THE RELATIONSHIP BETWEEN TRAFFIC CONGESTION AND ACCIDENTS IN THE LONG RANGE TRANSPORTATION PLANNING PROCESS: A CASE STUDY OF OAKLAND COUNTY, MICHIGAN

By

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This thesis is dedicated to the memory of my grandfather, Yin Ming Hom, who imparted to me at an early age the importance of education throughout one's life.

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ABSTRACT

THE RELATIONSHIP BETWEEN TRAFFIC CONGESTION AND ACCIDENTS
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This thesis analyzes the commonly held assumption in long range transportation planning that traffic congestion and accidents are highly correlated. This assumption has led to the development of long range plans and policies which do not specifically address accident deficiencies.

The analysis involves a plan consistency test and various statistical tests. The plan consistency test showed a close association between congestion and accidents in comparing these variables as they are defined in local plans. The statistical tests include a linear regression analysis using volume-to-capacity ratio as the independent variable and accident frequency and accident rate as separate dependent variables.

Results of the statistical tests indicate a statistically significant, but relatively weak relationship between congestion and accidents. This study concludes that future research should concentrate on the development of concepts and methods to incorporate accident analysis into the long range transportation planning process.

INTRODUCTION

The backbone of long range transportation systems planning has been the identification of capacity deficiencies based on forecast traffic volumes. Typical long range planning efforts involve preparing volume-to-capacity bandwidth plots summarizing road segment congestion and then testing alternative transportation policies and/or facility improvements (e.g., road widening) for alleviating this congestion.

Recently, this approach has been criticized for not taking into account other important indicators of transportation system deficiency, particularly accidents. Safety has become an increasingly important concern in the transportation planning, research and engineering fields. Many transportation officials and citizens would like to see safety incorporated into the development of systems plans. The response of the transportation planning profession has been lukewarm, primarily because accident data is so difficult to obtain and analyze on a systemwide and long range basis. Many transportation planners make the implicit assumption that accident experience and congestion are highly correlated, so that by identifying and addressing congested locations, the majority of high accident locations will also have been identified, albeit without specific accident data about those locations. Those who argue this viewpoint cite the many studies showing the positive relationship between vehicular accidents and traffic volume (see Part One). These studies have led to the following hypothesis: since highly congested locations are likely to correspond to high volumes and congestion leads to more conflicting traffic movements, highly congested locations are most likely to experience high levels of accident occurrence. Planning processes resting on this type of argument rely on subsequent corridor studies for the analysis of detailed accident data. But if the incidence of congestion and accidents is not strongly correlated, then these plans are not telling the whole story and may not be identifying critical locations for further study.

A good example of an assumed relationship between congestion and accidents was explicitly stated in the 1982 Michigan State Transportation Plan. In its assessment of State transportation needs (upon which decisions about important policy and funding issues are resolved) the Michigan Department of Transportation (MDOT) concluded that, "There is no safety-deficient miles projected. Safety deficiencies are resolved when other (service deficiency, i.e., capacity) improvements are made."[1] The implication of this statement on the level of planning and funding for safety related projects could be staggering. The question arises as to whether this is a proper and realistic assumption, or whether safety needs should have been analyzed, costed and addressed in a more formalized, systematic manner.

Scope of Study

The major objective of this Thesis is to evaluate the hypothesis that congested locations are more likely to experience high levels of accidents. The primary purpose of this thesis will not be to determine the causes of accidents. This evaluation will be accomplished primarily through a case study of Oakland County, Michigan, using systemwide traffic and accident data available from the Southeast Michigan Council of Governments (SEMCOG). Oakland County has been selected primarily because its road commission (and other community nonprofit organizations) have placed the highest priority on alleviating accident problems and have criticized SEMCOG for failing to account for accidents in the development of the region's 2005 Transportation Plan.

Thesis Methodology

The methodology to carry out the evaluation focuses on two basic tests:

1. A direct comparison of Oakland County congestion and accidents, including:
   a. A plot of congested road segments and an overlay of high accident locations on the congestion map for a visual inspection; and
   b. Various measures of accident indicators (e.g., percent of total accidents, accident rate) occurring on congested vs. uncongested facilities.
2. A statistical analysis of the relationship between congestion and accidents, including a linear regression analysis of the relationship between congestion (as measured by volume-to-capacity ratio) and accidents (as measured by accident frequency and accident rate).

Another issue is the extent to which not only accident occurrence, but also accident severity is related to congestion. This is significant because while more congestion may lead to a higher accident rate and a greater number of accidents, it may also lead to less severe accidents. This issue will be addressed through a comparison of accident rates by severity (i.e., fatal, injury and property damage) under congested and uncongested conditions.

An attempt was made to follow the definitions of key variables (e.g, high accident locations, congestion) that have been established at the local level by SEMCOG and/or Oakland County. This makes the conclusions more relevant to local plan development activities in Southeast Michigan.

In addition to the data analyses listed above, the thesis will also include a literature review of previous studies analyzing the relationship between accident occurrence and traffic flow.

The implications of this research are significant for such questions as:

1. Is there a need to consider systemwide accident analysis in the transportation planning process in general and as practiced in Southeast Michigan in particular?
2. Can systemwide accident standards be established to aid in evaluating accident location recommendations submitted by local agencies?
3. What are the possibilities for modeling accident deficiencies on a systemwide basis (particularly given the huge amounts of money and time spend developing and improving travel forecast models)?

There has been much written lately about the changing role of long range transportation planning and the inadequacy of the profession in identifying the needs of the transportation planning clientele.[2] This thesis is aimed at helping to determine whether more emphasis should be given to providing systemwide studies of accident deficiencies, as safety continues to grow as a concern among the transportation planning community.

Footnotes: Introduction

[1]Bureau of Transportation Planning, Michigan State Transportation Plan 1982-1990, (Lansing, Michigan: Michigan Department of Transportation, November, 1982), p. 73.

[2]Joseph L. Schofer, "Challenges to the Future of Urban Transportation Planning," in Transportation and Land Use Planning, Transportation Research Record 931, (Washington, D.C.: Transportation Research Board, 1983), p. 28.

PART ONE: LITERATURE REVIEW

The purpose of this section is to provide background on previous research relating measures of traffic flow, such as volume and congestion, with accident occurrence. This research is summarized because it serves as the basis for much of the predictive modeling of potential accident occurrence and the identification of "black spot" (i.e., high accident) locations. For example, Cooper (1973) found that "the best accident predictor models were those based on vehicular volumes."[1]

Traffic Volume and Accident Occurrence

The link between traffic volume and accident occurrence was identified as early as 1953 in a study by McDonald[2] which indicated that the number of accidents at a sample of rural intersections in California was positively related to intersection volumes in the following manner:

$$A = RV_1^{0.455} V_2^{0.633}$$

where A = annual number of accidents,

V_1 = average daily volume entering from the major road,

V_2 = average daily volume entering from the minor road, and

R is a constant.

This "cross-product" analysis has been substantiated in more recent articles, notably by Leong (1973)[3], who compared various measures of exposure to accidents and found that the relationship between accidents and volumes could be represented by:

$$A = R\ (V_1\ V_2)^{0.42}$$

Some researchers have been much more straightforward in their analysis of this relationship. For example, Cooper (1973) found that, "The simple sum of approach volume is perhaps the most commonly employed form of accident-predictor model..."[4] and that in comparison to the cross-product analysis of McDonald and others, "the best accident predictor was obtained using the simple sum of approach volumes."[5]

Similarly, Lalani and Walker (1981) found a good linear correlation between accident frequency and the daily average intersection volume at signalized intersections.[6] However, this study also found no linear correlation between accidents and volumes at unsignalized intersections and a positive curvilinear relationship at mid-block road segments.

Although general agreement has been reached regarding the linear (or near linear) relationship between accident frequency and volume, results have been mixed relating accident rate and traffic volume. The equations by McDonald, Leong and others[7] show a decreasing accident rate with increasing volumes (this can be derived from the formulas above, using accidents per million entering vehicles as the measure of accident rate). However, May (1964) found that, "Both at intersections and on the open highway, there is an increase in the accident rate with an increase in the traffic volume."[8] In addition, in a yet unpublished document on the use of accident surrogates in analyzing safety hazards, Tappan K. Datta found a strong positive correlation between average daily traffic and accident rate (as well as the more traditional relationship with accident frequency).

Traffic Congestion and Accident Occurrence

The literature on the relationship between traffic congestion and accident occurrence is much more sparse, but several references were found which offer some insight. Owens (1978), studying the causes and consequences of accidents on a major arterial, found that "The site studied on M1 was probably typical of busy motorways, with congestion and queueing occurring during peak periods. The majority of accidents occurred under these conditions...".[10] In making recommendations for alleviating accidents on this facility, Owens found that, "...in the long term the most effective solution would probably be to provide more lanes."[11]

Several studies have linked congestion with specific types of accidents. Nishimura and Takai (1979) found that "...the rate of outbreak of rear-end collisions is directly proportional to the degree of congestion...".[12] Similarly, Ceder (1982) found that congested traffic flows lead to rear-end and chain collisions, so that under these conditions "...the (multi-vehicle) accident rate is sharply increased with hourly flow."[13]

The most direct measure of congestion is volume-to-capacity (V/C) ratio. As the V/C ratio increase, level-of-service decreases eventually to the point where congested conditions are said to exist. In fact, in Taylor and Thompson's study of accident indicators (1977), V/C ratio was chosen as a more logical indicator of accidents than average daily traffic because V/C ratio "...incorporates the basic volume information, and yet 'normalizes' these data to compensate, to some extent, for the number of lanes, traffic mix, control devices, etc...".[14] This measure has been used in several studies of accidents. For example, Dart and Mann (1970) found the V/C ratio to be the most signficant factor in their attempt to establish the relationship between indicators of highway geometry and accidents.[15] They concluded that, "...the more nearly a roadway carries traffic volumes approaching or greater than its design service volume, the more likely it will experience a greater accident rate."[16]

Dart and Mann substantiated earlier studies establishing a positive correlation between congestion and accident rate. For example, as early as 1949, K.B. Rykken had found that accident rates on trunklines in Minnesota were directly related to V/C ratio. Rykken found a straight line relationship between accidents and the congestion index up to a V/C ratio of 1.0. After this point, the rate of increase in the accident rate increases uniformly until a V/C ratio of 1.4 is reached. Rykken concluded that, "...a congestion index of 1.0, in addition to indicating the point of near intolerable congestion, also indicates the point at which the accident rate may be expected to rise."[17] Rykken's curve is presented in Figure 1.

Rykken's findings are not entirely consistent with the results of other studies[18] which indicate a drop in accident rate during congested conditions. Pignataro (1973) found that, "Heavier traffic reduces the accident rate primarily because the extreme congestion at higher volumes makes it difficult for drivers to execute passing maneuvers."[19]

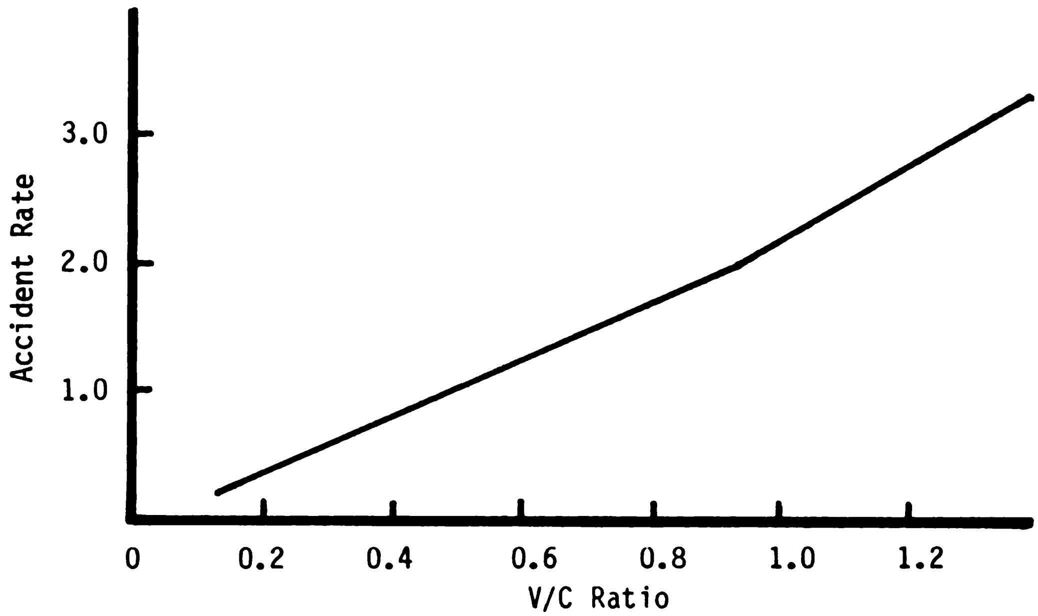


Figure 1. Rykken's Volume-to-Capacity Versus Accident Rate Curve

Source: Derived from K.B. Rykken, "A Rural Highway Congestion Index and Its Applications," in _Highway Research Board - Proceedings of the Twenty-ninth Annual Meeting_, Highway Research Board, Washington, D.C., 1949, p. 372.

The most recent study of the relationship between accidents and congestion was performed by Taylor and Thompson (1977) for the Federal Highway Administration (FHWA). In this study of accident indicators, entitled Identification of Hazardous Locations, the researchers compared professionals' rating of potential accident indicators with the actual statistical relationship of those indicators with accident frequency and accident rate. The traffic engineering professionals rated V/C ratio as the most likely traffic/geometric indicator of accident hazardousness. However, the researchers found a low statistical correlation between V/C ratio and accident frequency and accident rate. However, the researchers concluded that these findings "...may mean that appropriate data formats and scaling charts have not been formulated for the sight distance and volume/capacity ratio indicators, as these two indicators have considerable intuitive appeal."[20] The study thereby recommended that attention should be given to future research to the relationship between V/C ratio and accident occurrence.

Critique of FHWA Study

The procedures and results of Taylor and Thompson's study deserve some attention, inasmuch as it includes the latest analysis of the relationship between congestion and accidents. The authors found little correlation between volume-to-capacity ratio and accident frequency and accident rate (correlation coefficients of -0.207 and 0.080, respectively).[21] In general, it is believed their findings are invalid due to an inadequate sample size and improper scaling functions. In particular, the following factors raise questions as to the validity of their analysis:

1. The study was based on an analysis of only twelve (12) locations. While the authors were careful to select different types of locations for study (e.g., four-lane divided highway, narrow bridge), this sample size clearly is too small to make judgments from statistical tests. The authors note in their conclusions that a "large scale validation" is needed.[22]
2. The statistical analysis is based on a comparison of indicator values for each variable. These indicator values were derived from curves based on trends exhibited by the raw data for each variable. For the volume-to-capacity ratio variable, the indicator values were based on the curve shown in Figure 2. This figure was developed based on professionals' perceptions of the potential relationship between congestion and accidents. This is clearly not a very objective or scientific procedure for scaling a variable.

