
LPRINT "State Hwy. Only : "SPILL2
LPRINT "Mun. St. or Twshp. Rd. Only : "SPILL3
LPRINT "County Rd. : "SPILL4
LPRINT "Private Rd. or Area : "SPILL5
LPRINT "Interstate-Urban : "SPILL8
LPRINT "Interstate-Rural : "SPILL9
LPRINT
LPRINT "Percentage of all trucks carrying hazardous materials : "
LPRINT "State Hwy. & Mun. St. : "PCTFLOW1
LPRINT "State Hwy. Only : "PCTFLOW2
LPRINT "Mun. St. or Twshp. Rd. Only : "PCTFLOW3
LPRINT "County Rd. : "PCTFLOW4
LPRINT "Private Rd. or Area : "PCTFLOW5
LPRINT "Interstate-Urban : "PCTFLOW8
LPRINT "Interstate-Rural : "PCTFLOW9
LPRINT
LPRINT "Hazmat Type : "
IF HAZTYPE% = 1 THEN LPRINT "(A) Combustible Liquid"
IF HAZTYPE% = 2 THEN LPRINT "(B) Flammable Liquid"
IF HAZTYPE% = 3 THEN LPRINT "(C) Flammable Solid"
IF HAZTYPE% = 4 THEN LPRINT "(D) Flammable LCG"
IF HAZTYPE% = 5 THEN LPRINT "(E) Flammable CG"
IF HAZTYPE% = 6 THEN LPRINT "(F) Non-Flammable LCG"
IF HAZTYPE% = 7 THEN LPRINT "(G) Non-flammable CG"
IF HAZTYPE% = 8 THEN LPRINT "(H) Poison A CG"
IF HAZTYPE% = 9 THEN LPRINT "(I) Poison A LCG/Liquid"
IF HAZTYPE% = 10 THEN LPRINT "(J) Next Screen"
IF HAZTYPE% = 11 THEN LPRINT "(K) Poison B Liquid"
IF HAZTYPE% = 12 THEN LPRINT "(L) Poison B Solid"
IF HAZTYPE% = 13 THEN LPRINT "(M) Explosive A"
IF HAZTYPE% = 14 THEN LPRINT "(N) Explosive B"
IF HAZTYPE% = 15 THEN LPRINT "(O) Explosive C"
IF HAZTYPE% = 16 THEN LPRINT "(P) Blasting Agents"
IF HAZTYPE% = 17 THEN LPRINT "(Q) Corrosive Liquids"
IF HAZTYPE% = 18 THEN LPRINT "(R) Corrosive Solids"
IF HAZTYPE% = 19 THEN LPRINT "(S) Org. Peroxide Liq."
IF HAZTYPE% = 20 THEN LPRINT "(T) Org. Peroxide Sol."
IF HAZTYPE% = 21 THEN LPRINT "(U) Oxidizers"
IF HAZTYPE% = 22 THEN LPRINT "(V) Gasolines"
IF HAZTYPE% = 23 THEN LPRINT "(W) Oxygen"
IF HAZTYPE% = 25 THEN LPRINT "(Y) Anhydrous Ammonia"
IF HAZTYPE% = 26 THEN LPRINT "(Z) Chlorine"
IF HAZTYPE% = 27 THEN LPRINT "(AA) Ethylene Oxide"
IF HAZTYPE% = 28 THEN LPRINT "(BB) LPG"
IF HAZTYPE% = 29 THEN LPRINT "(CC) Custom corridor of width : "
MAXWIDTH
LPRINT
LPRINT "Severity of release : "
IF D% = 1 THEN LPRINT "(A) Not severe (in system effects only)"
IF D% = 2 THEN LPRINT "(B) Moderately severe"
IF D% = 3 THEN LPRINT "(C) Catastrophic"
IF HAZTYPE% = 29 GOTO 262
LPRINT
LPRINT "Hazmat Release Scenario : "
IF DA% = 1 THEN LPRINT "(A) Liquid Pool Fire"
IF DA% = 2 THEN LPRINT "(B) Dispersion of Vapor"
IF DA% = 3 THEN LPRINT "(C) Explosion"
262 LPRINT
LPRINT "Weight to Population Exposure : "PART1
LPRINT "Weight to Property Exposure : "PART2
LPRINT "Weight to Special Facilities Exposure : "PART3
LPRINT "Weight to Sensitive Areas Exposure : "PART4
LPRINT "Level of Severity : "SEVERITY
IF B% = 1 GOTO 265
IF B% = 3 GOTO 265
IF B% = 5 GOTO 265
LPRINT
IF FLAG1 < 0.5 THEN LPRINT "Police Response considered"
IF FLAG2 < 0.5 THEN LPRINT "Fire Response considered"
IF FLAG3 < 0.5 THEN LPRINT "Ambulance Response considered"
IF FLAG4 < 0.5 THEN LPRINT "Response Time considered"
265 CALL SCRNMKR4
LOCATE 8,10
PRINT "For how many of the most "BS" "CS
LOCATE 9,10
PRINT "do you wish to obtain output?"
LOCATE 11,20
PRINT "**Maximum no. of "CS" = "MAXASK
LOCATE 14,20
INPUT " == > " Z
IF B% = 5 GOTO 270 "Street Level Requested
IF B% = 6 GOTO 270
IF B% = 3 GOTO 310 "Municipality Level
IF B% = 4 GOTO 310 "Requested
IF B% = 1 GOTO 350 "County Level Requested
IF B% = 2 GOTO 350
" Begin Street Level Output Section :
270 IF Z > F THEN

```

```

PRINT "TOO MANY STREETS REQUESTED"
FOR I=1 TO 500000
NEXT I
GO TO 260          'Error Trapping
ELSE
END IF
IF B% = 6 GOTO 290
LPRINT
LPRINT
LPRINT "In the order of highest to lowest risk for highest ",Z,_
" streets : "
LPRINT
LPRINT
LPRINT " <<<<<<<<< EXPOSURE (per mile) >>>>>>>>"
LPRINT "Street Code Population Property Spec. Facilities"
LPRINT " (people) ($) (size by people)"
LPRINT "===== "
LPRINT
FOR U=1 TO F
FOR I=1 TO Z
IF RRANK(I) <> U GOTO 280
LPRINT
LPRINT YSTS(I)EXPOP(I) "TTL COST(I)" "SPECTTL(I)"
280 NEXT I
NEXT U
GO TO 260
290 LPRINT
LPRINT
LPRINT "In the order of highest to lowest vulnerability for"
LPRINT "highest ",Z," streets : "
LPRINT
LPRINT
LPRINT " <<<<<<<<< EXPOSURE (per mile) >>>>>>>>"
LPRINT "Street Code Population Property Spec. Facilities"
LPRINT " (people) ($) (size by people)"
LPRINT "===== "
LPRINT
FOR U=1 TO F
FOR I=1 TO Z
IF VRANK(I) <> U GOTO 300
LPRINT
LPRINT YSTS(I)EXPOP(I) "TTL COST(I)" "SPECTTL(I)"
300 NEXT I
NEXT U
GO TO 260
' Begin Municipality Level Output Section :
310 IF Z > B THEN
PRINT "TOO MANY MUNICIPALITIES REQUESTED"
FOR I=1 TO 500000
NEXT I
GO TO 260          'Error Trapping
ELSE
END IF
IF B% = 4 GOTO 330
LPRINT
LPRINT
LPRINT "In the order of highest to lowest risk for highest ",Z
LPRINT "municipalities : "
LPRINT
LPRINT
LPRINT " <<<<<<<<<<<<<<<<<<<<<<<<< EXPOSURE (per mile)_
>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>"
LPRINT "Munic. Code Population Property Spec. Facilities_
Sens. Areas"
LPRINT " (people) ($) (size by people)_
(pub. h2o.mgd)"
LPRINT "===== "
LPRINT
LPRINT
FOR U=1 TO B
FOR I=1 TO Z
IF RMRANK(I) <> U GOTO 320
LPRINT
LPRINT MUN#(I)MEXPOP(I) "MTTLCOST(I)" "MSPECTTL(I)_
" "MINTAKE(I)"
320 NEXT I
NEXT U
GO TO 260
330 LPRINT
LPRINT
LPRINT "In the order of highest to lowest vulnerability for"
LPRINT "highest ",Z," municipalities : "
LPRINT
LPRINT
LPRINT " <<<<<<<<<<<<<<<<<<<<<<<<< EXPOSURE (per mile)_
>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>"
LPRINT "Munic. Code Population Property Spec. Facilities_
Sens. Areas"
LPRINT " (people) ($) (size by people)_
(pub. h2o.mgd)"
LPRINT "===== "
LPRINT
LPRINT
FOR U=1 TO B
FOR I=1 TO Z
IF VMRANK(I) <> U GOTO 340

```

```

LPRINT
LPRINT MUN#(I)MEXPOP(I) "MTTLCOST(I)" "MSPECTTL(I)_"
  "MINTAKE(I)
340 NEXT I
NEXT U
GO TO 260
  Begin County Level Output Section :
350 IF Z>J THEN
LPRINT "TOO MANY COUNTIES REQUESTED"
FOR I = 1 TO 500000
NEXT I
GO TO 260          'Error Trapping
ELSE
END IF
IF B% = 2 GOTO 370
LPRINT
LPRINT
LPRINT "in the order of highest to lowest risk for highest ",Z,_"
  " counties : "
LPRINT
LPRINT
LPRINT "                <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<< EXPOSURE (per mile)_"
  ">>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>"
LPRINT "County Code  Population  Property  Spec. Facilities_"
  "Sens. Areas"
LPRINT "      (people)   ($)      (size by people)_"
  "(pub. h2o.mgd)
LPRINT "=====
  "=====
LPRINT
FOR U = 1 TO J
FOR I = 1 TO Z
IF RCRANK(I) < > U GOTO 360
LPRINT
LPRINT COU#(I)CEXPOP(I) "CTTLCOST(I)" "CSPECTTL(I)_"
  "CINTAKE(I)
360 NEXT I
NEXT U
GO TO 260
370 LPRINT
LPRINT
LPRINT "in the order of highest to lowest vulnerability for"
LPRINT "highest ",Z,_" counties : "
LPRINT
LPRINT
LPRINT "                <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<< EXPOSURE (per mile)_"
  ">>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>"
LPRINT "County Code  Population  Property  Spec. Facilities_"
  "Sens. Areas"
LPRINT "      (people)   ($)      (size by people)_"
  "(pub. h2o.mgd)
LPRINT "=====
  "=====
LPRINT
FOR U = 1 TO J
FOR I = 1 TO Z
IF VCRANK(I) < > U GOTO 380
LPRINT
LPRINT COU#(I)CEXPOP(I) "CTTLCOST(I)" "CSPECTTL(I)_"
  "CINTAKE(I)
380 NEXT I
NEXT U
GO TO 260
  If the scaled plots option is chosen then the
  following screen is displayed.
390 CALL SCRNMKR4
LOCATE 6,31
PRINT "FORMAT OPTION MENU"
B% = 1 : C% = 1 : DPLUS% = 1 : E% = 1
LOCATE 8,10
PRINT "No. of points to compare : "
DO
LOCATE 8,38 : COLOR 15 : PRINT "1"
IF B% = 1 THEN LOCATE 8,38 : COLOR 4 : PRINT "1"
LOCATE 8,40 : COLOR 15 : PRINT "2"
IF B% = 2 THEN LOCATE 8,40 : COLOR 4 : PRINT "2"
LOCATE 8,42 : COLOR 15 : PRINT "3"
IF B% = 3 THEN LOCATE 8,42 : COLOR 4 : PRINT "3"
LOCATE 8,44 : COLOR 15 : PRINT "4"
IF B% = 4 THEN LOCATE 8,44 : COLOR 4 : PRINT "4"
LOCATE 8,46 : COLOR 15 : PRINT "5"
IF B% = 5 THEN LOCATE 8,46 : COLOR 4 : PRINT "5"
LOCATE 8,48 : COLOR 15 : PRINT "6"
IF B% = 6 THEN LOCATE 8,48 : COLOR 4 : PRINT "6"
LOCATE 8,50 : COLOR 15 : PRINT "7"
IF B% = 7 THEN LOCATE 8,50 : COLOR 4 : PRINT "7"
DO
AS=""
AS=INKEY$
LOOP UNTIL AS < > ""
IF LEN(AS) = 2 THEN AS=MID$(AS,2,1)
IF ASC(MID$(AS,1,1)) = 13 THEN EXIT DO
IF ASC(MID$(AS,1,1)) = 77 THEN B% = B% + 1
IF ASC(MID$(AS,1,1)) = 75 THEN B% = B% - 1
IF ASC(MID$(AS,1,1)) = 71 THEN B% = 1
IF ASC(MID$(AS,1,1)) = 79 THEN B% = 7

```