Summary of Literature Review

The literature on the subject of accidents and traffic flow is both varied and divergent. The following are the major points derived from the literature review:

1. Although some disagreement exists as to the strength of the relationship, traffic volume appears to be perhaps the best indicator of accident occurrence.
2. The assumption that high volume, high congestion facilities would account for the most hazardous location cannot be summarily dismissed. Previous studies have established this as a credible

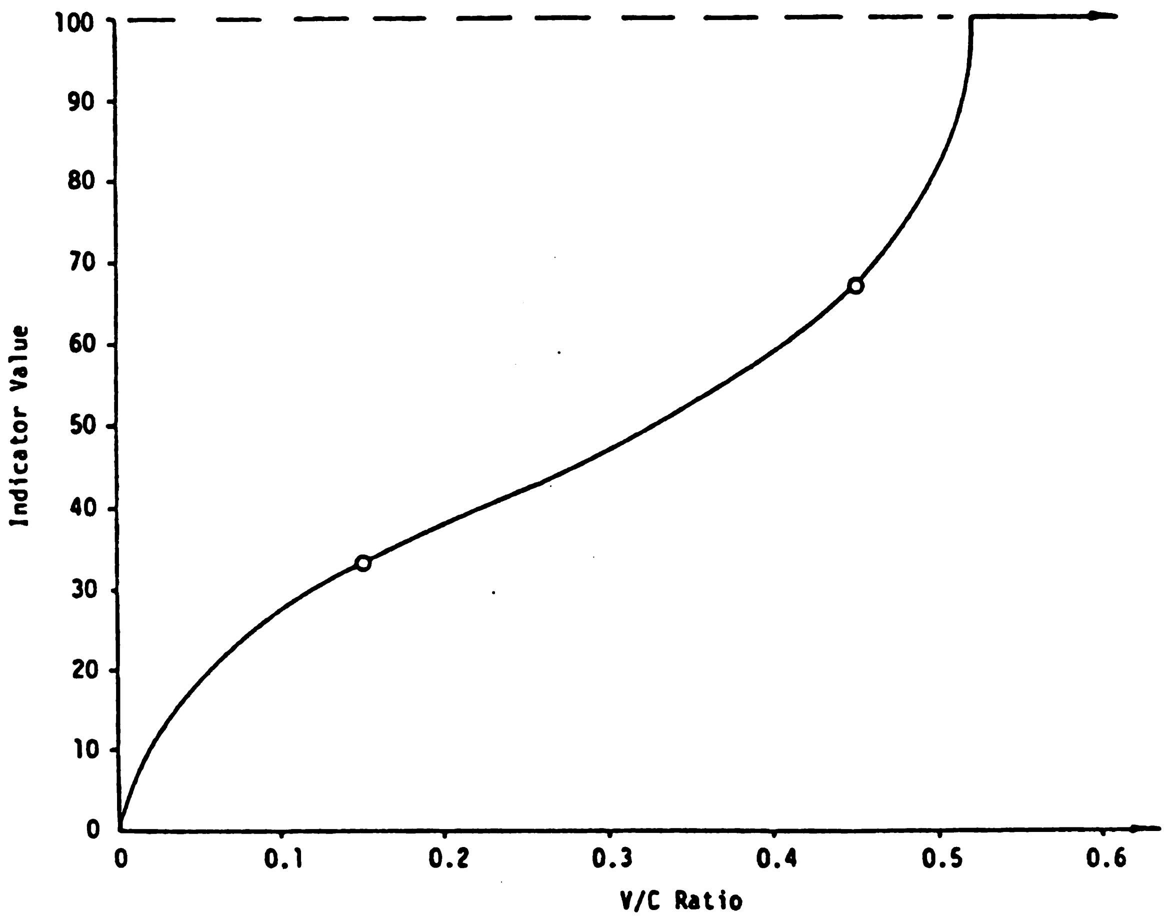


Figure 2. Taylor and Thompson's V/C Ratio Indicator Scale

Source: J. I. Taylor and H.T. Thompson, Identification of Hazardous Locations, Federal Highway Administration, Washington, D.C., 1977, p. 43.

area for further research.

3. There are many, many factors which cause accidents. In general, the cause of accidents can be attributed to the driver, the vehicle and/or the traffic environment. To suspect one element within one of these areas to be the major cause of accidents is unrealistic. However, it is helpful to determine the type of relationship between an indicator(s) and accident occurrence and whether this is a significant relationship. This is particularly true within the context of some practical application, such as determining the effectiveness of geometric improvements, whether the installation of a traffic signal is warranted, or in the case of this thesis, whether it is reasonable to use congestion as a surrogate measure of accident hazardousness.

4. There is some evidence that congestion may correlate more closely with multi-vehicle, rear-end accidents, rather than single-vehicle accidents. This suggests to some extent that although congestion may lead to more accidents, these accidents may be less severe than those that occur under uncongested conditions. This finding in the literature should be given consideration in the development of the research methodology.

Footnotes: Part One

[1]P.J. Cooper, Predicting Intersection Accidents, Road and Motor Traffic Safety, (Ottawa, Canada: Ministry of Transport, 1973), p. ii.

[2]John W. McDonald, "Relation Between Number of Accidents and Traffic Volume at Divided-Highway Intersections," in Traffic-Accident Studies, Highway Research Board Bulletin 74, (Washington, D.C.: Highway Research Board, 1953), pp. 7-17.

[3]H.J.W. Leong, "Relationship Between Accidents and Traffic Volumes at Urban Intersections," in Australian Road Research, Vol. 5, No.3, (Victoria, Australia: Australian Road Research Board, October, 1973), pp. 72-82.

[4]Cooper, Op. Cit., p. 58.

[5]Ibid., p. 58.

[6]Nazir Lalani and David Walker, "Correlating Accidents and Volumes at Intersections and On Urban Arterial Street Segments," in Traffic Engineering and Control, (London, England: Printerhall Limited, August/September, 1981), pp. 359-363.

[7]For example, one study found that the most significant variable in a multiple linear regression accident rate analysis was the sum of the average daily traffic of the approaches (in the negative direction), from Robert B. Shaw and Harold L. Michael, "Evaluation of Delays and Accidents at Intersections for Median Lane Construction," from Proceedings of the 52nd Annual Road School, (W. Lafayette, Indiana: Purdue University, July, 1966), pp. 156-179.

[8]John F. May, "A Determintion of an Accident Prone Location," in Traffic Engineering, Vol. 34, No. 5, (Washington, D.C.: Institute of Traffic Engineers, 1964), p. 28.

[9]Information gathered from January 3, 1985, telephone conversation with Mr. Tappan K. Datta of the consulting firm of Goodell-Grivas, Inc., Southfield, Michigan.

[10]D. Owens, Traffic Incidents on the M1 Motorway in Hertfordshire, (Berkshire, England: Transport and Road Research Laboratory, 1978), p. 7.

[11]Ibid., p. 8.

[12]From abstract (by author) of: T. Nishimura and H. Takai, "Basic Research on Rear-End Collisions," IATSS Research, Vol. 3, (Osaka City University, Japan: Kokusai Kotsu Anzen Dakkai Association, 1979), pp. 94-107, obtained with database search performed by Michigan Information Transfer Source, University of Michigan, Ann Arbor, Michigan.

[13]Avishai Ceder, "Relationship Between Road Accidents and Hourly Traffic Flow-II - Probabilistic Approach," in Accident Analysis and Prevention, Vol. 14, No. 1, (Oxford, England: Pergamon Press, Ltd., 1982), p. 43.

[14]J. I. Taylor and H. T. Thompson, Identification of Hazardous Locations - Final Report, (Washington, D.C.: Office of Research, Federal Highway Administration, 1977), p. 38.

[15]Olin K. Dart, Jr. and Lawrence Mann, Jr., "Relationship of Rural Highway Geometry to Accident Rates in Louisiana," in Relationships of Highway Geometry to Traffic Accidents, Highway Research Record 312, (Washington, D.C.: Highway Research Board, 1970).

[16]Ibid., p. 11.

[17]K. B. Rykken, "A Rural Highway Congestion Index and Its Application," in Highway Research Board - Proceedings of the Twenty-Ninth Annual Meeting, (Washington, D.C.: Highway Research Board, 1949), p. 372.

[18]Various studies of this nature are summarized in The Automotive Safety Foundation's Traffic Control and Roadway Elements - Their Relationship to Highway Safety, (Washington, D.C.: The U.S. Bureau of Public Roads, 1963), pp. 4-7.

[19]Louis J. Pignataro, Traffic Engineering - Theory and Practice, (Englewood Cliffs, New Jersey: Prentice-Hall, 1973), p. 283.

[20]Taylor and Thompson, Op. Cit., p. 89.

[21]Ibid., p. 81.

[22]Ibid., p. 92.

PART TWO: RESEARCH METHODOLOGY

The purpose of this section is to describe the methodological steps that will be used to evaluate the reasonableness of assuming a correlation between congestion and accidents. It is important to keep in mind that in most cases key definitions and assumptions are consistent with local practices, so that conclusions can be drawn that are particularly relevant for transportation planning activities in Southeast Michigan.

The methodology rests on both plan consistency and statistical tests. The plan consistency test is a comparison of highly congested locations as measured by the Southeast Michigan Council of Governmments (SEMCOG) with hazardous locations as identified by the Oakland County Transportation System Management (TSM) Committee.

The statistical tests that are applied are: (1) a simple comparison of congested versus uncongested mean accident rate and frequency; (2) a linear regression analysis of volume-to-capacity ratio versus accident rate and accident frequency; and (3) an anlysis of the percentage distribution of fatal, injury and property damage accidents under congested versus uncongested conditions.

The Case Study

The Southeast Michigan region is composed of seven counties, three of which, Wayne (including the City of Detroit), Oakland and

Macomb, are primarily urban in character. Oakland County (see map in Figure 3) was chosen to serve as the case study for the following reasons:

1. The Oakland County Road Commission has publicly stated that safety is their top priority and that safety concerns ought to play a greater role in the development of SEMCOG's transportation plans. As a reflection of this, the Oakland County Transportation System Management (TSM) Committee gave the greatest weight (40 of 100 points) for safety, while reducing the weight for congestion/delay from 25 to 15 points.[1]
2. Oakland County is a diverse area with a diverse highway network. The distribution of road mileage by functional classification and area type, as shown in Table 1 (compared to the distribution of the more rural Livingston County) will provide an adequate sample of cases (i.e., intersections) within each classification.

Another factor considered was the desirability to keep computer costs associated with these analyses reasonable.

The Data Base

All of the data used in the analyses are from SEMCOG's traffic and accident data files. The traffic data are from the 1982 intersection file, which contains essential data for the intersections in the SEMCOG highway network. A sample sheet of output from the intersection file is shown in Table 2. This data was chosen over the traditional highway link file because the intersection file uses actual green-to-cycle (G/C) length ratios in the calculation of signalized intersection capacity. As a result, the capacities in the

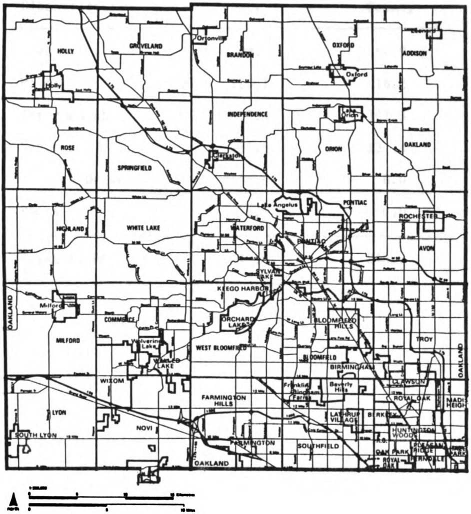


Figure 3. The Study Area - Oakland County, Michigan

Table 1. Road Mileage by Functional Classification

Functional Classification	Road Mileage: Oakland County	Road Mileage: Livingston County
Freeway	98.6	52.9
Major	120.1	16.2
Intermediate	489.4	141.3
Minor	314.6	137.4
Service Drive	16.4	0.0
Ramps	3.5	0.0
TOTAL MILES	1,042.6	348.7

Table 2. Sample Output from SEMCOG Intersection File

INTERSECTION NODE NAME	SIG	A-B NODE		SEQ NO.	NAME	LEG	FC	AT	SD	RAD	P	APP WID	LN	DIR	SIG	CON	PHS	APP. VOL	GC	INT. PROV	APP. CAP	VC	APP
1775 ADAMS		1775	1752	1080	ADAMS	SW	4	1	1	0	3	22	4	1	7	1	1	0	0	-	0	0.0	NEB
WHITHERELL		1775	1783	1080	ADAMS	NE	4	1	1	0	1	21	3	2	7	1	1	767	70	-	968	0.79	SWB
WITHERELL		1775	1774	75830	WHITHERELL	NW	4	1	1	0	1	16	3	1	0	0	2	0	0	-	0	0.0	SEB
		1776	1775	52180	WITHERELL	S	4	1	1	0	3	25	5	1	6	1	2	888	30	-	1717	0.52	NB
5042 GRAND RIVER	•	5042	5298	21710	GRAND RIVER	W	3	4	27	0	3	9	1	2	1	0	1	707	63	C	1085	0.65	EB
HAGGERTY RD		5042	5057	21720	GRAND RIVER	E	3	3	23	1	3	15	1	2	1	0	1	684	63	-	1067	0.64	WB
		5042	5043	25150	HAGGERTY RD	S	4	3	23	0	3	10	1	2	1	0	2	356	37	L	613	0.58	NB
		5040	5042	25160	HAGGERTY RD	N	4	3	23	0	3	11	1	2	1	0	2	433	37	L	664	0.65	SB
5043 HAGGERTY RD	•	5043	5044	25140	HAGGERTY RD	S	4	3	23	0	3	10	1	2	1	0	1	284	30	L+R	662	0.43	NB
TEN MILE		5042	5043	25150	HAGGERTY RD	N	4	3	23	0	3	10	1	2	1	0	1	358	30	L	502	0.71	SB
		5043	6276	66550	TEN MILE	W	4	4	27	0	3	11	1	2	2	0	2	964	70	L	1332	0.72	EB
		5043	5057	66560	TEN MILE	E	4	3	23	0	3	11	2	2	1	0	2	731	70	L	1269	0.58	WB
5048 GRAND RIVER	•	5047	5048	21810	GRAND RIVER	W	2	3	23	1	3	30	4	2	3	0	2	2028	52	M	1912	1.06	EB
MIDDLEBELT		5048	5049	21820	GRAND RIVER	SE	2	3	23	1	3	30	4	2	1	0	2	2166	52	M	1912	1.13	NWB
		4078	5048	44170	MIDDLEBELT	S	3	3	23	0	3	24	2	2	1	0	1	1234	48	-	1290	0.96	NB
		5048	5051	44180	MIDDLEBELT	N	3	3	23	0	3	12	1	2	1	0	1	1088	48	F	961	1.13	SB
5051 MIDDLEBELT	•	5048	5051	44180	MIDDLEBELT	S	3	3	23	0	3	12	1	2	1	0	1	1088	56	L+F	1435	0.76	NB
NINE MILE		5051	5063	44190	MIDDLEBELT	N	3	3	23	0	3	12	1	2	1	0	1	882	56	L+F	1535	0.57	SB
		5050	5051	48520	NINE MILE	E	3	3	23	0	3	11	1	2	3	0	2	548	45	L	723	0.76	WB
		5051	5052	48530	NINE MILE	W	3	3	23	0	3	11	1	2	1	0	2	548	45	F	854	0.64	EB
5052 GRAND RIVER	•	5052	5053	21790	GRAND RIVER	NW	3	3	23	1	3	24	2	2	1	0	1	1287	49	C	1515	0.85	SEB
NINE MILE		5047	5052	21800	GRAND RIVER	SE	3	3	23	1	3	24	2	2	3	0	1	1302	49	C	1515	0.86	NWB
ORCHARD LAKE		5051	5052	48530	NINE MILE	E	3	3	23	0	3	11	1	2	1	0	2	548	51	-	637	0.86	WB
		5046	5052	41880	ORCHARD LAKE	S	3	3	23	0	3	12	1	2	7	1	2	529	51	F	1029	0.51	NB
5053 GRAND RIVER	•	5053	5055	21780	GRAND RIVER	NW	3	3	23	1	3	18	2	2	5	1	1	1150	54	C	1569	0.73	SEB
ORCHARD LAKE		5052	5053	21790	GRAND RIVER	SE	3	3	23	1	3	24	2	2	1	0	1	1287	54	C	1661	0.77	NWB
		5053	5062	50520	ORCHARD LAKE	N	3	3	23	0	3	11	1	2	1	0	2	593	46	R	766	0.77	SB
5056 FARMINGTON	•	5056	5060	16680	FARMINGTON	N	4	3	23	0	3	10	1	2	2	0	2	668	56	-	631	1.06	SB
GRAND RIVER		5054	5056	16670	FARMINGTON	S	4	3	23	0	3	23	2	2	1	0	2	861	55	L+R	1826	0.47	NB
		1666	5056	21760	GRAND RIVER	NW	3	3	23	1	3	20	2	2	5	1	1	1142	45	-	1076	1.06	SEB
		5055	5056	21770	GRAND RIVER	SE	3	3	23	1	3	25	2	2	5	1	1	1014	46	-	1314	0.77	NWB
5057 GRAND RIVER	•	5042	5057	21720	GRAND RIVER	W	3	3	23	1	3	15	1	2	1	0	1	684	38	R	843	0.81	EB
TEN MILE		5057	5058	21730	GRAND RIVER	E	2	3	23	1	3	22	2	2	1	0	1	802	38	M	1011	0.79	WB
		5043	5057	66960	TEN MILE	W	4	3	23	0	3	11	2	2	1	0	2	731	62	-	901	0.81	EB
5062 ORCHARD LAKE	•	5062	5064	50510	ORCHARD LAKE	N	3	3	23	0	3	11	1	2	1	0	1	701	34	L+F	888	0.79	SB
TEN MILE		5053	5062	50520	ORCHARD LAKE	S	3	3	23	0	3	11	1	2	1	0	1	593	34	L+F	828	0.72	NB
		5062	5063	78710	TEN MILE	E	3	3	23	0	3	11	1	2	1	0	2	685	66	-	828	0.78	WB
5063 MIDDLEBELT	•	5063	5068	44200	MIDDLEBELT	N	3	3	23	0	3	12	1	2	1	0	2	887	56	L+F	1526	0.58	SB
TEN MILE		5051	5063	44190	MIDDLEBELT	S	3	3	23	0	3	12	1	2	1	0	2	882	56	L+F	1526	0.58	NB
		5062	5063	78710	TEN MILE	W	3	3	23	0	3	11	1	2	1	0	1	983	45	L+F	1111	0.88	EB
		4818	5063	78700	TEN MILE	E	3	3	23	0	3	11	1	2	1	0	1	569	45	L+F	1192	0.48	WB

intersection file are generally considered by SEMCOG staff to be more reflective of actual conditions.

The accident data are from the newly developed SEMCOG Accident Analysis System (SAAS) file, as shown in Figure 4. The base SAAS file as shown in Figure 4 summarizes accidents by intersection. The critical accident data used in this thesis include total accidents and accidents by type, including fatals, injury and property damage only.

The Plan Consistency Test

The assumption that congestion and accident occurrence are correlated will first be evaluated through the use of congestion and accident identifiers obtained from SEMCOG and the Oakland County TSM Committee. The question to be answered is this -- how does SEMCOG's identifcation of highly congested roads (as used in its development of the region's Year 2005 Transportation Plan) compare to locations of high accident hazard as defined by the Oakland County Road Commission and other local representatives? If these match closely, then from a practical standpoint SEMCOG's assumptions will have been proven, if not justified. If the congestion and accident maps do not match closely, then there is apparently some evidence suggesting that SEMCOG's assumptions may not have been the best for identifying deficient locations for study.

High Congested Roads

In the preparation of their Year 2005 Plan, SEMCOG developed a systematic approach for identifying the most deficient roadways that are in need of further study. This approach is presented in Figure 5.

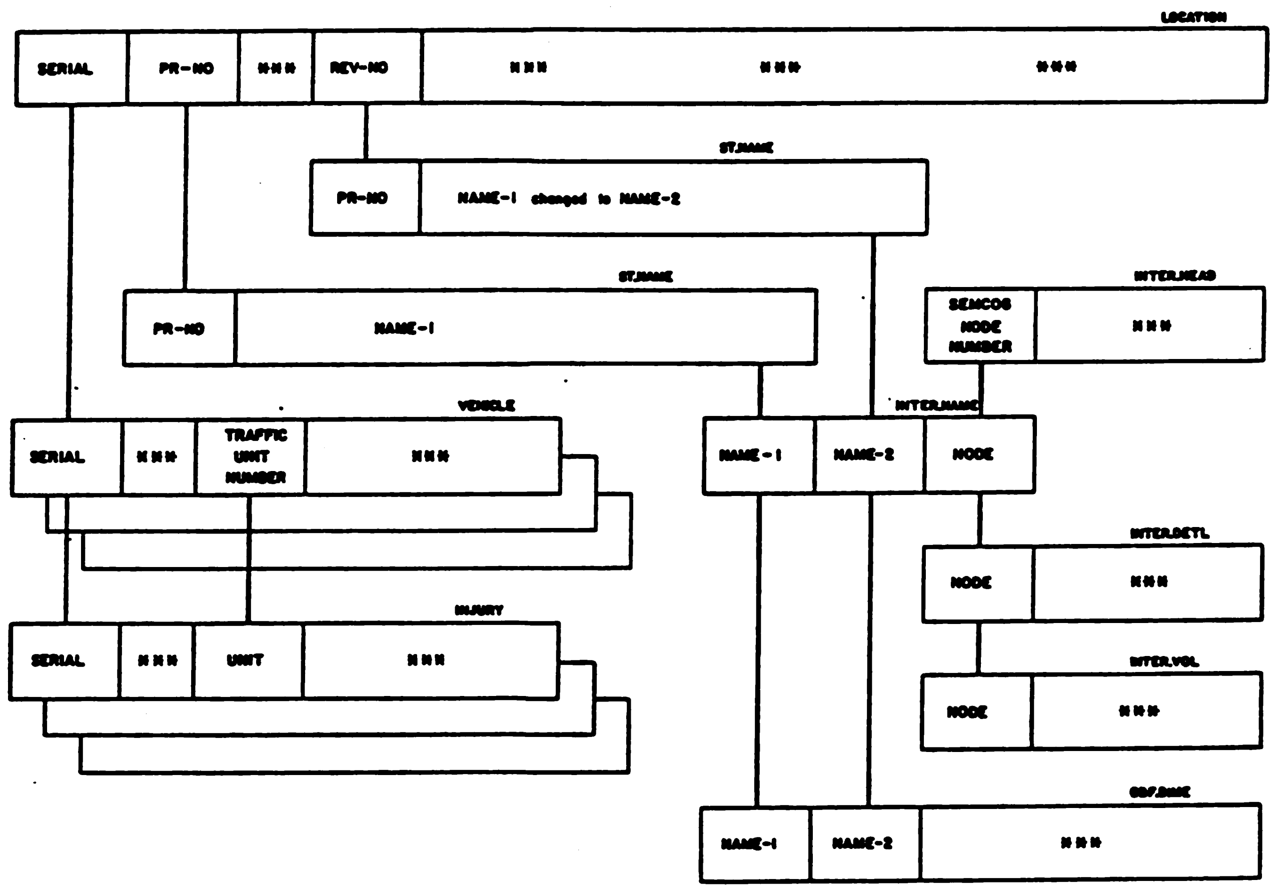


Figure 4. SEMCOG Accident Analysis System

Source: Thomas D. Mullin, SEMCOG Accident Analysis System Documentation, as yet unpublished draft report.

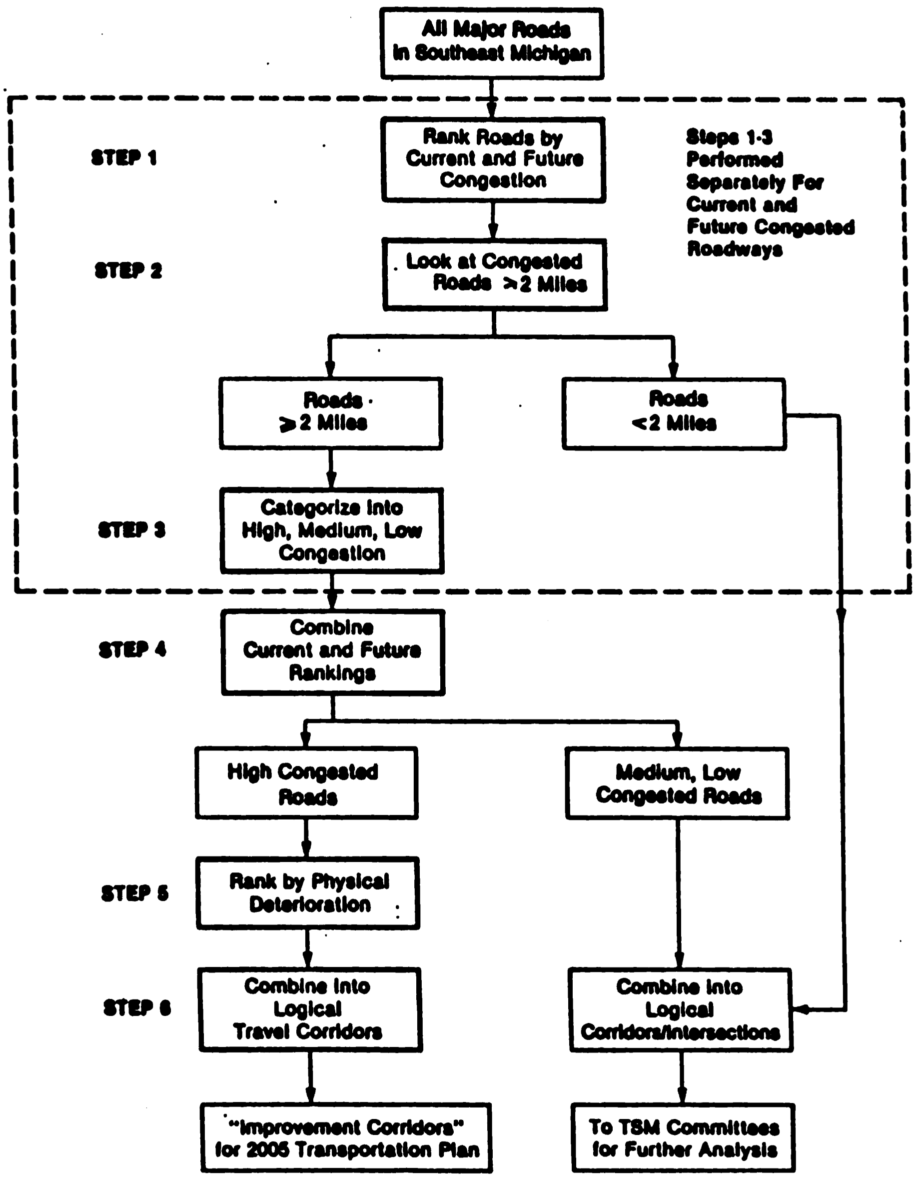


Figure 5. SEMCOG High Congestion Identification Process

Source: Keith Hom, "Procedures for Ranking Deficient Corridors," SEMCOG staff memo to SEMCOG Council on Regional Development, August 8, 1984.

The approach basically identifies and combines measures of congestion for 1982 and 2005. Congestion is defined in the SEMCOG process in terms of peak hour, peak direction vehicle miles of travel (VMT) operating at level-of-service E or F (i.e., roadway volume-to-capacity ratios greater than 0.90 and characterized by unstable traffic flow with frequent delays). The result of this procedure is shown in Figure 6. These are the most signficantly congested roadways for Oakland County, and, according to SEMCOG, require further detailed study.

High Accident Locations

The identification of high accident locations is based on an analysis of Oakland County accidents from 1980-1982 from Oakland County's 1983-1984 TSM Plan. This Plan uses a combined accident score based on accident frequency, accident rate and accident severity in ranking intersections throughout the County. Figure 7 shows the top 50 ranked inter- sections.

Comparing Congestion and Accidents

The top 50 ranked intersections from Oakland County's TSM Plan will be overlaid on SEMCOG's high congestion map to visually depict the interaction between what can be considered as each source's conception of the County's most serious deficiencies. While this is not a particularly scientific method, it is doubtful that the implication of assuming a strong correlation between congestion and accidents could be more simply or clearly illustrated.

In addition to the illustration, this comparison will also

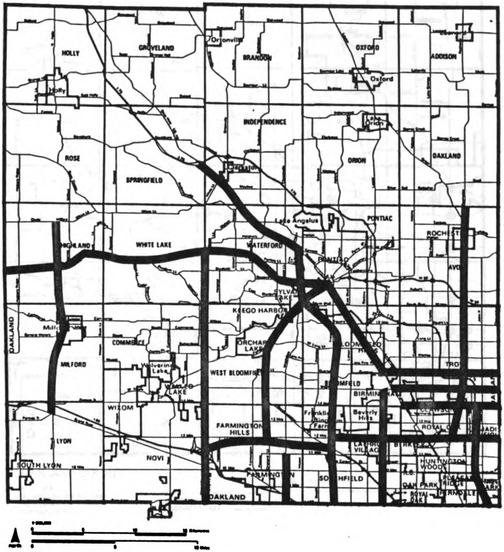


Figure 6. SEMCOG "High" Congestion Facilities

Source: Southeast Michigan Council of Governments, "Year 2005 Regional Transportation Plan for Southeast Michigan" brochure, SEMCOG, Detroit, Michigan, 1985.