```

IF B% >= 8 THEN B% = 1
IF B% <= 0 THEN B% = 7
LOOP
LOCATE 10,10 : COLOR 15
PRINT "Level of comparison : "
DO
  LOCATE 10,33 : COLOR 15 : PRINT "COUNTY"
  IF C% = 1 THEN LOCATE 10,33 : COLOR 4 : PRINT "COUNTY"
  LOCATE 10,41 : COLOR 15 : PRINT "MUNICIPALITY"
  IF C% = 2 THEN LOCATE 10,41 : COLOR 4 : PRINT "MUNICIPALITY"
  LOCATE 10,55 : COLOR 15 : PRINT "STREET"
  IF C% = 3 THEN LOCATE 10,55 : COLOR 4 : PRINT "STREET"
DO
  AS=""
  AS=INKEY$
  LOOP UNTIL AS<>" "
  IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
  IF ASC(MIDS(AS,1,1))=13 THEN EXIT DO
  IF ASC(MIDS(AS,1,1))=77 THEN C%=C%+1
  IF ASC(MIDS(AS,1,1))=75 THEN C%=C%-1
  IF C% >= 4 THEN C%=1
  IF C% <= 0 THEN C%=3
LOOP
G% = 1 : LOCATE 12,10 : COLOR 15
PRINT "Type of plot : "
DO
  LOCATE 12,25 : COLOR 15 : PRINT "RISK"
  IF G% = 1 THEN LOCATE 12,25 : COLOR 4 : PRINT "RISK"
  LOCATE 12,31 : COLOR 15 : PRINT "VULNERABILITY"
  IF G% = 2 THEN LOCATE 12,31 : COLOR 4 : PRINT "VULNERABILITY"
DO
  AS=""
  AS=INKEY$
  LOOP UNTIL AS<>" "
  IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
  IF ASC(MIDS(AS,1,1))=13 THEN EXIT DO
  IF ASC(MIDS(AS,1,1))=77 THEN G%=G%+1
  IF ASC(MIDS(AS,1,1))=75 THEN G%=G%-1
  IF G% >= 3 THEN G%=1
  IF G% <= 0 THEN G%=2
LOOP
LOCATE 14,10 : COLOR 15
PRINT "Measure of Exposure : "
DO
  LOCATE 15,12 : COLOR 15 : PRINT "POPULATION"
  IF DPLUS%=1 THEN LOCATE 15,12 : COLOR 4 : PRINT "POPULATION"
  LOCATE 15,24 : COLOR 15 : PRINT "PROPERTY"
  IF DPLUS%=2 THEN LOCATE 15,24 : COLOR 4 : PRINT "PROPERTY"
  LOCATE 15,34 : COLOR 15 : PRINT "SPECIAL FACILITIES"
  IF DPLUS%=3 THEN LOCATE 15,34 : COLOR 4 : _
  PRINT "SPECIAL FACILITIES"
  IF C%=3 GO TO 395
  LOCATE 15,54 : COLOR 15 : PRINT "SENSITIVE AREAS"
  IF DPLUS%=4 THEN LOCATE 15,54 : COLOR 4 : PRINT "SENSITIVE AREAS"
395 DO
  AS=""
  AS=INKEY$
  LOOP UNTIL AS<>" "
  IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
  IF ASC(MIDS(AS,1,1))=13 THEN EXIT DO
  IF ASC(MIDS(AS,1,1))=77 THEN DPLUS%=DPLUS%+1
  IF ASC(MIDS(AS,1,1))=75 THEN DPLUS%=DPLUS%-1
  IF DPLUS% >= 5 THEN DPLUS%=1
  IF DPLUS% <= 0 THEN DPLUS%=4
  IF C%=3 THEN DPLUS%=3
LOOP
LOCATE 18,10
PRINT "Are these selections correct?"
DO
  LOCATE 18,42 : COLOR 15 : PRINT "YES"
  IF E%=1 THEN LOCATE 18,42 : COLOR 4 : PRINT "YES"
  LOCATE 18,47 : COLOR 15 : PRINT "NO"
  IF E%=2 THEN LOCATE 18,47 : COLOR 4 : PRINT "NO"
DO
  AS=""
  AS=INKEY$
  LOOP UNTIL AS<>" "
  IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
  IF ASC(MIDS(AS,1,1))=13 THEN
  IF E%=1 THEN EXIT DO
  IF E%=2 GOTO 390
  END IF
  IF ASC(MIDS(AS,1,1))=77 THEN E%=2
  IF ASC(MIDS(AS,1,1))=75 THEN E%=1
LOOP
  Input of the code numbers to compare.
400 CALL SCRNMKR4
LOCATE 8,10 : COLOR 15
IF C%=1 THEN PRINT "County CODE no.s to consider (2 digit) --"
IF C%=2 THEN PRINT "Municipality CODE no.s to consider (5 digit) --"
IF C%=3 THEN PRINT "Street CODE no.s to consider (11 digit) --"
LOCATE 9,10
PRINT "A = " : IF C%=1 THEN LOCATE 9,12 : PRINT " _ "
IF C%=2 THEN LOCATE 9,12 : PRINT " _ _ _ _ "
IF C%=3 THEN LOCATE 9,12 : PRINT " _ _ _ _ _ _ _ _ _ _ "
FOR I=2 TO B%

```



```

ROW=8+I : LOCATE ROW,10
IF I=2 THEN LOCATE ROW,10 : PRINT "B="
IF I=3 THEN LOCATE ROW,10 : PRINT "C="
IF I=4 THEN LOCATE ROW,10 : PRINT "D="
IF I=5 THEN LOCATE ROW,10 : PRINT "E="
IF I=6 THEN LOCATE ROW,10 : PRINT "F="
IF I=7 THEN LOCATE ROW,10 : PRINT "G="
IF C%=1 THEN LOCATE ROW,12 : PRINT " "
IF C%=2 THEN LOCATE ROW,12 : PRINT " "
IF C%=3 THEN LOCATE ROW,12 : PRINT " "
NEXT I
FOR I=1 TO B%
F%=1
410 ROW=8+I : LOCATE ROW,12 : COLOR 15
INPUT ".YCODE(I) : LOCATE ROW,12 : COLOR 4 : PRINT YCODE(I)
LOCATE ROW,29 : COLOR 15 : PRINT "ACCEPT VALUE?"
DO
420 LOCATE ROW,44 : COLOR 15 : PRINT "YES"
IF F%=1 THEN LOCATE ROW,44 : COLOR 4 : PRINT "YES"
LOCATE ROW,49 : COLOR 15 : PRINT "NO"
IF F%=2 THEN LOCATE ROW,49 : COLOR 4 : PRINT "NO"
DO
AS=""
AS=INKEY$
LOOP UNTIL AS<>""

IF LEN(AS)=2 THEN AS=MID$(AS,2,1)
IF ASC(MID$(AS,1,1))=13 GOTO 430
IF ASC(MID$(AS,1,1))=77 THEN F%=2 : GOTO 420
IF ASC(MID$(AS,1,1))=75 THEN F%=1 : GOTO 420
430 IF F%=1 THEN EXIT DO
IF F%=2 GOTO 410
LOOP
NEXT I
LOCATE 17,17 : PRINT "The Spacebar toggles between the graph and CODE_
no s"
LOCATE 18,17 : PRINT "The <Esc> key returns you to the output option_
menu"
ALARM=11
FOR I=1 TO 48 'Loop flashes NOTE : in colors
ALARM=ALARM+1
IF ALARM>15 THEN ALARM=12
FOR U=1 TO 1500
NEXT U
COLOR ALARM : LOCATE 17,10 : PRINT "NOTE : "
NEXT I
435 RMAX=0.0 : CMAX=0.0 : PMAX=0.0 : RMIN=999999999
' The vector CON is the exposure parameter to be
used for plotting.
IF C%>1 GOTO 440 'County Level Plot
FOR I=1 TO B%
FOR U=1 TO J
IF (COU#(U)<>YCODE(I)) GOTO 436
NUM(I)=U : RSKO(I)=YCRISK(U)
IF RSKO(I)>RMAX THEN RMAX=RSKO(I)
IF RSKO(I)<RMIN THEN RMIN=RSKO(I)
IF DPLUS%=1 THEN CON(I)=CEXPPOP(U)
IF DPLUS%=2 THEN CON(I)=CTTLCOST(U)
IF DPLUS%=3 THEN CON(I)=CSPECTTL(U)
IF DPLUS%=4 THEN CON(I)=CINTAKE(U)
PROB(I)=YCRISK(U)/CON(I)
IF PROB(I)>PMAX THEN PMAX=PROB(I)
IF CON(I)>CMAX THEN CMAX=CON(I)
436 NEXT U
NEXT I
GO TO 455
440 IF C%>2 GOTO 450 'Municipality Level Plot
FOR I=1 TO B%
FOR U=1 TO B
IF (MUN#(U)<>YCODE(I)) GOTO 445
NUM(I)=U : RSKO(I)=YMRISK(U)
IF RSKO(I)>RMAX THEN RMAX=RSKO(I)
IF RSKO(I)<RMIN THEN RMIN=RSKO(I)
IF DPLUS%=1 THEN CON(I)=MEXPOP(U)
IF DPLUS%=2 THEN CON(I)=MTTLCOST(U)
IF DPLUS%=3 THEN CON(I)=MSPECTTL(U)
IF DPLUS%=4 THEN CON(I)=MINTAKE(U)
PROB(I)=YMRISK(U)/CON(I)
IF PROB(I)>PMAX THEN PMAX=PROB(I)
IF CON(I)>CMAX THEN CMAX=CON(I)
445 NEXT U
NEXT I
GO TO 455
450 FOR I=1 TO B% 'Street Level Plot
FOR U=1 TO F
IF (YSTS(U)<>YCODE(I)) GOTO 451
NUM(I)=U : RSKO(I)=YRISK(U)
IF RSKO(I)>RMAX THEN RMAX=RSKO(I)
IF RSKO(I)<RMIN THEN RMIN=RSKO(I)
IF DPLUS%=1 THEN CON(I)=EXPOPI(U)
IF DPLUS%=2 THEN CON(I)=TTLCOST(U)
IF DPLUS%=3 THEN CON(I)=SPECTTL(U)
PROB(I)=YRISK(U)/CON(I)
IF PROB(I)>PMAX THEN PMAX=PROB(I)
IF CON(I)>CMAX THEN CMAX=CON(I)
451 NEXT U

```