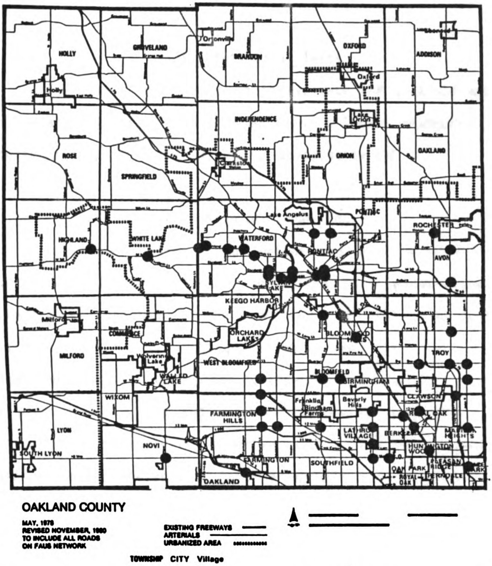


Figure 7. Top 50 Accident Locations - Oakland County (1980-1982)

Source: Oakland County Transportation System Management Committee, <u>1983-84 Oakland County Transportation System Management Update</u>, Department of Public Works, Division of County Planning, Oakland County, Michigan, 1984, p. 21.

include a simple analysis of the percentage of accidents occurring on the high congestion roadways. Various cutoff points will be evaluated (e.g., x% of top 20, y% of top 30, etc.).

The Statistical Tests

The statistical test used to evaluate the critical assumption include an analysis of accident means and a linear regression of total intersection accidents versus volume-to-capacity ratio.

Definition of Congestion

As stated earlier, local definitions will be used in most cases. SEMCOG's definition of congestion is a volume-to-capacity ratio greater than 0.90 in the peak direction, during the peak hour. This definition has been changed slightly for this thesis, so that congestion occurs as the volume-to-capacity ratio exceeds 0.90 during the peak hour for the two "critical movement" approaches. The critical movement analysis is derived from recent developments in the "quick response" analysis of level-of-service, as summarized in Quick Response Urban Travel Estimation Techniques and Transferable Parameters - User's Guide.

The procedures as outlined in the quick response manual calculates intersection level-of-service based on the "volume of travel (through and left turn) from both the north-south and east-west directions that ocurs during the peak hour."[2] Since turn movements are unavailable from SEMCOG's intersection file, the two highest volume through movements were used to define the intersections' volume-to-capacity ratios. These high volume approaches are considered the "critical" approaches. The V/C ratio is calculated by summing the two critical approach volumes and capacities and dividing the resulting total critical approach volume by the total critical approach capacity. An example of these calculations is shown in Figure 8.

The use of peak hour, rather than 24-hour traffic volume data, is not anticipated to have a limiting effect on the analysis. Mistro (1981) found that "...the use of peak hour volume data instead of 24-hour traffic volumes did not significantly reduce the ability of the model to predict accidents."[3]

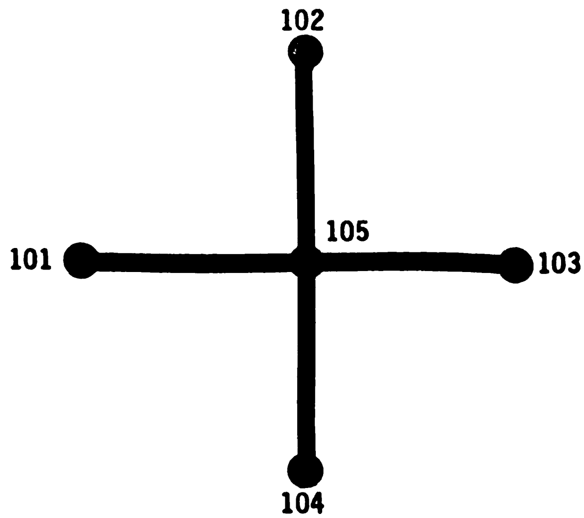
Definition of Accident Frequency

Accident frequency is defined as the total number of accidents occurring within 200 feet of each intersection, the standard used by the Michigan State Police in reporting accidents for Oakland County through the Michigan Accident Location Index (MALI) program.

Definition of Accident Rate

The accident rate is defined as the number of accidents per million vehicle miles approaching each intersection. The approach volume is based on the sum of all approaches at the intersection. The calculation of accident rate is based on the following formula, found in several manuals, including Box and Oppenlander (1976).[4]

$$\text{Accident Rate per Million Entering Vehicles} = \frac{\text{Number of Accidents in One Year} \times 1{,}000{,}000}{\text{24-Hour Approach Volume} \times 365}$$



LINK	APPROACH VOLUME (Per Hour)	APPROACH CAPACITY (Hourly)	VOLUME-TO-CAPACITY RATIO
101-105	550	800	0.69
102-105	700	800	0.88
103-105	1100	1200	0.92
104-105	1050	1400	0.75
TOTAL APPROACH VOLUME* =	3400		

- Critical movements occur on links 102-105 (V/C=0.88) and 103-105 (V/C=0.92)
- Critical intersection volume-to-capacity ratio = 700+1100/800+1200 = 1800/2000 = 0.90

*Used in calculating accident rate.

Figure 8. Derivation of Critical Volume-to-Capacity Ratio

Comparison of Congested Versus Uncongested Accident Means

The first statistical test will involve a broad comparison of accident occurrence at congested (i.e., volume-to-capacity ratio greater than 0.90) versus uncongested intersections, based on 1982 congestion and accident data. This will include:

1. Total number of accidents occurring on congested versus uncongested facilities.
2. Percentage of accidents occurring on congested versus uncongested facilities, in comparison to the percentage of congested versus uncongested approach volume.
3. Mean accident frequency on congested versus uncongested facilities.
4. Mean accident rate on congested versus uncongested facilities.

These broad indicators will allow for generalizations to be made about the relative state of accident occurrence on congested versus uncongested facilities.

Linear Regression Analysis

Using the program REGRESSN from the OSIRIS IV Statistical Package available through the Michigan Terminal System (MTS), a linear regression analysis will be performed with volume-to-capacity ratio serving as the independent variable and accident frequency and accident rate serving, in separate analyses, as the dependent variables. The REGRESSN program will result in the following statistical products:[5]

1. Scatterplots of volume-to-capacity (V/C) ratio versus accident frequency and accident rate.

2. Pearson's product-moment correlation (r) and significance of r for (1) above.

3. Coefficient of determination (r^2) for (1) above.

Linear regression was chosen over other statistical tests in order to take advantage of the interval data of both the independent and dependent variables. An excellent discussion of the strengths and weaknesses of these statistical tests was found in Wonnacott and Wonnacott (1972), who state, for example, that "Whenever numerical variables appear, they should be analyzed with a tool (such as multiple comparisons or regression) that exploits their numerical nature. A chi-square hypothesis test fails to do this."[6]

Analysis of Accident Severity

Although the primary purpose of this thesis is to evaluate the relationship between congestion and accident occurrence (frequency and rate), accident severity is also considered. The analysis of accident severity involves a comparison of the distribution of accidents by severity type - fatal, injury and property damage only - for congested versus uncongested intersections. The mean accident rate by type on congested versus uncongested facilities will also be compared.

Conclusion

The plan consistency and statistical tests outlined in this section will provide a framework for ascertaining, on both a practical and theoretical basis, the reasonableness of assuming a strong correlation between congestion and accidents in the conduct of transportation planning activities for Oakland County.

Footnotes: Part Two

[1]Oakland County Transportation System Management Committee, 1983-1984 Oakland County Transportation System Management Update, (Oakland County, Michigan: Department of Public Works, Division of County Planning, 1984), p. 56.

[2]Arthur B. Sosslau, et al., Quick Response Urban Travel Estimation Techniques and Transferable Parameters - User's Guide, (Washington, D.C.: Transportation Research Board, 1978), p. 144.

[3]From abstract of: R.F. Mistro, Accidents at Urban Intersections-A Second Study, (Pretoria, South Africa: National Institute for Transport and Road Research, 1981), obtained from MITS search.

[4]Paul C. Box and Joseph C. Oppenlander, Manual of Traffic Engineering Studies, (Arlington, VA: Institute of Transportation Engineers, 1976), p. 63.

[5]Survey Research Center, Computer Support Group, OSIRIS IV User's Manual, Seventh Edition, (Ann Arbor, Michigan: Institute for Social Research, University of Michigan, March, 1981).

[6]Thomas H. Wonnacott and Ronald J. Wonnacott, Introductory Statistics for Business and Economics, (New York, NY: John Wiley and Sons, Inc., 1972), p. 440.

PART THREE: STUDY RESULTS

The purpose of this section is to present the results of the empirical and statistical tests as outlined in Part Two. In general, judgment about the possible implications of these results are not included in this section, but are reserved for Part Four - Study Conclusions.

Plan Consistency Test Results

The empirical test involves comparing the high congested corridors identified in SEMCOG's Year 2005 Regional Transportation Plan with Oakland County's high accident locations, from the Oakland County TSM Plan. Figure 9 presents the incorporation of these two items on one map. The map indicates a relatively close relationship between high congested and hazardous corridors throughout the County.

Table 3 presents a numerical analysis of the top 50 accident locations and the extent to which they fall directly on one of the 24 high congested "core" facilities. A core facility is the roadway which accounts for the severe congestion upon which each congested corridor is defined. The table summarizes the 'within' category (i.e., accident location ranks) and cumulative number and percentage of locations and accidents occurring on high congested facilities.

The table shows, for example, that eight out of the top ten ranked accident locations occur on the core facilities. These top ten

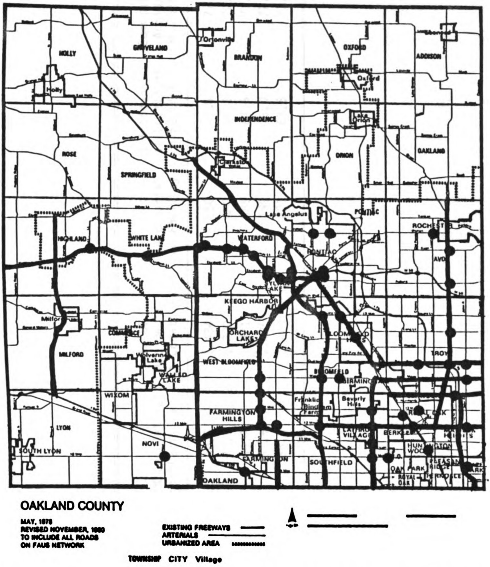


Figure 9. High Accident Locations and High Congestion Corridors

Table 3. Accidents on High Congested "Core" Facilities

Accident Location Rank Category	Total Locations on Facility	Cumulative Total on Facility	% Cumulative on Facility	Total Accidents at Locations	Accidents on Facility	% Accidents at Locations on Facility	Cumulative % Accidents on Facility
1-10	8	8	80.0	1,484	1,150	77.5	77.5
11-20	6	14	70.0	1,200	802	66.8	72.7
21-30	6	20	66.7	1,271	885	69.6	71.7
31-40	7	27	67.5	1,095	799	73.0	72.0
41-50	6	33	66.0	1,220	823	67.5	71.1

locations account for a total of 1,484 accidents during the 1980-1982 period (an average of 49 accidents per year per intersection). The eight locations on congested core facilities account for 1,150 accidents, or 77.5 percent of the total accidents for the top ten locations. On a cumulative basis, 72.7 percent of accidents in the top twenty locations occur on core facilities and 71.7 percent and 72.0 percent of accidents in the top 30 and 40 locations, respectively, occur on core facilities. Overall, 71.1 percent of all accidents occurring in the top 50 accident locations in Oakland County from 1980-1982 occur on a SEMCOG high congestion core facility.

In the development of its Year 2005 Plan, SEMCOG defined its "improvement corridors" as extending one mile either side of the high congestion core facility. This was done as a recognition that making significant improvements to a severely congested, regionally significant travel thoroughfare will impact more than just the core facility. The minimum sphere of influence was therefore established as extending one mile either side of the core facility. On this basis, Table 4 presents high accident locations and associated accidents occurring within high congested, two-mile wide corridors. The table indicates that all of the ten and nineteen of the top twenty accident locations fall within the corridors. Overall, 42 (84%) of the top 50 accident locations and 88.1 percent of total accidents attributable to these locations occur within SEMCOG's high congestion corridors.

Table 4. Accidents Within High Congested Corridors

Accident Location Rank	Cumulative Total Locations Within Corridor	% Cumulative Locations Within Corridor	Total Accident Within Corridor	% Accidents at Locations Within Corridor	Cumulative % Accidents Within Corridor
1-10	10	100.0	1,484	100.0	100.0
11-20	19	95.0	1,123	93.6	97.1
21-30	25	83.3	885	69.6	88.3
31-40	33	82.5	911	83.2	87.2
41-50	42	84.0	1,123	92.0	88.1

Statistical Test Results

The statistical tests employed in the study are much more involved than the plan consistency test. The statistical tests include an analysis of standard distributions, linear regression (including various log transformations) and analysis of variance.

Standard Distributions

Tables 5 and 6 present the basic statistical items for congested (volume- to-capacity (V/C) ratio greater than 0.90) versus uncongested (V/C ratio less than or equal to 0.90) facilities, respectively. The total number of intersections (or cases) in the study is 331. This represents the total number of valid intersections from SEMCOG's 1982 intersection file matched with the information from SEMCOG's Accident Analysis System (SAAS) file. Due to the nature of the intersection file and SAAS file, this dataset does not include:

1. Freeway traffic/accident statistics.
2. Local street traffic/accident statistics.
3. Traffic/accident statistics on service drives.

These tables show that the mean total number of accidents on congested facilities is significantly higher than on uncongested facilities (23.96 to 13.91, respectively). However, the proportion of accidents occurring on congested facilities (40.59%) is somewhat less than the proportion of traffic occurring on these facilities (42.97%). Conversely, the proportion of accidents occurring on uncongested facilities (59.41%) is higher than the traffic occurring on these facilities (57.03%). These proportions are borne out in the mean accident rates. The mean accident rate for uncongested facilities

Table 5. Traffic and Accident Statistics - Uncongested Facilities

Variable	N (71.6% of cases)	Mean	Minimum	Maximum	Total	% of Total
1. Volume-to-Capacity Ratio	237	.61	.12	.90	-	-
2. Total Accidents	237	13.91	1	66	3,296	59.41
3. Accident Rate	237	1.48	0.09	6.03	-	-
4. Daily Approach Volume	237	29,808	1,362	99,225	7.06M	57.03

Table 6. Traffic and Accident Statistics - Congested Facilities

Variable	N (28.4% of cases)	Mean	Minimum	Maximum	Total	% of Total
1. Volume-to-Capacity Ratio	94	1.12	.91	1.97	-	-
2. Total Accidents	94	23.96	1	73	2,252	40.59
3. Accident Rate	94	1.25	.04	4.74	-	-
4. Daily Approach Volume	94	56,621	10,037	117,400	5.3M	42.97

(1.48) is higher than the accident rate for congested facilities (1.25).

Table 6 also indicates that the mean V/C ratio for all congested facilities is 1.12. In theory, volume does not exceed capacity. This is true when capacity is equal to some "saturation" level beyond which more autos simply cannot be accommodated. In practice, however, capacity is rarely defined in terms of saturation. Rather, as in the case of SEMCOG's intersection file, capacity is derived from the 1965 Highway Capacity Manual, which presents standard capacities based on "prevailing," or average conditions. Some of these conditions, such as minimum acceptable headway, may not be exhibited by heavy volume roads during the peak hour. Peak hour traffic is normally characterized by journey-to-work travelers who have an intimate knowledge of, for example, the traffic signal timing along their particular route.

The 1965 Highway Capacity Manual was also developed based on 1950's traffic data, when autos were less responsive (manual transmissions) and bigger and when coordinated, actuated and interconnected traffic signals were rarely the norm. Several studies have shown the HCM capacities to be low compared to other methods of determining capacity. May, et al. (1983), for example, showed that the HCM capacity for typical intersections was considerably lower than capacities for the same intersections derived from other methods. The study indicated that the mean lane saturation flow by approach for five intersections derived from the HCM was 1,393 vehicles per hour of green. The four other methods (British, Swedish, Australian, and National Cooperative Highway Research Program) yielded predicted flows of 1,907, 1,692, 1,576, and 1,522 vehicles per hour of green, respectively.[1] The fact that the 1965 HCM capacities are generally low was the impetus for development of an updated capacity manual, draft portions of which have recently been published.

The practical result of the above discussion is that it is not uncommon for volumes to exceed HCM capacities, particularly on high volume roads during the peak hour. In conversation with Doyle Clear, Principal Associate and Director of Traffic Engineering for Barton-Aschman Associates, Inc., he indicated that in urban areas during the peak hour, volumes sometimes exceed capacities by as much as 30-50 percent.

Recognizing that volumes may exceed capacities, recent articles have attempted to translate V/C ratios greater than 1.0 into a measure of delay at an intersection. Hurdle (1984), for example, gives special attention to the delay effects of "oversaturated" facilities. In assessing the applicability of various delay models, Hurdle notes that, "...there is one group of models, the steady-state queing models, that work when when V/C is considerably less than one and another type, the deterministic queing model...that works well when V/C is considerably more than one."[2] Draft portions of the new Highway Capacity Manual concerning level-of-service criteria note that, "When demand volume exceeds the capacity of the lane, extreme delays will be encountered with queing which may cause severe congestion affecting other traffic movements in the intersection. This condition usually warrants improvement to the intersection."[3]

Although V/C ratios exceeding one are not uncommon, V/C ratios exceeding about 1.50 are uncommon. The 1.97 value shown in Table 6 and the other four intersections exhibiting extremely high V/C ratios (greater than 1.80) may be due to abnormally high volumes associated with the procedure of using a uniform 8.0 percent peak hour factor to derive peak hour volumes. Nevertheless, these cases were left in the analysis because (1) they are likely congested locations and (2) their small number compared to the total cases (331) is not likely to affect the linear regression analysis.

Table 6 also reflects the locally accepted definition of congestion as V/C ratio greater than 0.90. This relatively high value was selected as representing the starting point of level-of-service (LOS) E, although according to most references a V/C ratio of 0.90 would indicate congestion well beyond the threshold of LOS E. According to SEMCOG staff (and agreed to by its advisory committees), the more restrictive V/C guideline was chosen as a more realistic benchmark, given the range of V/C ratios achieved by using the HCM capacities.

Tables 7 and 8 present the basic statistical items for uncongested versus congested facilities using a less restrictive congestion threshold of V/C ratio equal to 0.75. These tables do not present results which are significantly different than those of Tables 5 and 6. The mean accident rate for uncongested facilities (1.48) is, again, higher than the accident rate for congested intersections (1.28). Apparently, the sensitivity of basic accident statistics with respect to V/C ratios in the congested range is fairly elastic.

Table 7. Traffic and Accident Statistics - Uncongested (V/C <.75)

	Variable	N (54.1% of cases)	Mean	Minimum	Maximum	Total	% of Total
1.	Volume-to-Capacity Ratio	179	.55	.12	.75	-	-
2.	Total Accidents	179	12.01	1	55	2,150	38.75
3.	Accident Rate	179	1.48	.09	6.03	-	-
4.	Daily Approach Volume	179	25,384	1,362	85,812	4.5M	36.68

Table 8. Traffic and Accident Statistics - Congested (V/C >.75)

	Variable	N (45.9% of cases)	Mean	Minimum	Maximum	Total	% of Total
1.	Volume-to-Capacity Ratio	152	1.00	.76	1.97	-	-
2.	Total Accidents	152	22.36	1	73	3.398	61.25
3.	Accident Rate	152	1.28	.04	4.74	-	-
4.	Daily Approach Volume	152	51,600	4,100	117,400	7.8M	63.32

Linear Regression Analysis

Based on the findings of Rykken and others, a linear regression analysis was undertaken to ascertain the strength, if any, of the relationship between congestion (as measured by volume-to-capacity ratio) and accident frequency and accident rate in Oakland County. An assumption that the variable populations are normally (or near normally) distributed was made. This is considered a relatively safe assumption, given the size of the sample (331) and the fact that "...as sample size increases the distribution of $\hat{\beta}$ (the least squares estimator of β) will usually approach normality."[4] Further, the Gauss-Markov theorem justifying least squares requires no special assumption about the normality of the dependent variable (y). This "...greatly generalizes the application of the regression model."[5]

Volume-to-Capacity Ratio Versus Total Accidents

The first regression performed was with volume-to-capacity ratio as the independent variable and total accidents as the dependent variable. Figure 10 shows the scatterplot of these data, indicating a potential linear relationship, but with several "outliers" surrounding the main body of cases.

Table 9 presents the results of the linear regression program REGRESSN from the OSIRISIV statistical package. The table indicates an observed t-statistic of 7.96, which far exceeds a critical t-value of 2.576 at the .005 significance level, providing significant evidence that a linear relationship exists between volume-to-capacity ratio and total accidents. The multiple correlation coefficient of

```
X = V1, V/C RATIO                 MEAN =      0.7572  ST.DEV =      0.2873
Y = V2, TOTAL ACCIDENTS           MEAN =     16.7613  ST.DEV =     13.8376
N =      331.000 C 0 CASES OMITTED - MD IN X OR Y OR OFF SCALE
R =  0.4017 REGRESSION: CONSTANT=    2.6035  B=   18.6971
```

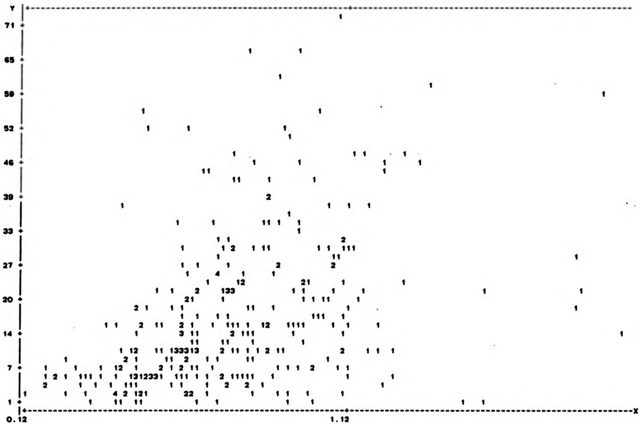


Figure 10. Scatterplot of Volume-to-Capacity Ratio by Total Accidents

Table 9. Regression Statistics - V/C Ratio Vs. Total Accidents

The dependent variable is V2 Total Accidents

Standard error of estimate	12.70		
F-ratio for the regression	63.302		
Multiple correlation coefficient	0.4017		
Fraction of explained variance	0.1614		
Determinant of the correlation matrix	1.00000		
Residual degrees of freedom (N-K-1)	329		
Constant term	2.60353	Std. error	1.91149

VARIABLE	B	SIGMA(B)	BETA	SIGMA(BETA)	MARGINAL RSQD	T-RATIO	VARIABLE NAME
V1	18.69705	2.34998	0.40170	0.05049	0.1614	7.9563	V/C Ratio

.4017 represents a fair "goodness of fit" about the regression line, particularly given the "outliers." The regression line is defined as:

$$y = 2.6035 + 18.6971x$$

Given this regression equation, a volume-to-capacity ratio of 0.75, for example, would result in an expected value of 17 total accidents.

Although there is significant evidence pointing to a linear relationship, the strength of this relationship appears to be weak, as symbolized by the coefficient of determination (r^2) of .1614.

Volume-to-Capacity Ratio Versus Accident Rate

The scatterplot of V/C ratio as the independent variable and accident rate as the dependent variable is shown in Figure 11. This scatterplot leads itself to a much less clear interpretation of the potential linear relationship between congestion and accident rate. This is reflected in the regression statistics as shown in Table 10. The coefficient of determination is only .0231. Nevertheless, the t-statistic of 2.7869 still exceeds the critical t-value of 2.576 at .005 level of significance. The regression equation for this relationship was calculated as:

$$y = 1.7795 - 0.51534x$$

A volume-to-capacity ratio of 0.90, for example, would result in an expected accident rate of 1.32 accidents per million entering vehicles.

The important statistic in this relationship is, of course, the Pearson"s product-moment correlation (partial r) of -.151, indicating an inverse relationship between V/C ratio and accident

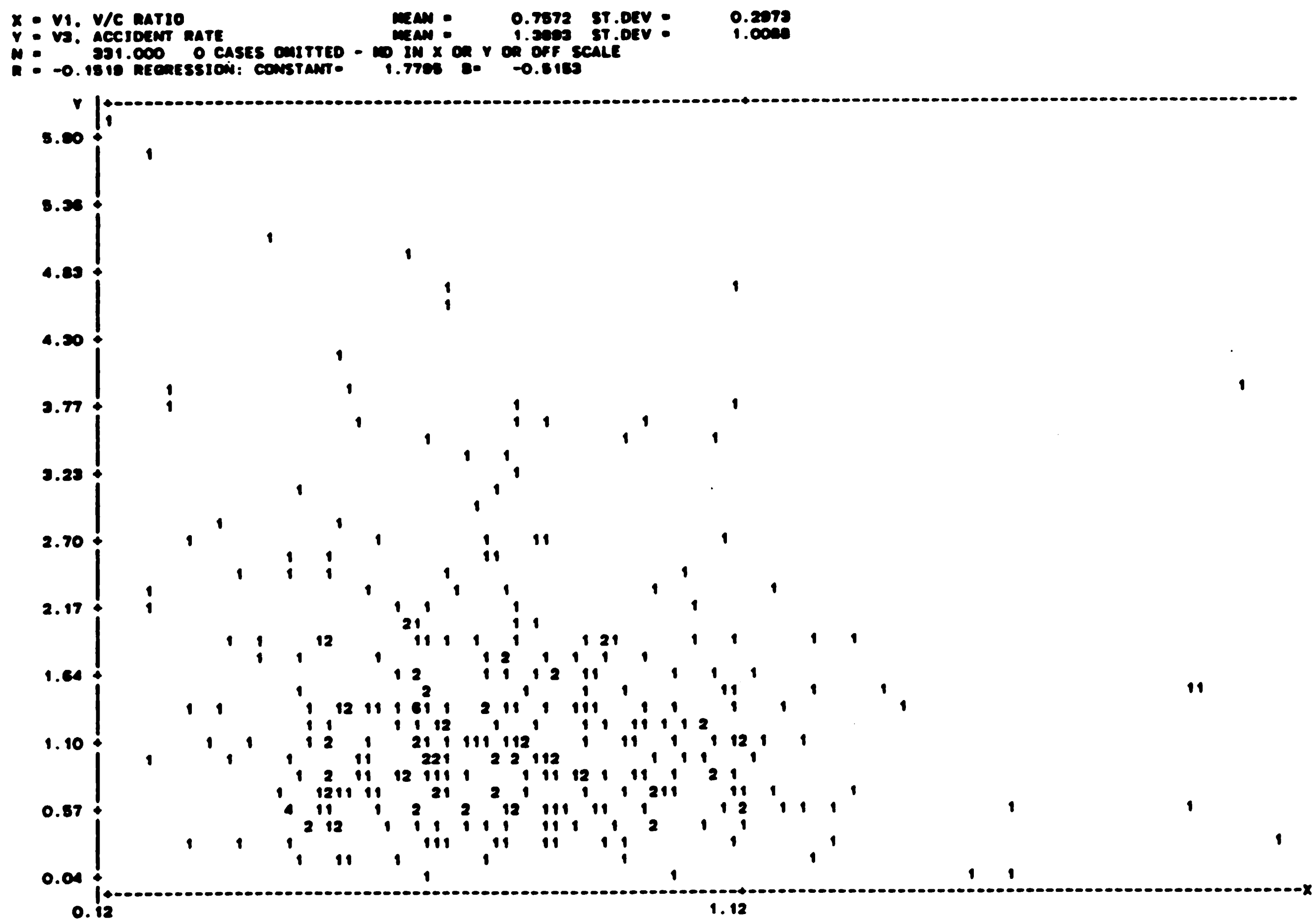


Figure 11. Scatterplot of Volume-to-Capacity Ratio by Accident Rate

Table 10. Regression Statistics - V/C Ratio Vs. Accident Rate

The dependent variable is V3 Accident Rate

Standard error of estimate	1.00		
F-ratio for the regression	7.767		
Multiple correlation coefficient	0.1519		
Fraction of explained variance	0.0231		
Determinant of the correlation matrix	1.00000		
Residual degrees of freedom (N-K-1)	329		
Constant term	1.77950	Std. error	1.15041

VARIABLE	B	SIGMA(B)	BETA	SIGMA(BETA)	PARTIAL R	MARGINAL RSQD	T-RATIO	VARIABLE NAME
V1	-0.51534	0.18491	-0.15186	0.05449	-0.151	0.0231	2.7869	V/C Ratio

rate. This means that while more accidents occur at congested facilities, they occur at a declining rate as congestion increases. While caution should be exercised in interpreting this result given the low r^2, the negative r value offers some substantiation for Pignataro's claim, as referenced earlier, that accident rates decline under congested conditions.