```

NEXT I
' Determine the power of ten magnitude for the
' highest Probability to be plotted.
455 IF G% > 1 GOTO 529
' Begin Risk Graph :
FOR I = 1 TO 14
EVAL = 10
IF PMAX/EVAL > 1 GOTO 460
NEXT I
460 EVAL * PROB = 10 (1-1)
FOR I = 1 TO B%
PLOT(I) = 172 - CINT((PROB(I) * EVAL) * 150)
NEXT I
' Determine the order of magnitude of the high
' est exposure to be considered.
FOR J = 0 TO 14
I) IF CMAX < 470 GOTO 470
I) IF CMAX < 480 GOTO 480
NEXT I
470 ICOND = 0 :
POWER = I
SCALES = " 5 10 15 20 25 30 35 40 45 50 55 60 65 70 _
75 80"
FOR U = 1 TO B%
PLOT(U) = 80 + CINT((CON(U)) / (10
NEXT U
GO TO 490
480 ICOND = 1 :
POWER = I
SCALES = "10 20 30 40 50 60 70 80 90 100 110 120 130 140 _
150 160"
FOR U = 1 TO B%
PLOT(U) = 80 + CINT((CON(U)) / (10
NEXT U
490 KEY OFF : CLS
SCREEN 8,0,0 : COLOR 7,0 : PALETTE 1,9 : PALETTE 2,12 : _
PALETTE 3,7 : _
PALETTE 4,5
PALETTE 5,3
C0 = 0 : C1 = 1 : C2 = 2 : C3 = 3 : C4 = 4 : C5 = 5 *****EGA 640x200 16-color mode*****
' Draw risk grid
FOR SY = 22 TO 172 STEP 15 : LINE (80,SY)-(623,SY),C3,&H8888 : NEXT SY
FOR SX = 80 TO 623 STEP 34 : LINE (SX,22)-(SX,172),C3,&HAAAA : NEXT SX
' Draw risk border
LINE (80,22)-(623,172),C1,B
DIM PROBINC(R),CONMAX(100),CONMIN(100),PLOTINC(101),PLOTMAX(101)
DIM PLOTMIN(101)
' Draw isorisk lines
500 FOR I = 1 TO 100 STEP 0.1
PROBINC(I) = I * I * PROB * 0.01
CONMAX(I) = RMAX / PROBINC(I)
CONMIN(I) = RMIN / PROBINC(I)
PLOTINC(I) = 172 - CINT(172 * PROBINC(I) * EVAL * 150)
IF CONMAX(I) < 80 THEN PLOTMAX(I) = 80 + CINT((CONMAX(I)) / (10
(543/80)) :
PLOTMIN(I) = 80 + CINT((CONMIN(I)) / (10
(543/160)) :
IF PLOTINC(I) < 22 GOTO 500
IF PLOTINC(I) > 172 GOTO 500
IF PLOTMAX(I) > 623 GOTO 500
IF PLOTMAX(I) < 80 GOTO 500
TEST1$ = "BM " + STR$(PLOTMAX(I)) + ", " + STR$(PLOTINC(I))
TEST2$ = "M " + STR$(PLOTMAX(I)) + ", " + STR$(PLOTINC(I)) + "C4"
505 IF PLOTMIN(I) > 623 GOTO 500
IF PLOTMIN(I) < 80 GOTO 500
TEST3$ = "BM " + STR$(PLOTMIN(I)) + ", " + STR$(PLOTINC(I))
TEST4$ = "M " + STR$(PLOTMIN(I)) + ", " + STR$(PLOTINC(I)) + "C2"
DRAW TEST1$ : DRAW TEST2$ : DRAW TEST3$ : DRAW TEST4$
NEXT I
GOSUB 675 'Plot risk values (crosshairs)
LOCATE 23,15
COLOR 14
PRINT SCALES
LOCATE 24,35
IF DPLUS% = 1 THEN PRINT "population exposed (pop. x'ICON)"
IF DPLUS% = 2 THEN PRINT "property exposed ($ x'ICON)"
IF DPLUS% = 3 THEN PRINT "spec. facil. exposed (pop./facil. x'ICON)"
IF DPLUS% = 4 THEN PRINT "sens. areas exposed (mgd x'ICON)"
LOCATE 1,40
PRINT "RISK PROFILE"
LOCATE 1,3
PRINT "probability (x'IPROB)"
LOCATE 2,7
PRINT "1.0"
LOCATE 4,7
PRINT "0.9"
LOCATE 6,7
PRINT "0.8"
LOCATE 8,7
PRINT "0.7"
LOCATE 10,7
PRINT "0.6"
LOCATE 12,7
PRINT "0.5"

```

```

LOCATE 14,7
PRINT "0.4"
LOCATE 16,7
PRINT "0.3"
LOCATE 18,7
PRINT "0.2"
LOCATE 20,7
PRINT "0.1"
' Toggle to code no. screen or return to output
' option menu
515 DO
AS=""
AS=INKEYS
LOOP UNTIL AS<>" "
IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
IF ASC(MIDS(AS,1,1))=27 THEN ERASE YCODE,PROB,CON,NUM,PLOTP,PLOTG : _
ERASE PROBINC,CONMAX,CONMIN,PLOTINC : _
ERASE PLOTMAX,PLOTMIN : GOTO 520
IF ASC(MIDS(AS,1,1))=32 GOTO 520
GO TO 515
520 CALL SCRNMKR4 'code no. screen
FOR I=1 TO B%
U=5+2*I : LOCATE U,30
IF I=1 THEN PRINT "A="
IF I=2 THEN PRINT "B="
IF I=3 THEN PRINT "C="
IF I=4 THEN PRINT "D="
IF I=5 THEN PRINT "E="
IF I=6 THEN PRINT "F="
IF I=7 THEN PRINT "G="
LOCATE U,32
PRINT YCODE(I)
NEXT I
' Toggle to risk graph screen or return to output
' option menu
525 DO
AS=""
AS=INKEYS
LOOP UNTIL AS<>" "
IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
IF ASC(MIDS(AS,1,1))=27 THEN ERASE YCODE,PROB,CON,NUM,PLOTP,PLOTG : _
ERASE PROBINC,CONMAX,CONMIN,PLOTINC : _
ERASE PLOTMAX,PLOTMIN : GO TO 250
IF ASC(MIDS(AS,1,1))=32 THEN
IF G%=1 GOTO 435
IF G%=2 GO TO 529
END IF
GO TO 525
' Begin Vulnerability Surfaces
529 GOTO 615 'Configure System
530 GOSUB 620 'Assign Scalar Data
-----
' Master Routine : Draw Blips
' Blips are 3D crosshairs to locate vulnerability
' values.
DIM XMOD(7),YMOD(7),ZMOD(7),RELIEF(7)
ERASE PLOTP,PLOTG
' Determine the power of ten magnitude for the
' highest Probability to be plotted.
FOR I=1 TO 14 STEP 1
(-) PRINT GOTO 532
NEXT I
532 APOWER=-(-I-1)
' Determine the order of magnitude of the high
' est exposure to be considered.
FOR I=-5 TO 14 STEP 1
(-) PRINT GOTO 535
NEXT I
535 BPOWER=-(-I-1)
RELMAX=0.0
' The vector RELIEF is the response parameter to
' be used for plotting.
IF C% > 1 GOTO 545 'County Level Vulnerability
FOR I=1 TO B%
FOR U=1 TO J
IF COU#(U)=YCODE(I) GOTO 540
NEXT U
540 IF DPLUS%=1 THEN RELIEF(I)=LOG(FACTOR3(U))
IF DPLUS%=2 THEN RELIEF(I)=LOG(FACTOR2(U))
IF DPLUS%=3 THEN RELIEF(I)=LOG(FACTOR1(U))
IF RELIEF(I) > RELMAX THEN RELMAX=RELIEF(I)
NEXT I
GO TO 585
545 IF C% > 2 GOTO 555 'Municipality Level Vulnerability
FOR I=1 TO B%
COUTEST3=FIX(YCODE(I)/1000)
FOR W=1 TO J
IF COU#(W)=COUTEST3 GOTO 550
NEXT W
550 IF DPLUS%=1 THEN RELIEF(I)=LOG(FACTOR3(W))
IF DPLUS%=2 THEN RELIEF(I)=LOG(FACTOR2(W))
IF DPLUS%=3 THEN RELIEF(I)=LOG(FACTOR1(W))
IF RELIEF(I) > RELMAX THEN RELMAX=RELIEF(W)
NEXT I
GO TO 585
555 'Street Level Vulnerability

```