Analysis of "Outliers"

One of the more sensitive aspects of regression analysis is the handling of "outlier" cases, which present values so outside the norm that their presence as valid cases comes into question. Outliers can be caused by clerical errors, such as coding in the wrong number of accidents or incorrect traffic volume count. The rule used in this thesis is based on eliminating the 5 percent of extreme cases, so that an outlier occurs when the value of either the number of accidents or daily approach volume is within two and one-half percent of the minimum or maximum value for each variable. Based on this guideline, 31 cases were eliminated (one case overlapping). The intersections based on accident outliers had one accident in the low extreme range (eight one-accident locations were eliminated randomly among all accident locations) or 55-73 accidents in the high extreme range. Intersections eliminated through outlier volumes ranged from 1,362-4,800 vehicles per day at the low extreme and 97,012-117,400 vehicles per day at the high extreme.

The scatterplots of the remaining 300 cases for V/C ratio as the independent variable and total accidents and accident rate as the

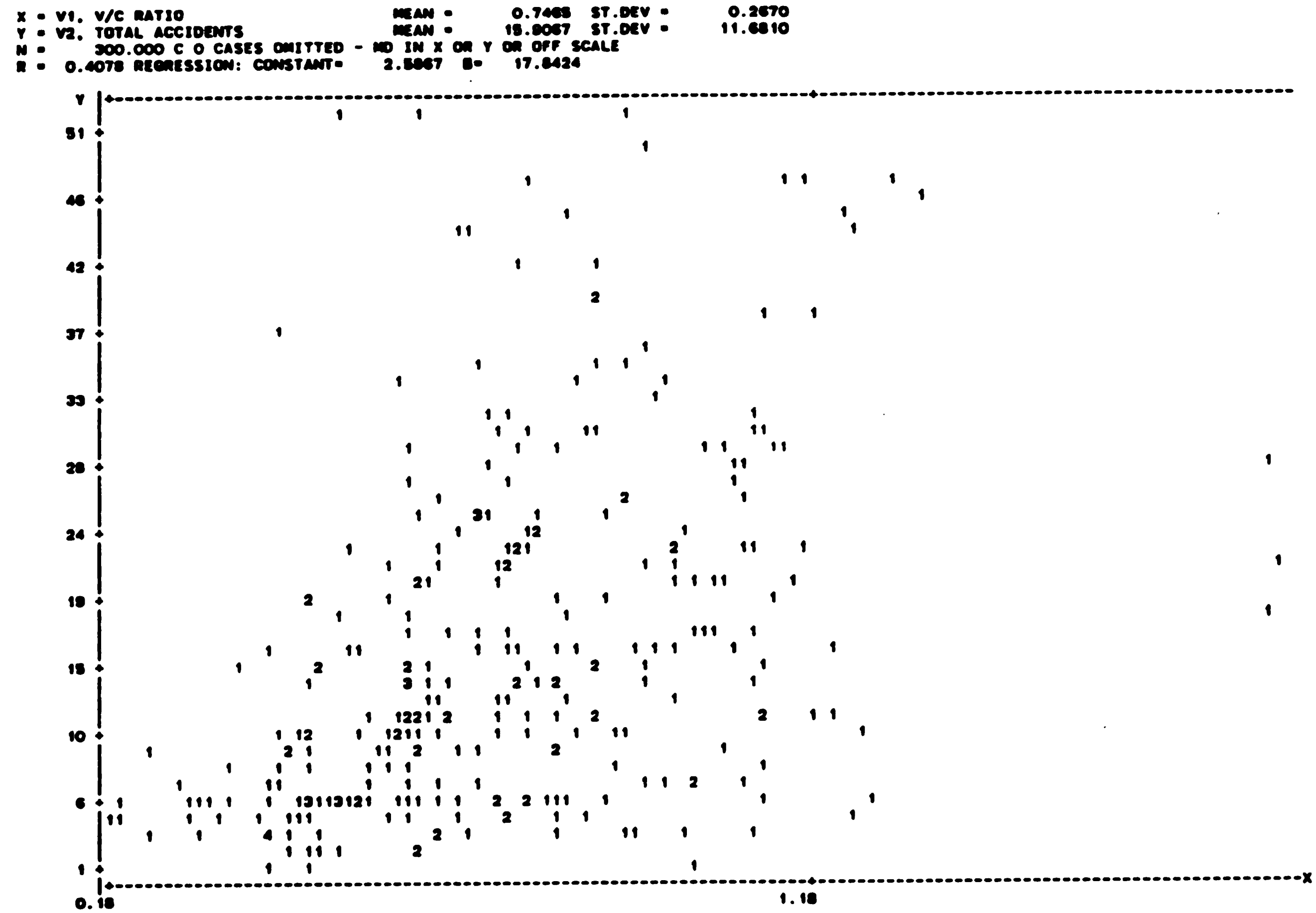


Figure 12. Plot of Volume-to-Capacity Ratio by Total Accidents (Restricted Dataset)

X = V1. V/C RATIO MEAN = 0.7465 ST.DEV = 0.2670
Y = V3. ACCIDENT RATE MEAN = 1.3267 ST.DEV = 0.8618
N = 300.000 0 CASES OMITTED - MD IN X OR Y OR OFF SCALE
R = -0.1006 REGRESSION: CONSTANT= 1.5689 B= -0.3244

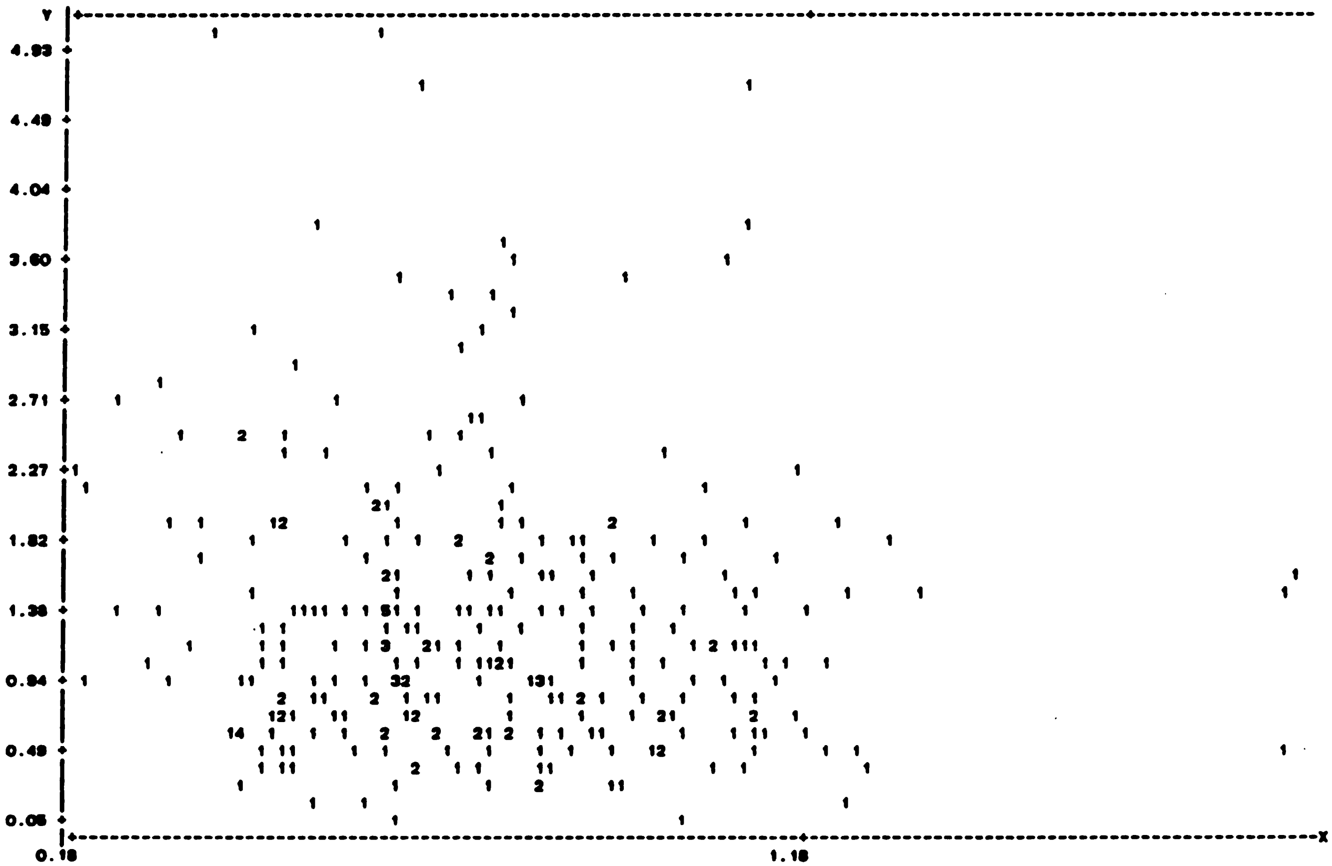


Figure 13. Plot of Volume-to-Capacity Ratio by Accident Rate (Restricted Dataset)

dependent variables, are shown in Figures 12 and 13, respectively. These plots still show some cases in the extreme ranges. This is probably due to the fact that: (1) approach volume, rather than V/C ratio, was selected as the more appropriate variable to eliminate outliers from (this assumes capacities have been accurately calculated and reported); and (2) that outliers in the form of high V/C ratios matched with low total accidents or accident rates (and vice versa) were not eliminated.

The regression statistics for the outlier statistics are shown in Tables 11 and 12. The new coefficients of determination for total accidents and accident rate are .1663 and .0101, respectively. Compared to the original dataset, this represents a marginal improvement for total accidents, while indicating a weaker relationship between congestion and accident rate.

Logarithmic Transformations

As a first analysis at testing the possibility that the relationships are of a curvilinear, rather than linear nature, log transformations of both the independent and dependent variables were performed. These transformations lead to the following regression equations:

(1) $\log y = a + bx$; and

(2) $y = a + b \log x$

The Statistical Package for the Social Sciences (SPSS) manual[6] recognizes these as two of the simpler log transformations. Table 13 presents the coefficients of determination for each of these transformations.

Table 11. Regression Statistics - V/C Ratio Vs. Total Accidents (Restricted Dataset)

The dependent variable is V2 Total Accidents

Standard error of estimate	10.69		
F-ratio for the regression	59.444		
Multiple correlation coefficient	0.4078		
Fraction of explained variance	0.1663		
Determinant of the correlation matrix	1.00000		
Residual degrees of freedom (N-K-1)	298		
Constant term	2.58669	Std. error	1.83460

VARIABLE	B	SIGMA(B)	BETA	SIGMA(BETA)	PARTIAL R	MARGINAL RSQD	T-RATIO	VARIABLE NAME
V1	17.84242	2.31419	0.40780	0.05289	0.407	0.1663	7.7100	V/C Ratio

Table 12. Regression Statistics - V/C Ratio Vs. Accident Rate (Restricted Dataset)

The dependent variable is V3 Accident Rate

Standard error of estimate	0.86		
F-ratio for the regression	3.041		
Multiple correlation coefficient	0.1005		
Fraction of explained variance	0.0101		
Determinant of the correlation matrix	1.00000		
Residual degrees of freedom (N-K-1)	298		
Constant term	1.56888	Std. error	0.14749

VARIABLE	B	SIGMA(B)	BETA	SIGMA(BETA)	PARTIAL R	MARGINAL RSQD	T-RATIO	VARIABLE NAME
V1	-0.32441	0.18604	-0.10050	0.05764	-0.100	0.0101	1.7437	V/C Ratio

Table 13. Coefficients of Determination for Log Transformations

Dependent Variable	R^2 Regression Equation logy=a+bx	y=a+b logx
- Total Accidents	.1498	.1733
- Accident Rate	.0219	.0444

These results indicate that the log transformations do not uncover significantly stronger relationships between the variables.

Analysis of Variance

As a final check of the significance of the relationship between congestion and total accidents and accident rate, an analysis of variance (ANOVA) test was performed. The analysis of variance test makes no assumptions about the nature of the relationship between variables (e.g., linear, curvilinear), but simply determines the likelihood that "...in grouping a set of observations for a variable y according to the nominal values of a variable x, the observed differences in the group means could have merely been the result of sampling error rather than the result of an underlying relationship between y and x."[7] The x variable (V/C ratio) was nominally scaled by establishing V/C ratio ranges which resulted in an approximately equal number of cases in each V/C category.

Results of the ANOVA test are presented in Table 14. The table summarizes the analysis by including the two critical ANOVA statistics: eta-squared (the correlation ratio) and its associated F-statistic.

Table 14. Results of Analysis of Variance

DEPENDENT VARIABLE	ETA-SQUARED	F-STATISTIC
1. Total Accidents	.19	8.41
2. Accident Rate	.045	1.681

The F-statistic for total accidents indicates that a statistically signficant relationship exists at a .01 confidence level (the critical F-value with nine degrees of freedom (df) for the numerator and 321 df for the denominator is 2.70). The F-statistic for accident rate indicates that a statistically signficant relationship between congestion and accident rate can be assumed at a .10 confidence level.

Accident Occurrence and Daily Approach Volume

To ascertain the possiblity of a third variable contributing to the prediction of accident occurrence, daily approach volume was included as an independent variable with volume-to-capacity ratio in a multiple regression analysis. The analysis resulted in a coefficient of determination (r^2) of .4007 for total accidents, a distinct improvement over the r^2 of .1614 when taking V/C ratio alone as the independent variable. The r^2 for accident rate given the two independent variables was .0634, a marginal improvement over the r^2 of .0231 given V/C ratio alone. However, the regression of total accidents and accident rate on daily approach volume alone was also performed and r^2 scores of .4006 and .0632, respectively, were achieved. The scatterplots using daily approach volume as the independent variable are shown on Figures 14 and 15. The fact that

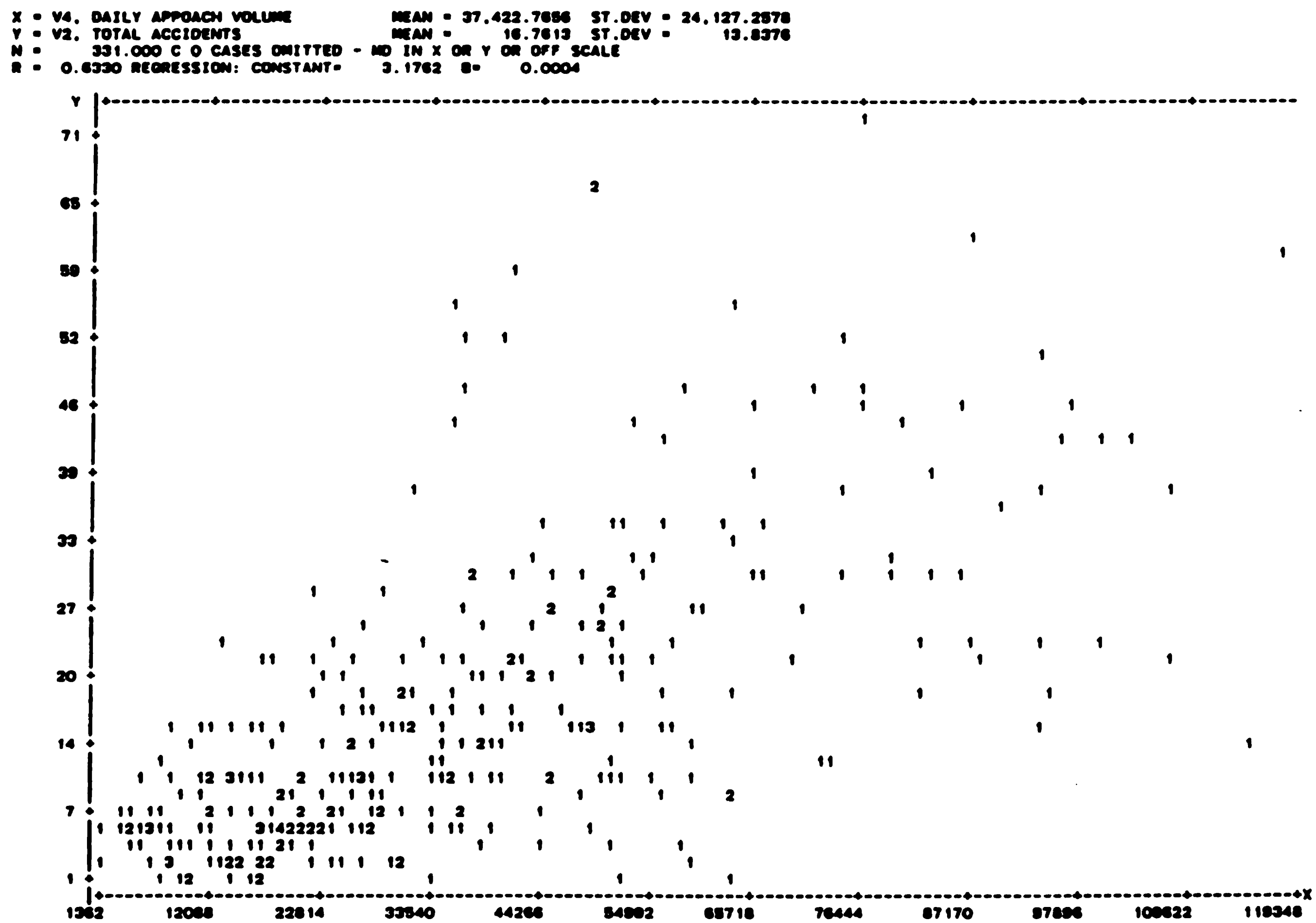


Figure 14. Scatterplot of Daily Approach Volume by Total Accidents

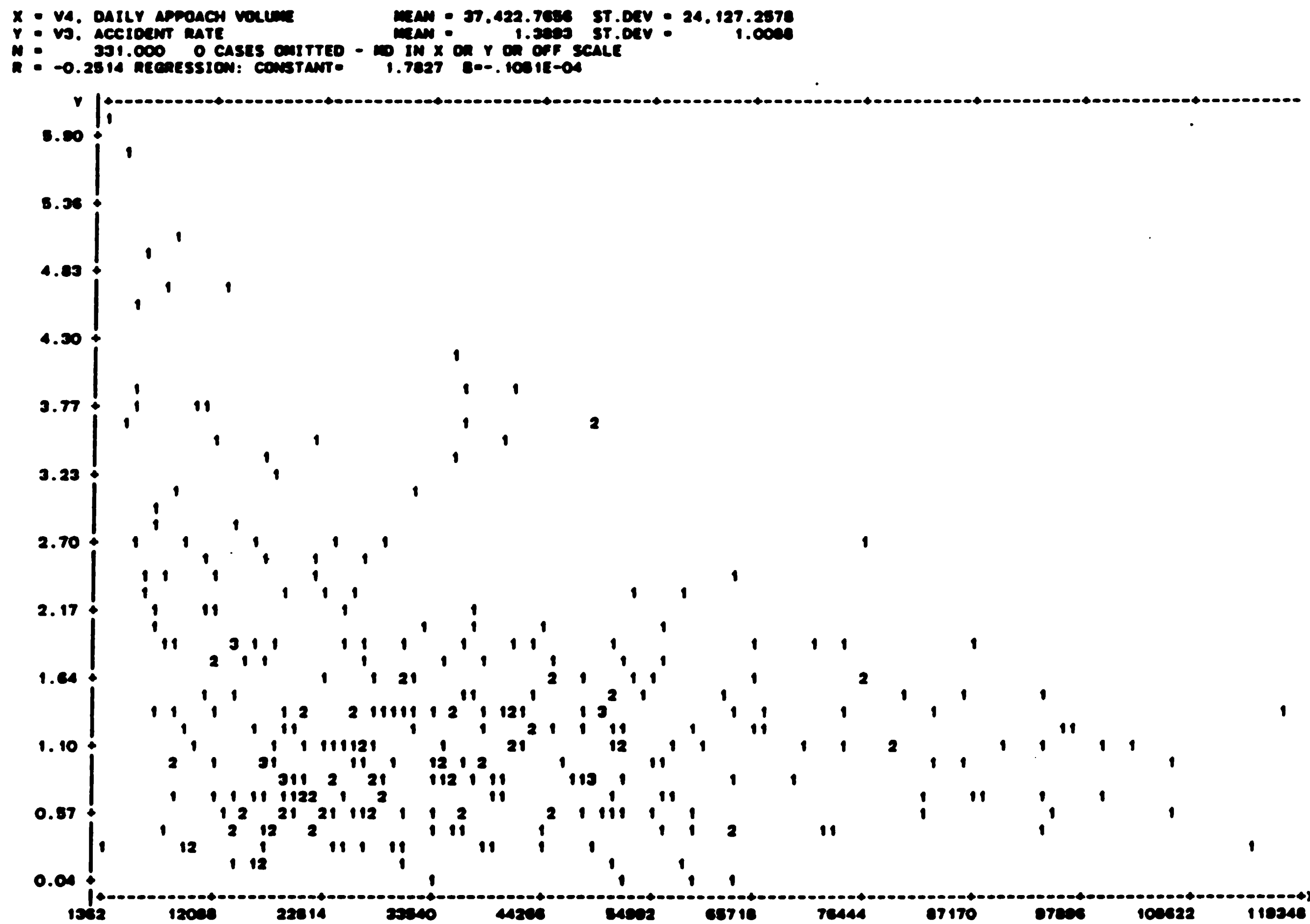


Figure 15. Scatterplot of Daily Approach Volume by Accident Rate

these plots show less divergence than those in Figure 10 and 11 (showing V/C ratio as the independent variable) is not surprising given the results of the literature review, which point to a substantiaal body of research showing the strength of relationship between accidents and traffic volume.

Congestion and Accident Hazardousness

A final, simple statistical analysis was performed comparing the distribution of accidents by severity type (fatal, injury and property damage) on congested versus uncongested facilities. These statistics are presented in Tables 15 and 16. The tables show that although the mean accident frequency for injury accidents on congested facilities is significantly higher than on uncongested facilities (8.18 to 4.87), the proportion of injury accidents as a percentage of all accidents occurring on congested facilities (34.15%) is slightly lower than the proportion of injury accidents as a percentage of all accidents on uncongested facilities (34.98%). Similarly, the percentages of property damage accidents occurring on congested versus uncongested facilities are near equal (64.72% and 65.76%, respectively).

Although the number of cases is not large, the proportion of fatal accidents occurring on uncongested facilities (.30%) is, in relative terms, larger than the proportion of fatal accidents occurring on congested facilities (.09%).

Table 15. Accident Statistics by Severity Type - Congested Facilities

Variable	Mean	Minimum	Maximum	Total	% of Total
1. Total Accidents	23.96	1	73	2,252	100.00
2. Fatal Accidents	.02	0	1	2	.09
3. Injury Accidents	8.18	0	28	769	34.15
4. Property Damage Accidents	15.75	0	61	1,481	65.76

Table 16. Accident Statistics by Severity Type - Uncongested Facilities

Variable	Mean	Minimum	Maximum	Total	% of Total
1. Total Accidents	13.91	1	66	3,296	100.00
2. Fatal Accidents	.04	0	1	10	.30
3. Injury Accidents	4.87	0	28	1,153	34.98
4. Property Damage Accidents	9.00	0	40	2,133	64.72

Footnotes: Part Three

[1]Adolf D. May, Ergun Gedizlioglu and Lawrence Tai, "Comparative Analysis of Signalized-Intersection Capacity Methods," in Transportation Research Board, Traffic Flow, Capacity and Measurements, (Washington, D.C.: Transportation Research Board, 1983), p. 123.

[2]V.F. Hurdle, "Signalized Intersection Delay Models - A Primer for the Uninitiated," in Transportation Research Board, Traffic Capacity and Characteristics, (Washington, D.C.: Transportation Research Board, 1984), p. 97.

[3]Transportation Research Board, Proposed Chapters for the 1985 Highway Capacity Manual, (Washington, D.C.: Transportation Research Board, 1984), p. 10-9.

[4]Wonnacott and Wonnacott, Op. Cit., p. 202.

[5]Ibid., p. 202.

[6]Norman H. Nie, et al., SPSS-Statistical Package for the Social Sciences, Second Edition, (New York, NY: McGraw-Hill Book Company, 1975), p. 370.

[7]Donald A. Kruekeberg and Arthur L. Silvers, Urban Planning Analysis: Methods and Models, (New York, NY: John Wiley & Sons, Inc., 1974), p. 157.

PART FOUR: STUDY CONCLUSIONS

The purpose of this section is to interpret the results of Part Three and to make some observations about the original question posed at the outset of this thesis--is it reasonable to assume a strong relationship between congestion and accidents in the conduct of long range transportation planning?

Interpretation of Plan Consistency Results

Using a very strict interpretation, one which would restrict the study of a corridor to the core facility which provides its primary definition, the SEMCOG Long Range Plan would account for roughly two-thirds of the top 50 accident locations in Oakland County and their associated accidents. Assuming, as SEMCOG has, that a corridor study will investigate in detail the transportation problems of a subarea at least one mile either side of the core facility, the results are even more impressive. Figure 16 summarizes these results by showing the cumulative percentage of high accident locations and their associated accidents occurring within SEMCOG corridors. Figure 16 shows that every one of the top ten accident locations and nineteen of the top twenty fall within a high congested corridor. Overall, 42 of the 50 locations are within corridors and 88.1 percent of all accidents occurred at these 42 locations.

These are very impressive statistics and, one would expect, not

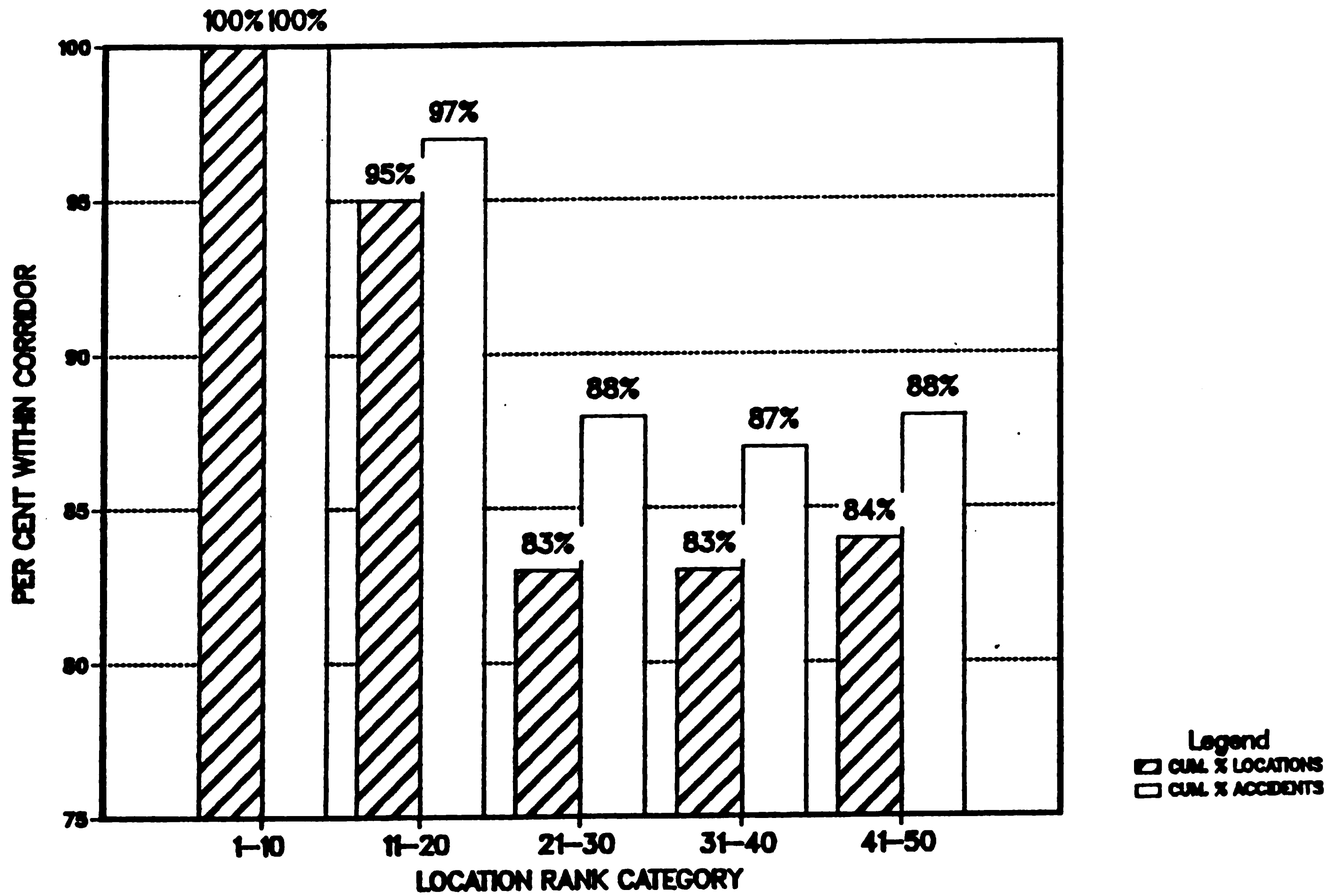


Figure 16. Percentage of High Accidents in SEMCOG Corridors

likely the result of coincidence. Based on these results alone, a fairly strong intuitive argument could be made that congestion and accident occurrence are highly correlated and, hence, that it is not improper to consider only congestion in identifying deficient locations in need of detailed study. These results seem to support the contention that the safety issue has been adequately addressed in the SEMCOG Long Range Plan.

Interpretation of Statistical Results

Far from supporting the plan consistency results, the statistical results offered no clear indication of the strength in relationship between congestion and accident occurrence. Although the mean accident frequency on congested facilities is higher than on uncongested facilities, the linear regression analysis indicated this reflected a weak relationship between congestion and accident frequency. From the standard distribution statistics, it was found that the mean accident rate on uncongested facilities (1.48 accidents per million vehicles) was higher than the accident rate on congested facilities (1.25 accidents per million vehicles). So right away there is evidence that a definition of hazardousness based on the rate at which accidents occur at intersections would not support an assumed close correspondence between high congested locations and hazardous locations.