```

FOR I=1 TO B%
COUTEST4=FIX(YCODE(I)/100000000)
FOR W=1 TO J
IF COU#(W)=COUTEST4 GOTO 560
NEXT W
560 IF DPLUS%=1 THEN RELIEF(I)=LOG(FACTOR3(W))
IF DPLUS%=2 THEN RELIEF(I)=LOG(FACTOR2(W))
IF DPLUS%=3 THEN RELIEF(I)=LOG(FACTOR1(W))
IF RELIEF(I)>RELMAX THEN RELMAX=RELIEF(W)
NEXT I
565 W=0 : MAXVULN=0 : MINVULN=99999999
Sort routine to weed out points that won't plot
FOR I=1 TO B%
APOR=INT(ROB(I)*573
APOR=INT(ROB(I)*573
573
BPOV=INT(COBI(I)*1673
BPOV=INT(COBI(I)*1673
573
IF CINT(RELIEF(I)*100)<-100 GOTO 573
IF CINT(RELIEF(I)*100)>100 GOTO 573
Plotting 3D coordinates
XMOD(I)=INT(CON(I)/(10
YMOD(I)=INT(PROB(I)/(10
ZMOD(I)=CINT(RELIEF(I)*100)
GO TO 572
W=W+1 : LOCATE 4,1 : PRINT "Code #s don't plot : "
LOCATE 4+W,1
PRINT YCODE(I)
GO TO 573
Find the maximum and minimum vulnerabilities for
isovulnerability surfaces.
572 VULNY=CDBL((PROB(I)*CON(I))/EXP(RELIEF(I)))
IF VULNY>MAXVULN THEN MAXVULN=VULNY
IF VULNY<MINVULN THEN MINVULN=VULNY
573 NEXT I
Construct the Blips
575 FOR I=1 TO B%
RESTORE 645 : READ X,Y,Z
X=X+XMOD(I) : Y=Y+YMOD(I) : Z=Z+ZMOD(I)
GOSUB 610 : PSET (SX,SY),C5 : FOR T=1 TO 4 STEP 1 : READ X,Y,Z
X=X+XMOD(I) : Y=Y+YMOD(I) : Z=Z+ZMOD(I)
GOSUB 610 : LINE-(SX,SY),C5 : NEXT T 'Blip X axis
RESTORE 655 : READ X,Y,Z
X=X+XMOD(I) : Y=Y+YMOD(I) : Z=Z+ZMOD(I)
GOSUB 610 : PSET (SX,SY),C5 : FOR T=1 TO 4 STEP 1 : READ X,Y,Z
X=X+XMOD(I) : Y=Y+YMOD(I) : Z=Z+ZMOD(I)
GOSUB 610 : LINE-(SX,SY),C5 : NEXT T 'Blip Z axis
RESTORE 665 : READ X,Y,Z
X=X+XMOD(I) : Y=Y+YMOD(I) : Z=Z+ZMOD(I)
GOSUB 610 : PSET (SX,SY),C5 : FOR T=1 TO 4 STEP 1 : READ X,Y,Z
X=X+XMOD(I) : Y=Y+YMOD(I) : Z=Z+ZMOD(I)
GOSUB 610 : LINE-(SX,SY),C5 : NEXT T 'Blip Y axis
H1=(SY+299)\24 : H2=(SX+399)\10 'Label coordinates
IF H1<1 GOTO 580 'ignore points that don't plot
IF H2<0 GOTO 580
IF H1>24 GOTO 580
IF H2>79 GOTO 580
LOCATE H1,H2
IF I=1 THEN PRINT "A" 'Print nonplotting labels
IF I=2 THEN PRINT "B"
IF I=3 THEN PRINT "C"
IF I=4 THEN PRINT "D"
IF I=5 THEN PRINT "E"
IF I=6 THEN PRINT "F"
IF I=7 THEN PRINT "G"
580 NEXT I
Draw coordinate axes
RESTORE 625 : READ X,Y,Z : GOSUB 610 : MAP1=SX : MAP2=SY : PSET (SX,SY),C3
FOR T=1 TO 4 STEP 1 :
READ X,Y,Z : GOSUB 610 : LINE-(SX,SY),C3 : NEXT T ' + X axis
H3=(MAP2+299)\24 : H4=(MAP1+399)\10-1
IF H3<1 GOTO 585
IF H4<0 GOTO 585
IF H3>24 GOTO 585
IF H4>79 GOTO 585
LOCATE H3,H4 : COLOR 14 : PRINT "EXPOS."
LOCATE H3+1,H4 : PRINT "100"
While drawing coordinate axes, add x,z grid
585 FOR I=100 TO 10 STEP -10
RESTORE 625 : READ X,Y,Z
Z=Z+1 : GOSUB 610 : PSET (SX,SY),C1
FOR T=1 TO 4 STEP 1
READ X,Y,Z
Z=Z+1 : GOSUB 610 : LINE-(SX,SY),C1,,&H8888
NEXT T
NEXT I
FOR I=-100 TO -10 STEP 10
RESTORE 625 : READ X,Y,Z
Z=Z+1 : GOSUB 610 : PSET (SX,SY),C2
FOR T=1 TO 4 STEP 1
READ X,Y,Z
Z=Z+1 : GOSUB 610 : LINE-(SX,SY),C2,,&H8888
NEXT T
NEXT I
RESTORE 630 : READ X,Y,Z : GOSUB 610 : MAP1=SX : MAP2=SY : PSET (SX,SY),C3

```

```

FOR T=1 TO 4 STEP 1 :
READ X,Y,Z : GOSUB 610 : LINE-(SX,SY),C3 : NEXT T ' + Z axis
H3=(MAP2+299)\24 : H4=(MAP1+399)\10-5
IF H3<1 GOTO 590
IF H4<0 GOTO 590
IF H3>24 GOTO 590
IF H4>79 GOTO 590
LOCATE H3-1,H4 : COLOR 14 : PRINT "+ log(R/Ravg)"
LOCATE H3,H4 : PRINT "+ 1"
590 FOR I=10 TO 100 STEP 10
RESTORE 630 : READ X,Y,Z
X=X+I : GOSUB 610 : PSET (SX,SY),C1
FOR T=1 TO 4 STEP 1
READ X,Y,Z
X=X+I : GOSUB 610 : LINE-(SX,SY),C1,,&HAAAA
NEXT T
NEXT I
FOR T=1 TO 4 STEP 1 :
READ X,Y,Z : GOSUB 610 : LINE-(SX,SY),C3 : NEXT T ' Y axis
H3=(MAP2+299)\24+1 : H4=(MAP1+399)\10
IF H3<1 GOTO 595
IF H4<0 GOTO 595
IF H3>24 GOTO 595
IF H4>79 GOTO 595
LOCATE H3,H4 : COLOR 14 : PRINT "PROB"
LOCATE H3+1,H4 : PRINT "1"
595 RESTORE 640 : READ X,Y,Z : GOSUB 610 : PSET (SX,SY),C3 : FOR T=1 TO 4_
STEP 1 :
READ X,Y,Z : GOSUB 610 : LINE-(SX,SY),C3 : NEXT T ' -Z axis
While drawing coordinate axes, add z,x grid
FOR I=10 TO 100 STEP 10
RESTORE 640 : READ X,Y,Z
X=X+I : GOSUB 610 : PSET (SX,SY),C2
FOR T=1 TO 4 STEP 1
READ X,Y,Z
X=X+I : GOSUB 610 : LINE-(SX,SY),C2,,&HAAAA
NEXT T
NEXT I
Determine coordinates for isovulnerability
surfaces.
FOR I=1 TO B%
FOR U=1 TO 100
W=U*(BPOWER) :
V=EXP(RELIEF(I))
CONMAX(U)=(MAXVULN*V)/W
CONMIN(U)=(MINVULN*V)/W
PLOTMAX(U)=PLOT(CONMAX(U))/(10
PLOTMIN(U)=PLOT(CONMIN(U))/(10
IF U=1 GOTO 600
Plot maximum isovulnerability surface over each
point to be considered (maximum of 7)
X=PLOTMAX(U-1) : Y=U-1 : Z=CINT(RELIEF(I)*100)
GOSUB 610
IF SX<-399 GOTO 600
IF SY<-299 GOTO 600
IF SX>400 GOTO 600
IF SY>300 GOTO 600
PSET(SX,SY)
X=PLOTMAX(U) : Y=U : Z=CINT(RELIEF(I)*100)
GOSUB 610 : LINE-(SX,SY),C4
Plot minimum isovulnerability surface over each
point to be considered (maximum of 7)
X=PLOTMIN(U-1) : Y=U-1 : Z=CINT(RELIEF(I)*100)
GOSUB 610
IF SX<-399 GOTO 600
IF SY<-299 GOTO 600
IF SX>400 GOTO 600
IF SY>300 GOTO 600
PSET (SX,SY)
X=PLOTMIN(U) : Y=U : Z=CINT(RELIEF(I)*100)
GOSUB 610 : LINE-(SX,SY) C2
600 NEXT U
602 NEXT I
Print scale magnitudes
LOCATE 1,30 : COLOR 14 : PRINT "VULNERABILITY SURFACES"
LOCATE 1,1 : PRINT "PROB. (x^-(APOWER))^"
LOCATE 2,1 : PRINT "EXP. (x^-(BPOWER))^"
LOCATE 3,1 : PRINT "log(R/Ravg)x100"
Rotate and zoom plot
DO
DO
AS=""
AS=INKEYS
LOOP UNTIL AS<>""
IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
IF ASC(MIDS(AS,1,1))=13 THEN EXIT DO
IF ASC(MIDS(AS,1,1))=32 GOTO 520
IF ASC(MIDS(AS,1,1))=77 THEN R1=R1+0.19635 : CLS : LOCATE 24,20 : _
PRINT "ROTATE + PI/16"
IF ASC(MIDS(AS,1,1))=75 THEN R1=R1-0.19635 : CLS : LOCATE 24,20 : _
PRINT "ROTATE - PI/16"
IF ASC(MIDS(AS,1,1))=80 THEN D=D-100 : CLS : LOCATE 24,20 : PRINT_

```

```

"ZOOM OUT"
IF ASC(MID$(A$,1,1))=72 THEN D=D+100 : CLS : LOCATE 24,20 : PRINT _
"ZOOM IN"
IF ASC(MID$(A$,1,1))=27 THEN ERASE YCODE,PROB,CON,NUM,PLOTP,PLOTC : _
GOTO 250
LOOP
GOSUB 622 'Change 3D coordinates to comply
GO TO 575 'Replot
605 END

```

Main Program

End

```

Module : perspective calculations for cartesian world
coordinates
610 X=i-1)*X :
XA=CR1*X-SR1*Z : ZA=SR1*X+CR1*Z : 'Yaw rotation
X=CR2*XA+SR2*Y : YA=CR2*Y-SR2*XA : 'Roll rotation
Z=CR3*ZA-SR3*Y : Y=SR3*ZA+CR3*YA : 'Pitch rotation
X=X+MX : Y=Y+MY : Z=Z+MZ : 'Translation
SX=D*X/Z : SY=D*Y/Z : 'Rotation
RETURN
-----
Module : Return to BASIC interpreter
CLS : WINDOW : SCREEN 0,0,0 : WIDTH 80 : COLOR 7,0,0 : CLS : LOCATE 1,1,1 : END
-----
Module : Screen setup
615 KEY OFF : CLS
SCREEN 9,0,0 : COLOR 7,0 : PALETTE 1,9 : PALETTE 2,12 : PALETTE 3,7 : _
PALETTE 4,5
PALETTE 5,3
C0=0 : C1=1 : C2=2 : C3=3 : C4=4 : C5=5 '*****EGA 640x200 16-color_
mode*****
WINDOW SCREEN (-399,-299)-(400,300)
GO TO 530 'Return to main program
-----
Module : Assign variables
620 D=1200 : R1=5.68319 : R2=6.28319 : R3=5.79778 : MX=0 : MY=0 : MZ=-350_
'3D parameters
622 SR1=SIN(R1) : CR1=COS(R1) : SR2=SIN(R2) : CR2=COS(R2) : SR3=SIN(R3) : _
CR3=COS(R3) : _
RETURN
-----
Module : Database of Cartesian XYZ world coordinates
Grid Data
625 DATA 100,-30,0, 0,-30,0, 0,-30,0, 100,-30,0, 50,-30,0
630 DATA 0,-30,100, 0,-30,0, 0,-30,0, 0,-30,100, 0,-30,50
635 DATA 0,70,0, 0,-30,0, 0,-30,0, 0,70,0, 0,5,0
640 DATA 0,-30,-100, 0,-30,0, 0,-30,0, 0,-30,-100, 0,-30,-50
-----
Blip Data
645 DATA 5,-30,0, 5,-30,0, -5,-30,0, -5,-30,0, 0,-30,0
655 DATA 0,-30,5, 0,-30,-5, 0,-30,-5, 0,-30,5, 0,-30,0
665 DATA 0,-35,0, 0,-25,0, 0,-25,0, 0,-35,0, 0,-30,0
-----
Module : Print labels
675 FOR W=1 TO B%
X2=PLOT(W)+5
Y2=PLOT(W)+3
X3=PLOT(W)-5
Y3=PLOT(W)-3
LINE (X2,PLOT(W))-(X3,PLOT(W)),C5
LINE (PLOT(W),Y2)-(PLOT(W),Y3),C5
H1=(PLOT(W)/8)+1
H2=PLOT(W)/8
LOCATE H2,H1
IF W=1 THEN PRINT "A"
IF W=2 THEN PRINT "B"
IF W=3 THEN PRINT "C"
IF W=4 THEN PRINT "D"
IF W=5 THEN PRINT "E"
IF W=6 THEN PRINT "F"
IF W=7 THEN PRINT "G"
NEXT W
RETURN
-----
SUB SCREENMKR STATIC 'Probability screen generator
REM SDYNAMIC
CLS
SCREEN 9
DRAW "BM 10,20"
DRAW "M 630,20"
DRAW "M 630,338"
DRAW "M 10,338"
DRAW "M 10,20"
DRAW "BM 18,35"
DRAW "M 622,35"
DRAW "M 622,335"
DRAW "M 18,335"
DRAW "M 18,35"
COLOR 14,4,12
LOCATE 25,65
PRINT " MacroRADSS "
DRAW "BM 10,100"
DRAW "M 10,335"

```

```
DRAW "BM 630,100"
DRAW "M 630,335"
COLOR 15
END SUB
```

```

'~~~~~ Begin Exposure Subprogram ~~~~~
SUB CONSSUB STATIC
REM $DYNAMIC
SHARED SEVERITY,COUNAMES,MUNNAMES,STRNAMES,HAZTYPE%,DA%,D%,MAXWIDTH
SEVERITY=0.0 576 CALL SCRNMKR3 Exposure screen generator
COLOR 15
LOCATE 8,10
PRINT "Which hazmat type do you wish to consider in the analysis?_"
PRINT "The"
LOCATE 9,10
PRINT "following selections are currently available : "
HAZTYPE%=1
DO
LOCATE 12,10
COLOR 15
IF HAZTYPE%=1 THEN COLOR 10
PRINT "(A) Combustible Liquid"
LOCATE 14,10
COLOR 15
IF HAZTYPE%=2 THEN COLOR 10
PRINT "(B) Flammable Liquid"
LOCATE 16,10
COLOR 15
IF HAZTYPE%=3 THEN COLOR 10
PRINT "(C) Flammable Solid"
LOCATE 18,10
COLOR 15
IF HAZTYPE%=4 THEN COLOR 10
PRINT "(D) Flammable LCG"
LOCATE 20,10
COLOR 15
IF HAZTYPE%=5 THEN COLOR 10
PRINT "(E) Flammable CG"
LOCATE 12,42
COLOR 15
IF HAZTYPE%=6 THEN COLOR 10
PRINT "(F) Non-Flammable LCG"
LOCATE 14,42
COLOR 15
IF HAZTYPE%=7 THEN COLOR 10
PRINT "(G) Non-flammable CG"
LOCATE 16,42
COLOR 15
IF HAZTYPE%=8 THEN COLOR 10
PRINT "(H) Poison A CG"
LOCATE 18,42
COLOR 15
IF HAZTYPE%=9 THEN COLOR 10
PRINT "(I) Poison A LCG/Liquid"
LOCATE 20,42
COLOR 15
IF HAZTYPE%=10 THEN COLOR 10
PRINT "(J) Next Screen"
DO
AS=""
AS=INKEY$
LOOP UNTIL AS<>" "
IF LEN(AS)=2 THEN AS=MID$(AS,2,1)
IF ASC(MID$(AS,1,1))=13 THEN EXIT DO
IF ASC(MID$(AS,1,1))=80 THEN HAZTYPE%=HAZTYPE%+1
IF ASC(MID$(AS,1,1))=72 THEN HAZTYPE%=HAZTYPE%-1
IF HAZTYPE%>=11 THEN HAZTYPE%=1
IF HAZTYPE%<=0 THEN HAZTYPE%=10
LOOP
IF HAZTYPE%<10 GOTO 680
HAZTYPE%=11
CALL SCRNMKR3
DO
LOCATE 8,10
COLOR 15
IF HAZTYPE%=11 THEN COLOR 10
PRINT "(K) Poison B Liquid"
LOCATE 10,10
COLOR 15
IF HAZTYPE%=12 THEN COLOR 10
PRINT "(L) Poison B Solid"
LOCATE 12,10
COLOR 15
IF HAZTYPE%=13 THEN COLOR 10
PRINT "(M) Explosive A"
LOCATE 14,10
COLOR 15
IF HAZTYPE%=14 THEN COLOR 10
PRINT "(N) Explosive B"
LOCATE 16,10
COLOR 15
IF HAZTYPE%=15 THEN COLOR 10
PRINT "(O) Explosive C"
LOCATE 18,10

```

```

COLOR 15
IF HAZTYPE% = 16 THEN COLOR 10
PRINT "(P) Blasting Agents"
LOCATE 20,10
COLOR 15
IF HAZTYPE% = 17 THEN COLOR 10
PRINT "(Q) Corrosive Liquids"
LOCATE 8,42
COLOR 15
IF HAZTYPE% = 18 THEN COLOR 10
PRINT "(R) Corrosive Solids"
LOCATE 10,42
COLOR 15
IF HAZTYPE% = 19 THEN COLOR 10
PRINT "(S) Org. Peroxide Liq."
LOCATE 12,42
COLOR 15
IF HAZTYPE% = 20 THEN COLOR 10
PRINT "(T) Org. Peroxide Sol."
LOCATE 14,42
COLOR 15
IF HAZTYPE% = 21 THEN COLOR 10
PRINT "(U) Oxidizers"
LOCATE 16,42
COLOR 15
IF HAZTYPE% = 22 THEN COLOR 10
PRINT "(V) Gasolines"
LOCATE 18,42
COLOR 15
IF HAZTYPE% = 23 THEN COLOR 10
PRINT "(W) Oxygen"
LOCATE 20,42
COLOR 15
IF HAZTYPE% = 24 THEN COLOR 10
PRINT "(X) Next Screen"
DO
  AS=""
  AS=INKEY$
  LOOP UNTIL AS<>" "
  IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
  IF ASC(MIDS(AS,1,1))=13 THEN EXIT DO
  IF ASC(MIDS(AS,1,1))=80 THEN HAZTYPE%=HAZTYPE%+1
  IF ASC(MIDS(AS,1,1))=72 THEN HAZTYPE%=HAZTYPE%-1
  IF HAZTYPE%>=25 THEN HAZTYPE%=11
  IF HAZTYPE%<=10 THEN HAZTYPE%=24
LOOP
  IF HAZTYPE%<24 GOTO 680
  HAZTYPE%=25
  CALL SCRNMKR3
  DO
LOCATE 8,10
COLOR 15
IF HAZTYPE%=25 THEN COLOR 10
PRINT "(Y) Anhydrous Ammonia"
LOCATE 10,10
COLOR 15
IF HAZTYPE%=26 THEN COLOR 10
PRINT "(Z) Chlorine"
LOCATE 12,10
COLOR 15
IF HAZTYPE%=27 THEN COLOR 10
PRINT "(AA) Ethylene Oxide"
LOCATE 14,10
COLOR 15
IF HAZTYPE%=28 THEN COLOR 10
PRINT "(BB) LPG"
LOCATE 16,10
COLOR 15
IF HAZTYPE%=29 THEN COLOR 10
PRINT "(CC) Other..."
LOCATE 18,10
COLOR 15
IF HAZTYPE%=30 THEN COLOR 10
PRINT "(DD) Original Screen"
DO
  AS=""
  AS=INKEY$
  LOOP UNTIL AS<>" "
  IF LEN(AS)=2 THEN AS=MIDS(AS,2,1)
  IF ASC(MIDS(AS,1,1))=13 THEN EXIT DO
  IF ASC(MIDS(AS,1,1))=80 THEN HAZTYPE%=HAZTYPE%+1
  IF ASC(MIDS(AS,1,1))=72 THEN HAZTYPE%=HAZTYPE%-1
  IF HAZTYPE%>=31 THEN HAZTYPE%=25
  IF HAZTYPE%<=24 THEN HAZTYPE%=30
LOOP
  IMMEDIAT=0
  ' Local hazards don't have mean distances reported
  ' in Dr. Raj's impact area widths.
  IF HAZTYPE%=18 THEN IMMEDIAT=1
  IF HAZTYPE%=20 THEN IMMEDIAT=1
  IF HAZTYPE%=21 THEN IMMEDIAT=1
  IF HAZTYPE%<29 GOTO 680
  IF HAZTYPE%<30 GOTO 678
  GO TO 676
678 COLOR 15
  CALL SCRNMKR3

```



```

LOCATE 8,10
PRINT "Please input the impact corridor width for the release"
LOCATE 9,10
PRINT "of this hazmat (miles) : "
LOCATE 20,32
INPUT " = = > ",MAXWIDTH
GO TO 684
680 CALL SCRNMKR3
LOCATE 8,10
PRINT "How severe a release do you wish to consider? The following"
LOCATE 9,10
PRINT "selections are available : "
D%=1
DO
LOCATE 12,25
COLOR 15
IF D%=1 THEN COLOR 10
PRINT "(A) Not severe (in system effects only)"
LOCATE 14,25
COLOR 15
IF IMMEDIAT > 0.5 THEN D%=3 : GOTO 681
IF D%=2 THEN COLOR 10
PRINT "(B) Moderately severe"
681 LOCATE 16,25
COLOR 15
IF D%=3 THEN COLOR 10
PRINT "(C) Catastrophic"
DO
AS=""
AS=INKEYS
LOOP UNTIL AS < > ""
IF LEN(AS)=2 THEN AS=MID$(AS,2,1)
IF ASC(MID$(AS,1,1))=13 THEN EXIT DO
IF ASC(MID$(AS,1,1))=80 THEN D%=D%+1
IF ASC(MID$(AS,1,1))=72 THEN D%=D%-1
IF D% > 4 THEN D%=1
IF D% <= 0 THEN D%=3
LOOP
IF D%=1 THEN MAXWIDTH=0 : GOTO 684
IF D%=2 THEN SEVERITY=0.5
IF D%=3 THEN SEVERITY=1.0
' Evaluate the size of the corridor impact width
' based on hazmat type and severity
IF HAZTYPE%=1 THEN
IF SEVERITY=0.5 THEN MAXWIDTH=0.041 : GOTO 684
IF SEVERITY=1.0 THEN MAXWIDTH=0.094 : GOTO 684
END IF
IF HAZTYPE%=2 THEN
IF SEVERITY=0.5 THEN MAXWIDTH=0.009 : GOTO 684
IF SEVERITY=1.0 THEN MAXWIDTH=0.105 : GOTO 684
END IF
IF HAZTYPE%=3 THEN
CALL SCRNMKR3
LOCATE 14,10
PRINT "Selection Unavailable. Please try another."
FOR I=1 TO 50000
NEXT I
GO TO 676
END IF
IF HAZTYPE%=4 GOTO 682
IF HAZTYPE%=5 GOTO 682
IF HAZTYPE%=6 THEN
IF SEVERITY=0.5 THEN MAXWIDTH=12.5 : GOTO 684
IF SEVERITY=1.0 THEN MAXWIDTH=23.5 : GOTO 684
END IF
IF HAZTYPE%=7 THEN
IF SEVERITY=0.5 THEN MAXWIDTH=0.022 : GOTO 684
IF SEVERITY=1.0 THEN MAXWIDTH=0.080 : GOTO 684
END IF
IF HAZTYPE%=8 THEN
IF SEVERITY=0.5 THEN MAXWIDTH=0.394 : GOTO 684
IF SEVERITY=1.0 THEN MAXWIDTH=3.650 : GOTO 684
END IF
IF HAZTYPE%=9 THEN
CALL SCRNMKR3
LOCATE 14,10
PRINT "Selection Unavailable. Please try another."
FOR I=1 TO 50000
NEXT I
GO TO 676
END IF
IF HAZTYPE%=9 THEN
CALL SCRNMKR3
LOCATE 14,10
PRINT "Selection Unavailable. Please try another."
FOR I=1 TO 50000
NEXT I
GO TO 676
END IF
IF HAZTYPE%=10 THEN
CALL SCRNMKR3
LOCATE 14,10
PRINT "Selection Unavailable. Please try another."
FOR I=1 TO 50000
NEXT I
GO TO 676

```

```

END IF
IF HAZTYPE% = 11 THEN
CALL SCRNMKR3
LOCATE 14,10
PRINT "Selection Unavailable. Please try another."
FOR I = 1 TO 50000
NEXT I
GO TO 676
END IF
IF HAZTYPE% = 12 THEN
CALL SCRNMKR3
LOCATE 14,10
PRINT "Selection Unavailable. Please try another."
FOR I = 1 TO 50000
NEXT I
GO TO 676
END IF
IF HAZTYPE% = 13 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 0.231 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 0.261 : GOTO 684
END IF
IF HAZTYPE% = 14 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 0.231 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 0.261 : GOTO 684
END IF
IF HAZTYPE% = 15 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 0.231 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 0.261 : GOTO 684
END IF
IF HAZTYPE% = 16 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 0.231 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 0.261 : GOTO 684
END IF
IF HAZTYPE% = 17 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 0.016 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 0.031 : GOTO 684
END IF
IF HAZTYPE% = 18 THEN MAXWIDTH = 0.013 : GOTO 684
IF HAZTYPE% = 19 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 0.016 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 0.040 : GOTO 684
END IF
IF HAZTYPE% = 20 THEN MAXWIDTH = 0.013 : GOTO 684
IF HAZTYPE% = 21 THEN MAXWIDTH = 0.013 : GOTO 684
IF HAZTYPE% = 22 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 0.052 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 0.105 : GOTO 684
END IF
IF HAZTYPE% = 23 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 0.002 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 0.024 : GOTO 684
END IF
IF HAZTYPE% = 25 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 13.688 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 25.375 : GOTO 684
END IF
IF HAZTYPE% = 26 THEN
IF SEVERITY = 0.5 THEN MAXWIDTH = 42.5 : GOTO 684
IF SEVERITY = 1.0 THEN MAXWIDTH = 55.313 : GOTO 684
END IF
682 CALL SCRNMKR3
LOCATE 10,10
PRINT "Which release sequence do you wish to consider?"
DA% = 1
IF HAZTYPE% = 5 THEN DA% = 2
IF HAZTYPE% = 27 THEN DA% = 2
DO
LOCATE 12,25
COLOR 15
IF HAZTYPE% = 5 GOTO 683
IF HAZTYPE% = 27 GOTO 683
IF DA% = 1 THEN COLOR 10
PRINT "(A) Liquid Pool Fire"
LOCATE 14,25
COLOR 15
683 IF DA% = 2 THEN COLOR 10
PRINT "(B) Dispersion of Vapor"
LOCATE 16,25
COLOR 15
IF DA% = 3 THEN COLOR 10
PRINT "(C) Explosion"
DO
AS = ""
AS = INKEY$
LOOP UNTIL AS <> ""
IF LEN(AS) = 2 THEN AS = MID$(AS,2,1)
IF ASC(MID$(AS,1,1)) = 13 THEN EXIT DO
IF ASC(MID$(AS,1,1)) = 80 THEN DA% = DA% + 1
IF ASC(MID$(AS,1,1)) = 72 THEN DA% = DA% - 1
IF DA% >= 4 THEN DA% = 1
IF DA% <= 0 THEN DA% = 3
IF DA% = 1 THEN
IF HAZTYPE% = 5 THEN DA% = 2
IF HAZTYPE% = 27 THEN DA% = 2
END IF
LOOP

```

```

IF HAZTYPE% = 4 THEN
  IF DA% = 1 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.042 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.105 : GOTO 684
  END IF
  IF DA% = 2 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 2.0 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 3.688 : GOTO 684
  END IF
  IF DA% = 3 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.133 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.245 : GOTO 684
  END IF
END IF
IF HAZTYPE% = 5 THEN
  IF DA% = 2 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.046 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.168 : GOTO 684
  END IF
  IF DA% = 3 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.034 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.127 : GOTO 684
  END IF
END IF
IF HAZTYPE% = 27 THEN
  IF DA% = 2 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.259 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.506 : GOTO 684
  END IF
  IF DA% = 3 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.131 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.241 : GOTO 684
  END IF
END IF
IF HAZTYPE% = 28 THEN
  IF DA% = 1 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.005 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.123 : GOTO 684
  END IF
  IF DA% = 2 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.283 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.565 : GOTO 684
  END IF
  IF DA% = 3 THEN
    IF SEVERITY = 0.5 THEN MAXWIDTH = 0.028 : GOTO 684
    IF SEVERITY = 1.0 THEN MAXWIDTH = 0.242 : GOTO 684
  END IF
END IF
END IF
* MAXWIDTH is the corridor width adjusted for the
* severity of the release.
684 CALL SCRNMKR3
COUCONS = "counties"
MUNCONS = "munics"
STRCONS = "streets"
LOCATE 5,10
PRINT "PLEASE ENTER YOUR COUNTY LEVEL CONSEQUENCE DATA FILE NAME FOR_"
FILE
LOCATE 6,10
PRINT "IN DRIVE A. DO NOT ENTER THE EXTENSION (.DAT IS ASSUMED)._"
DEFAULT
LOCATE 7,10
PRINT "FILENAME IS : " COUCONS
LOCATE 8,10
INPUT " = = = > ", TEST1$
IF TEST1$ <> "" THEN COUCONS = TEST1$
COUNAMES = "A : " + COUCONS + ".DAT"
LOCATE 9,10
PRINT "Thank you..."
LOCATE 11,10
PRINT "PLEASE ENTER YOUR MUNICIPALITY LEVEL CONSEQUENCE DATA FILE NAME"
LOCATE 12,10
PRINT "FOR FILE IN DRIVE A. DO NOT ENTER THE EXTENSION (.DAT IS_"
ASSUMED)."
LOCATE 13,10
PRINT "DEFAULT FILENAME IS : " MUNCONS
LOCATE 14,10
INPUT " = = = > ", TEST2$
IF TEST2$ <> "" THEN MUNCONS = TEST2$
MUNNAMES = "A : " + MUNCONS + ".DAT"
LOCATE 15,10
PRINT "Thank you..."
LOCATE 17,10
PRINT "PLEASE ENTER YOUR STREET LEVEL CONSEQUENCE DATA FILE NAME_"
FOR FILE
LOCATE 18,10
PRINT "IN DRIVE A. DO NOT ENTER THE EXTENSION (.DAT IS ASSUMED)._"
DEFAULT
LOCATE 19,10
PRINT "FILENAME IS : " STRCONS
LOCATE 20,10
INPUT " = = = > ", TEST3$
IF TEST3$ <> "" THEN STRCONS = TEST3$
STRNAMES = "A : " + STRCONS + ".DAT"
LOCATE 21,10
PRINT "Thank you..."
* Read in county, municipality and street level

```

```

' exposure data.
OPEN MUNNAMES FOR RANDOM AS #4 LEN=87
FIELD #4,2 AS AGES,5 AS MUNICS,4 AS AREAS,2 AS MUNHOSPS,
3 AS MUNSCHS,7 AS MUNWORKS,7 AS MUNRESIS,7 AS MUNDUS,
5 AS MUNCOMMS,4 AS MUNINDS,4 AS MUNAGRIS,6 AS MUNH2OS,
29 AS DUMMYS
OPEN COUNAMES FOR RANDOM AS #5 LEN=41
FIELD #5,2 AS AGES,2 AS COUNS,2 AS COUHOSPS,3 AS COUSCHS,
5 AS COUBEDSS,6 AS COUENRLS,5 AS PCTURBNS,14 AS DUMMY2S
OPEN STRNAMES FOR RANDOM AS #6 LEN=75
FIELD #6,2 AS AGES,11 AS STCODES,2 AS SPDLIMS,7 AS STADTS,6 AS H2OS,
45 AS DUMMY3S
DIM ADT(F),SPEED(F)
DIM CHOSPIT(J),CSCHOOLS(J),CBEDS(J),CENROLL(J),URBAN(J)
DIM MUNAREA(B),WORK(B),RESIDE(B),MHOSPIT(B),MSCHOOLS(B),MNODU(B),
MNOCOMMR(B),MNOINDUS(B),MNOAGRI(B)
FOR I=1 TO B
  GET #4,I
  MUNAREA(I)=VAL(AREAS)
  WORK(I)=VAL(MUNWORKS)
  RESIDE(I)=VAL(MUNRESIS)
  MHOSPIT(I)=VAL(MUNHOSPS)
  MSCHOOLS(I)=VAL(MUNSCHS)
  MNODU(I)=VAL(MUNDUS)
  MNOCOMMR(I)=VAL(MUNCOMMS)
  MNOINDUS(I)=VAL(MUNINDS)
  MNOAGRI(I)=VAL(MUNAGRIS)
  MINTAKE(I)=VAL(MUNH2OS)/MRDSGLTH(I)
  MUN#(I)=VAL(MUNICS)
NEXT I
FOR I=1 TO J
  GET #5,I
  CHOSPIT(I)=VAL(CDUHOSPS)
  CSCHOOLS(I)=VAL(COUSCHS)
  CBEDS(I)=VAL(COUBEDSS)
  CENROLL(I)=VAL(COUENRLS)
  URBAN(I)=VAL(PCTURBNS)
  COU#(I)=VAL(COUNS)
NEXT I
FOR I=1 TO F
  GET #6,I
  ADT(I)=VAL(STADTS)
  SPEED(I)=VAL(SPDLIMS)
  INTAKE(I)=VAL(H2OS)/RDSEGLTH(I)
  STR#(I)=VAL(STCODES)
NEXT I
'-----Corridor Size Determination-----
DIM CORRIDOR(F),RATIO(F),MRATIO(B)
MCCORRID=0.0
FOR I=1 TO B
  FOR U=1 TO F
    ' For each municipality : determine those streets
    ' within the municipality, calculate their corridor
    ' sizes, and add them for municipality total sizes.
    IF (FIX(STR#(U)/1000000) < > MUN#(I)) THEN
      MCCORRID=0.0
      GO TO 685
    ELSE
      CORRIDOR(U)=(RDSEGLTH(U)/5280)*MAXWIDTH
      MCCORRID=MCCORRID+CORRIDOR(U)
    END IF
  685 NEXT U
  ' Adjust the municipality corridor size if it ex-
  ' ceeds the municipality total area.
  ADJUST=1.0
  IF MUNAREA(I) < MCCORRID GO TO 695
  ADJUST=1.0
  GO TO 705
  695 ADJUST=(MUNAREA(I)/MCCORRID)
  ' Compute the percentage of the municipality that
  ' is exposed by individual streets and in total.
  705 FOR U=1 TO F
    IF (FIX(STR#(U)/1000000) < > MUN#(I)) GOTO 715
    CORRIDOR(U)=CORRIDOR(U)*ADJUST
    RATIO(U)=CORRIDOR(U)/MUNAREA(I)
    MCCORRID=MCCORRID+CORRIDOR(U)
  715 NEXT U
  MRATIO(I)=MCCORRID/MUNAREA(I)
  MCCORRID=0.0
NEXT I
'-----Population Exposure Computations-----
DIM HOSPSIZE(J),SCHSIZE(J),MINDIG(B),MINSYS(B),MBEDS(B),MENROLL(B),
MPOP(B),IND,G(F),INSYS(F)
' Compute the average number of beds per hospital
' and enrollment per school for each county.
FOR I=1 TO J
  HOSPSIZE(I)=CBEDS(I)/CHOSPIT(I)
  SCHSIZE(I)=CENROLL(I)/CSCHOOLS(I)
NEXT I
FOR I=1 TO B
  COUNO=FIX(MUN#(I)/1000)
  ' Find the county which contains the municipality
  ' in question and determine the number of hospital
  ' beds and the school enrollment for the municipality.
  FOR W=1 TO J
    IF (COU#(W)=COUNO) GO TO 725

```

```

NEXT W
725 MPOP(I) = 0
MBEDS(I) = HOSPSIZE(W)*MHOSPIT(I)
MENROLL(I) = SCHSIZE(W)*MSCHOOLS(I)
' Determine if the municipality residential or
' employment population is larger.
IF RESIDE(I) < WORK(I) GO TO 735
MPOP(I) = MBEDS(I) + MENROLL(I) + RESIDE(I)
GO TO 745
' Determine total municipality population & total
' indigenous population exposed.
735 MPOP(I) = MBEDS(I) + MENROLL(I) + WORK(I)
745 MINDIG(I) = MRATIO(I)*MPOP(I)
' For each street, determine the street's indig-
' enous population exposed.
FOR U = 1 TO F
IF (FIX(STR#(U)/1000000) < > MUN#(I)) GO TO 785
INDIG(U) = RATIO(U)*MPOP(I)
FOR W = 1 TO J
IF (FIX(MUN#(I)/1000) = COU#(W)) GO TO 755
NEXT W
755 IF URBAN(W) > 50 GO TO 775
' If the county is rural, use the following ex-
' pressions to determine the highway user (in system)
' population exposed (assumes 1.3 people per vehicle &
' that average vehicle speed is 0.8 x Speed Limit).
PHFLOW = ADT(U)/15 'Approx. Peak Hour Flow
RDDENSE = PHFLOW/(0.8*SPEED(U)) 'Road Density
INSYS(U) = RDSEGLTH(U)*RDDENSE*1.3
' Sums in system population exposed for the total
' municipality and determines total exposed people for
' the street.
MINSYS(I) = MINSYS(I) + INSYS(U)
EXPOP(U) = INDIG(U) + INSYS(U)
765 GO TO 785
' If the county is urban, use the following ex-
' pressions to determine the highway user (in system)
' population exposed (assumes 1.5 people per vehicle &
' that average vehicle speed is 0.5 x Speed Limit).
775 PHFLOW = ADT(U)*0.10 'Approx. Peak Hour Flow
RDDENSE = PHFLOW/(0.5*SPEED(U)) 'Road Density
INSYS(U) = RDSEGLTH(U)*RDDENSE*1.5
' Sums in system population exposed for the total
' municipality and determines total exposed people for
' the street.
MINSYS(I) = MINSYS(I) + INSYS(U)
EXPOP(U) = INDIG(U) + INSYS(U)
785 NEXT U
' Determine total exposed people for the muni-
' pality.
MEXPOP(I) = MINDIG(I) + MINSYS(I)
NEXT I
' Divide exposed populations (both levels) by the
' road lengths involved to obtain exposed population
' per mile of road.
FOR I = 1 TO B
MEXPOP(I) = MEXPOP(I)/MRDSEGLTH(I)
NEXT I
FOR I = 1 TO F
EXPOP(I) = EXPOP(I)/RDSEGLTH(I)
NEXT I
-----Property Exposure Computations-----
DIM LF(67),COUNUM(67)
' Read in the locality cost adjustment factors.
CDRIVE1$ = "factors.dat"
OPEN CDRIVE1$ FOR RANDOM AS #7 LEN = 25
FIELD #7,2 AS AGES,2 AS COUNTY$,5 AS LFACTORS$,14 AS CNAMES
FOR I = 1 TO 67
GET #7,1
LF(I) = VAL(LFACTORS)
COUNUM(I) = VAL(COUNTYS)
NEXT I
' Read in the cost to build a building for each
' land use type in urban or rural environments.
CDRIVE2$ = "bldcosts.dat"
OPEN CDRIVE2$ FOR RANDOM AS #8 LEN = 29
FIELD #8,7 AS RESBASES,7 AS COMBASES,7 AS INDBASES,8 AS AGRBASES
DIM DUBASE(2),COMBASE(2),INDBASE(2),AGRIBASE(2)
DIM CDUCOST(J),CCOMCOST(J),CINDCOST(J),CAGRCOST(J)
FOR I = 1 TO 2 'Urban and Rural respectively
GET #8,1
DUBASE(I) = VAL(RESBASES)
COMBASE(I) = VAL(COMBASES)
INDBASE(I) = VAL(INDBASES)
AGRIBASE(I) = VAL(AGRBASES)
NEXT I
' For each county, determine if it's primarily
' urban or rural and assign a locally factored set of
' building replacement costs.
FOR I = 1 TO J
FOR W = 1 TO 67
IF COUNUM(W) = COU#(I) GO TO 795
NEXT W
795 IF (URBAN(I) > 50) GO TO 805
Q = 1
GO TO 815

```

```

805 Q=2
815 CDUCOST(I)=LF(I)*DUBASE(Q)
   CCOMCOST(I)=LF(I)*COMBASE(Q)
   CINDCOST(I)=LF(I)*INDBASE(Q)
   CAGRCOST(I)=LF(I)*AGRIBASE(Q)
NEXT I
MSEARCH=FIX(YSTREET(1)/1000000)
FOR I=1 TO F
MNO=FIX(YSTREET(I)/1000000)
FOR W=1 TO B
IF (MUN#(W)=MNO) GO TO 825
NEXT W
' For each street, determine the total cost to
' rebuild exposed buildings based on the county cost
' for each building type, the number of each type in
' the municipality and the percentage of the municipi-
' pality exposed. Sum for the municipality.
825 FOR U=1 TO J
IF (FIX(YSTREET(I)/1000000000) < > COU#(U)) GO TO 845
DUCOST=CDUCOST(U)*MNODU(W)*RATIO(I)
COMCOST=CCOMCOST(U)*MNOCOMM(W)*RATIO(I)
INDCOST=CINDCOST(U)*MNOINDUS(W)*RATIO(I)
AGRICOST=CAGRCOST(U)*MNOAGRI(W)*RATIO(I)
TTLCOST(I)=DUCOST+COMCOST+INDCOST+AGRICOST
IF HAZTYPE%=7 THEN TTLCOST(I)=0.0
IF (MSEARCH=MNO) GO TO 835
MTTLCOST(W)=TTLCOST(I)
GO TO 845
835 MTTLCOST(W)=MTTLCOST(W)+TTLCOST(I)
845 NEXT U
MSEARCH=MNO
NEXT I
' Divide exposed properties (both levels) by the
' road lengths involved to obtain exposed property per
' mile of road.
FOR I=1 TO B
MTTLCOST(I)=MTTLCOST(I)/MRDSGLTH(I)
NEXT I
FOR I=1 TO F
TTLCOST(I)=TTLCOST(I)/RDSEGLTH(I)
NEXT I
'-----Special Facilities Exposure Computations-----
' Determines the total number of hospital beds &
' total size of school enrollment which are exposed
' for each street and municipality (already computed)
FOR I=1 TO B
MSPECTTL(I)=(MBEDS(I)+MENROLL(I))*MRATIO(I)
NEXT I
FOR I=1 TO F
MNUM=FIX(YSTREET(I)/1000000)
FOR W=1 TO B
IF (MUN#(W)=MNUM) GO TO 855
NEXT W
855 SPECHOS=RATIO(I)*MBEDS(W)
   SPECSCH=RATIO(I)*MENROLL(W)
   SPECTTL(I)=SPECHOS+SPECSCH
NEXT I
FOR I=1 TO B
MSPECTTL(I)=MSPECTTL(I)/MRDSGLTH(I)
NEXT I
FOR I=1 TO F
SPECTTL(I)=SPECTTL(I)/RDSEGLTH(I)
NEXT I
END SUB

```

of Exposure Subprogram

End

```

'~~~~~
SUB SCRNMKR3 STATIC      Exposure screen generator
REM $DYNAMIC
CLS
SCREEN 9
DRAW "BM 10,20"
DRAW "M 630,20"
DRAW "M 630,338"
DRAW "M 10,338"
DRAW "M 10,20"
DRAW "BM 18,35"
DRAW "M 622,35"
DRAW "M 622,335"
DRAW "M 18,335"
DRAW "M 18,35"
COLOR 14,2,12
LOCATE 25,65
PRINT " MacroRADSS "
DRAW "BM 10,100"
DRAW "M 10,335"
DRAW "BM 630,100"
DRAW "M 630,335"
COLOR 15
END SUB

```

```

'~~~~~
'~~~~~ Begin Response Subprogram ~~~~~

```

```

SUB RESPSUB STATIC
REM SDYNAMIC
SHARED RAFNAMES
DEFDBL X
FLAG1=0.0
FLAG2=0.0
FLAG3=0.0
FLAG4=0.0
FOR I=1 TO J
  FACTOR1(I)=1.0
  FACTOR2(I)=1.0
  FACTOR3(I)=1.0
  FACTOR4(I)=1.0
NEXT I
CALL SCRNMKR2      'Response screen generator
NAMES="REACT"
LOCATE 12,10
PRINT "PLEASE ENTER YOUR RESPONSE DATA FILE NAME FOR FILE IN DRIVE A."
LOCATE 13,10
PRINT "DO NOT ENTER THE EXTENSION (.DAT IS ASSUMED).  DEFAULT FILENAME_
IS"
LOCATE 14,10
PRINT "REACT "
LOCATE 20,32
INPUT "====> ",NAMES
RAFNAMES="A:" + NAMES + ".DAT"
LOCATE 21,32
PRINT "Thank you."
CALL SCRNMKR2
'-----Read Random Access File-----
LOCATE 12,10
PRINT "Now reading response data..."
FOR I = 1 TO 5000
NEXT I
OPEN RAFNAMES FOR RANDOM AS #2 LEN=38
FIELD #2,2 AS AGES,2 AS COUNS,3 AS POLICES,3 AS HKNLDRS,3 AS AMBUS,_
2 AS RESPONDS,7 AS POPS,14 AS CNAMES
TOTAL%=LOF(2)/38
FOR I%=1 TO TOTAL%
GET #2, I% 'READ RECORD I% INTO THE FILE BUFFER
NEXT I%
J=TOTAL%
DIM COU(J),COPS(J),FIRE(J),RESQ(J),TIME(J),DUMMY(J),CPOP(J)
FOR I=1 TO J
  GET #2,1
  COU(I)=VAL(COUNS)
  COPS(I)=VAL(POLICES)
  FIRE(I)=VAL(HKNLDRS)
  RESQ(I)=VAL(AMBUS)
  TIME(I)=VAL(RESPONDS)
  CPOP(I)=VAL(POPS)
NEXT I
CALL SCRNMKR2
'-----Display Menu-----
LOCATE 4,26
PRINT "Response Parameters to Consider : "
LOCATE 8,10
PRINT "(A) All (Default)"
LOCATE 9,10
COLOR 9
PRINT "(B) Police Only"
LOCATE 10,10
COLOR 10
PRINT "(C) Fire Only"
LOCATE 11,10
COLOR 12
PRINT "(D) Ambulance Only"
LOCATE 12,10
COLOR 11
PRINT "(E) Response Time Only"
LOCATE 13,10
COLOR 9
PRINT "(F) Police"
LOCATE 14,10
COLOR 10
PRINT " & Fire"
LOCATE 15,10
COLOR 9
PRINT "(G) Police"
LOCATE 16,10
COLOR 12
PRINT " & Ambulance"
LOCATE 17,10
COLOR 9
PRINT "(H) Police"
LOCATE 18,10
COLOR 11
PRINT " & Time"
LOCATE 19,42
COLOR 9
PRINT "(I) Police,"
LOCATE 20,10
COLOR 10
PRINT " Fire"
LOCATE 21,11
COLOR 11
PRINT " & Time"
LOCATE 22,42
COLOR 9
PRINT "(J) Police,"
LOCATE 23,12

```

```

PRINT " Ambulance"
COLOR 11
PRINT " & Time"
LOCATE 10,42
COLOR 9
PRINT "(K) Police,"
COLOR 10
PRINT " Fire"
COLOR 12
PRINT " & Ambulance"
LOCATE 11,42
COLOR 10
PRINT "(L) Fire"
COLOR 12
PRINT " & Ambulance"
LOCATE 12,42
COLOR 10
PRINT "(M) Fire"
COLOR 11
PRINT " & Time"
LOCATE 13,42
COLOR 12
PRINT "(N) Ambulance"
COLOR 11
PRINT " & Time"
LOCATE 14,42
COLOR 10
PRINT "(O) Fire"
COLOR 12
PRINT " Ambulance"
COLOR 11
PRINT " & Time"
LOCATE 15,42
COLOR 15
PRINT "(P) None"
LOCATE 20,37
COLOR 15
INPUT LS
IF LS="" GOTO 860
IF LS=" " GOTO 860
XS=LS : GO TO 862
860 XS="A"
-----Evaluate Parameters-----
862 IF XS="a" THEN XS="A"
IF XS="A" GOTO 865
IF XS="b" THEN XS="B"
IF XS="B" GOTO 865
IF XS="f" THEN XS="F"
IF XS="F" GOTO 865
IF XS="g" THEN XS="G"
IF XS="G" GOTO 865
IF XS="h" THEN XS="H"
IF XS="H" GOTO 865
IF XS="i" THEN XS="I"
IF XS="I" GOTO 865
IF XS="j" THEN XS="J"
IF XS="J" GOTO 865
IF XS="k" THEN XS="K"
IF XS="K" GOTO 865
ERASE COPS 'No Police response
DIM COPS(J)
FLAG1=1.0
865 IF XS="A" GOTO 875
IF XS="c" THEN XS="C"
IF XS="C" GOTO 875
IF XS="F" GOTO 875
IF XS="I" GOTO 875
IF XS="K" GOTO 875
IF XS="l" THEN XS="L"
IF XS="L" GOTO 875
IF XS="m" THEN XS="M"
IF XS="M" GOTO 875
IF XS="o" THEN XS="O"
IF XS="O" GOTO 875
ERASE FIRE 'No Fire Response
DIM FIRE(J)
FLAG2=1.0
875 IF XS="A" GOTO 885
IF XS="d" THEN XS="D"
IF XS="D" GOTO 885
IF XS="G" GOTO 885
IF XS="J" GOTO 885
IF XS="K" GOTO 885
IF XS="L" GOTO 885
IF XS="n" THEN XS="N"
IF XS="N" GOTO 885
IF XS="O" GOTO 885
ERASE RESQ 'No Ambulance Response
DIM RESQ(J)
FLAG3=1.0
885 IF XS="A" GOTO 895
IF XS="e" THEN XS="E"
IF XS="E" GOTO 895
IF XS="H" GOTO 895
IF XS="I" GOTO 895
IF XS="J" GOTO 895

```



```

IF X5="M" GOTO 895
IF X5="N" GOTO 895
IF X5="O" GOTO 895
ERASE TIME 'No Response Time
DIM TIME(J)
FLAG4=1.0
895 IF X5="P" GOTO 935
IF X5="P" GOTO 935
DIM XCOPS(J),XFIRE(J),XRESQ(J),XTIME(J)
For each type of response considered, normalize
the response by the county population, determine the
state average value for the normalized response, and
determine the ratio of the individual county normal-
ized responses to the state average.
IF FLAG1>0.0 GOTO 905
XSUMCOPS=0.0
FOR I=1 TO J
XCOPS(I)=COPS(I)/CPOP(I)
XSUMCOPS=XSUMCOPS+XCOPS(I)
NEXT I
XAVGCOPS=XSUMCOPS/J
FOR I=1 TO J
FACTOR1(I)=XCOPS(I)/XAVGCOPS
NEXT I
905 IF FLAG2>0.0 GOTO 915
XSUMFIRE=0.0
FOR I=1 TO J
XFIRE(I)=FIRE(I)/CPOP(I)
XSUMFIRE=XSUMFIRE+XFIRE(I)
NEXT I
XAVGFIRE=XSUMFIRE/J
FOR I=1 TO J
FACTOR2(I)=XFIRE(I)/XAVGFIRE
NEXT I
915 IF FLAG3>0.0 GOTO 925
XSUMRESQ=0.0
FOR I=1 TO J
XRESQ(I)=RESQ(I)/CPOP(I)
XSUMRESQ=XSUMRESQ+XRESQ(I)
NEXT I
XAVGRESQ=XSUMRESQ/J
FOR I=1 TO J
FACTOR3(I)=XRESQ(I)/XAVGRESQ
NEXT I
925 IF FLAG4>0.0 GOTO 935
SUMTIME=0.0
FOR I=1 TO J
SUMTIME=SUMTIME+TIME(I)
NEXT I
AVGTIME=SUMTIME/J
FOR I=1 TO J
FACTOR4(I)=AVGTIME/TIME(I)
NEXT I
935 END SUB

```

of Response Subprogram

End

```

'~~~~~
SUB SCRNMKR2 STATIC 'Response screen generator
REM $DYNAMIC
CLS
SCREEN 9
DRAW "BM 10,20"
DRAW "M 630,20"
DRAW "M 630,338"
DRAW "M 10,338"
DRAW "M 10,20"
DRAW "BM 18,35"
DRAW "M 622,35"
DRAW "M 622,335"
DRAW "M 18,335"
DRAW "M 18,35"
COLOR 14,3,12
LOCATE 25,65
PRINT " MacroRADSS "
DRAW "BM 10,100"
DRAW "M 10,335"
DRAW "BM 630,100"
DRAW "M 630,335"
COLOR 15
END SUB

```

```

'~~~~~
SUB SCRNMKR4 STATIC 'Main program 's screen generator
REM $DYNAMIC
CLS
SCREEN 9
DRAW "BM 10,20"
DRAW "M 630,20"
DRAW "M 630,338"
DRAW "M 10,338"
DRAW "M 10,20"
DRAW "BM 18,35"
DRAW "M 622,35"
DRAW "M 622,335"
DRAW "M 18,335"

```

```
DRAW "M 18,35"  
COLOR 14,1,12  
LOCATE 25,65  
PRINT " MacroRADSS "  
DRAW "BM 10,100"  
DRAW "M 10,335"  
DRAW "BM 630,100"  
DRAW "M 630,335"  
COLOR 15  
END SUB
```

VITA

Charles E. ("Chip") Taylor was born to Charles S. Jr. and Jean W. Taylor on August 28, 1961 in Bethesda, Maryland. He graduated as a two time Who's Who Among American High School Students and National Merit honorable mention student from Robert E. Lee High School in Springfield, Virginia in 1979.

Having attended Northern Virginia Community College, the University of Virginia and Virginia Tech, he received a Bachelor degree in Civil Engineering Cum Laude from Virginia Tech in 1983. Prior to graduation, he was elected to the honor societies of Tau Beta Pi, Phi Kappa Phi, and Chi Epsilon.

Work experience prior to his staff position at the Center for Transportation Research consisted of over three years civil engineering experience with Wiley & Wilson of Lynchburg, Virginia as well as similar experience with Dove & Associates in Fairfax, Virginia in addition to previous employment with two firms as an engineering technician. As of this writing he is employed as the Chief of Transportation Research for the Fifth Planning District Commission in Roanoke, Virginia.

Mr. Taylor currently makes his home in Blacksburg, Virginia.



Charles E. Taylor