Interpretation of Linear Regression Results

In general, these analyses did nothing to increase the confidence in assuming a strong relationship between congestion and

accident occurrence. In comparing volume-to- capacity ratio and total accidents, a statistically significant, yet weak positive linear relationship was found. There are several likely reasons why a stronger relationship was not found, including:

1. The relationship between V/C ratio and total accidents is, in fact, a weak one.
2. There are other variables which play an equally or more important role in determining the frequency of accidents at intersections.
3. The scaling or measurement of the volume-to-capacity variable was not appropriate.
4. The traffic and accident data were biased.

There is probably some truth to each of these assertions, as discussed below.

The Relationship Between V/C Ratio and Accidents. The linear regression analysis of these variables produced an r of .4017 and r^2 of .1614. This represents a statistically significant, weak relationship between the variables. Various log transformations and elimination of outliers did not serve to improve this result. An analysis of variance also seemed to confirm the finding of a weak relationship. In addition, it was shown that the difference in r^2 between a multiple regression of total accidents on V/C ratio and daily approach volume (.4007) was only marginally better than the r^2 of the regression of total accidents on daily approach volume alone (.4006). This suggests that daily approach volume is a better variable to start off with in attempting to relate traffic flow to accident occurrence and that the significance in the relationship between V/C ratio and accidents is probably due to the strong influence of daily approach volume. By introducing the capacity factor into the equation (which thereby introduces the index of congestion), the capability to predict accident frequency with more confidence has been signficantly weakened.

The Potential Impact of Other Variables. As was mentioned earlier, there are many variables which cause accidents. It would be inappropriate to expect one variable to, for example, explain 70-80 percent of the variation in accident occurence. But we have seen that one variable, daily approach volume, explains roughly 40 percent of the variation in total accidents. Volume-to-capacity ratio explains approximately 16 percent of this variation. An important aspect of further research may therefore be to use approach volume as an initial variable and to add other variables, perhaps some which may be a function or approach volume, to the predictive equation.

Volume-to-Capacity Ratio as a Measurement of Congestion. Volume-to-capacity ratio is the traditional measure of congestion, but there are several ways of defining it for the purposes of a regression analysis. For example, a procedure which incorporates turning movements into a definition of congestion (which would more closely match the "quick response" method) may produce better results. Another possible way to measure congestion would be over individual road segments, rather than in a composite fashion at intersections.

Data Bias. The data used in the regression analyses are one-year data, because there was only one year of data at the time in

SEMCOG's accident file to extract. Ideally, three-year average data would be used in the analysis, as suggested by May, so as to "...reduce the possibility of using accident statistics derived from the chance occurrence of many unexplained accidents which can happen at a location during a short period of time."[1]

The Relationship Between V/C Ratio and Accident Rate

The linear regression analysis resulted in a very low r^2 for this relationship. The r of -.151 indicates a negative relationship and, again, these regression statistics probably reflect the residual influence of daily approach volume. The scatterplot in Figure 15, showing daily approach volume as the independent variable, points to a negative, curvilinear relationship. An analysis of variance with daily approach volume as the independent variable and accident rate as the dependent variable resulted in an eta-squared of .18, a distinct improvement over the eta-squared of .045 using V/C ratio as the independent variable.

The negative, weak relationship between V/C ratio and accident rate contradicts the findings of Rykken, who apparently found a strong relationship between these variables, as depicted in Figure 1. However, upon closer examination of Rykken's methodology, it was found that "accident rate" was defined in his study as the number of accidents per mile, which is something quite different than accidents per million vehicles, the more common definition of accident rate. Number of accidents per mile is merely a direct function of total accidents on the roadway and would be expected, as earlier results have shown, to increase linearly with V/C ratio.

Congestion and Accident Hazardousness

Figure 17 summarizes the mean accident rate for uncongested versus congested facilities by accident type. The rates on uncongested facilities are higher than the rates on congested facilities across the board. From this perspective, travel on uncongested facilities is more unsafe. However, as we have seen in Tables 13 and 14, the percentage of accidents by type within each travel category (uncongested, congested) is roughly the same. This means that if one is involved in an accident on a congested facility, it is just as likely to be a more severe accident involving injury as an accident occurring on an uncongested facility.

Comparing the Plan Consistency and Statistical Results

From the preceding discussion, there seems to be a conflict between conclusions rendered from the plan consistency results compared to those from the statistical results. The plan consistency results show an apparently strong relationship between congestion and accidents. The statistical results, conversely, indicate a weak positive relationship between congestion and total accidents and a negative relationship between congestion and accident rate. Further, congested facilities appear to result in less severe accidents on the whole. These apparently contradicting results mask a very interesting relationship that uncovers itself as one considers the way high accident locations and high congestion corridors are identified in the respective planning processes of the Oakland County TSM Committee and SEMCOG. In both cases, the underlying factor influencing both deficiency indicators is traffic volume and it is this common thread

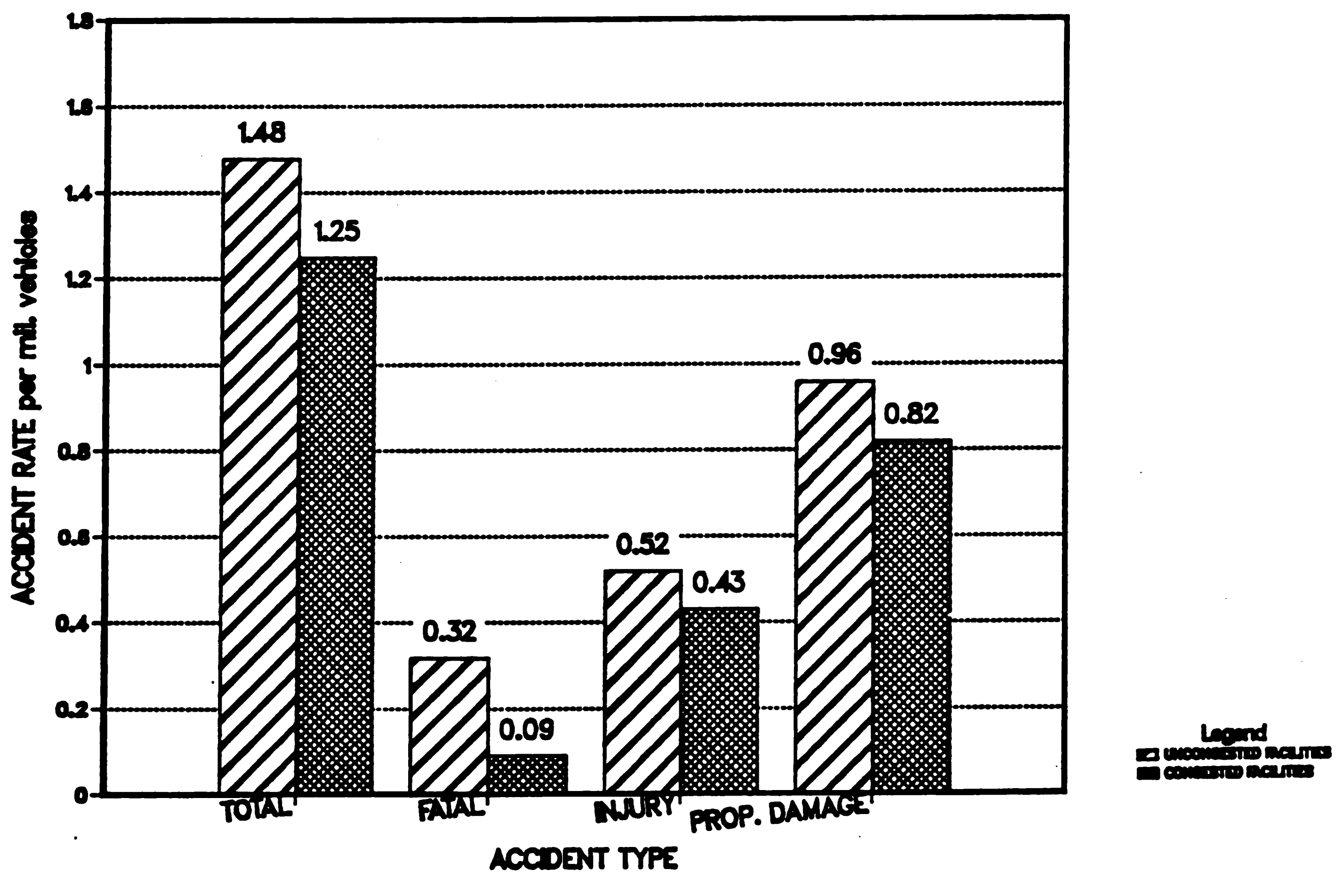


Figure 17. Accident Rate of Uncongested Versus Congested Facilities

*Note: Fatal accident rates are per 100 million vehicles.

which produces the closeness of fit underscored in Figure 16.

Defining High Accident Locations

The Oakland County TSM Committee ranked intersections from 1980-1982 based on a formula using the following criteria: total accident frequency, accident rate (per million vehicles), and severe (fatal and injury) accident frequency. Each of these criteria were converted to a scale and the following formula determined an intersection's ranking:[2]

Frequency Scale Number + Rate Scale Number + 2 (Severity Scale Number) = Score

The fact is that the criterion having the greatest impact on an intersection's ranking is the number of accidents occurring at the intersection. This is illustrated by Table 17, which shows the average number of accidents within each group of ten locations for five location group categories.

Table 17. Average Number of Accidents Within Accident Categories

ACCIDENT LOCATION RANK CATEGORY	AVERAGE NUMBER OF ACCIDENTS WITHIN EACH 10 LOCATION GROUP
1- 20	1,342
1- 40	1,183
41- 60	1,097
61- 80	868
81-100	768

The table shows that, for example, the average of accidents occurring within the first location cateogry (1-20) equals:

[1,484 (number of accidents at locations 1-10) +
1,200 (number of accidents at locations 11-20)] /2 = 1,342

As the table shows, the lower ranking categories have fewer average accidents. This effect becomes more pronounced when the "accident severity" index (based on number of fatal and injury accidents) is taken into account, because more accidents at a location generally means more injury accidents as well.

The point of this is to show the importance of accident frequency in the ranking of intersections within the Oakland County TSM Plan. It was noted in several places earlier in this thesis that accident frequency and traffic volume are strongly correlated. The higher the volume at an intersection, the more accidents occur at that intersection and, as was just illustrated, as a general rule, the higher an intersection will be ranked. Based on this reasoning, one would expect higher volume roadways to experience more accidents and to include intersections ranked higher than those locations on lower volume roads. This is precisely what has been found, as the highest volume arterial roadways within the County, including M-59, Orchard Lake Road, Woodward Avenue, M-150 (Rochester Road), Big Beaver Road, Southfield Road, and Telegraph Road (US-10/US-24), include a majority of the top 50 accident locations from 1980-1982.

Defining High Congestion Locations

Looking back at Figure 5, the SEMCOG process for identifying the most severely congested locations involved categorizing congested roadways into three categories: high congestion, medium congestion, and low congestion (Step 3). This categorization was based on peak hour, peak direction vehicle miles of travel (VMT) occurring during that peak congestion hour. The high congestion category included those roadways which accounted for the top 25 percent of the total VMT occurring under congested conditions. Vehicle miles of travel is simply the product of traffic volume and roadway length. So in order for a roadway to rank highly under SEMCOG's guidelines, it must be: (1) congested in the peak hour and peak direction; (2) fairly continuous (roadway length) in its congestion; and (3) most importantly, a high volume roadway. High volume roads will generally ensure conditions (1) and (2) and will result in high VMT values.

The same high volume roadways which ensured high accident frequency (and thereby rank) in the Oakland County TSM Plan also account for the high congested (high VMT) corridors in SEMCOG's Long Range Plan--M-59, Orchard Lake Road, Telegraph Road, etc. The important point is that the close association between the high accident locations in the Oakland County TSM Plan and the corridors in the SEMCOG Long Range Plan is not due to a common thread of congestion, but of high volume. This is an important distinction, because it follows that the apparently strong relationship between congestion and accidents as exhibited by the empirical results is rather a by-product of the unique ways high accident and congested locations have been defined and the influence of traffic volume within each definition.

Implications for Transportation Planning

This section has summarized several important aspects of the research:

1. From a statistical standpoint, the relationship between congestion and accidents can be characterized as weak.
2. Keeping in mind these weak correlations, congestion is positively related to accident frequency (total accidents) and appears to be negatively related to accident rate.
3. Daily approach volume is apparently a better predictor of both accident frequency and accident rate than is volume-to-capacity ratio.
4. The mean accident rate for uncongested faciities is significantly higher than the accident rate for congested facilities and this is true for each accident type (fatal, injury, property damage).
5. The close correspondence between high accident locations and high congestion corridors in Oakland County is a function of the common, overriding influence of approach volume in the procedures developed to identify high accident intersections and high congested corridors.

What do these findings mean for the way transportation planning is conducted? First, it means that it is probably incorrect to use a presumed close relationship between congestion and accidents as a priori evidence for completely ignoring accident deficiencies. There is also no assurance that the same close correspondence between high accident locations and high congestion locations would hold true throughout other areas. More importantly, in those counties with relatively few high volume arterials, the absence of "high" congested corridors is not likely to mean an absence of what, from a regional or local perspective, are considered hazardous intersections. The SEMCOG Long Range Plan, for example, identifies no corridors outside the tri-county (Wayne, Oakland and Macomb) urban area as "high" congestion thoroughfares. The residents of Washtenaw County are likely to be surprised that they have no serious "deficiencies," though in 1983 the intersection of Carpenter at Packard experienced 47 accidents. There should be a place in the long range planning process to recognize this discrepancy and to accommodate alternative notions of what is a critical deficiency.

Long Range Accident Planning - A Redundancy?

Many planners and engineers argue that accident investigation is meant to be strictly short range in nature--that an analysis of the causes and effects of accidents is restricted to an indepth analysis of a location's traffic and geometric characteristics. This perspective, however, just perpetuates the very tired conception of long range planning as the practice of identifying capacity deficiencies through the use of long-winded (and expensive) computer models.

Long range planning is simply the practice of anticipation. Given conditions x and y, what is the potential for problem z to occur and what can we do to try and prevent condition z? Stated in terms relevant to this thesis--given the accident history and the congestion and traffic volumes forecasted at Woodward Avenue and Ten Mile Road, what is the likely accident potential at this intersection and how does it compare to other intersections? Furthermore, given the accident potential throughout the region, or Oakland County, what traffic enforcement, land use and funding policies should be considered? These are legitimate questions and long range planning has a place in answering these and the many other concerns that are arising as a result of the growing concern over traffic safety.

Systemwide Accident Analysis

This thesis has pointed to a need to consider accident deficiencies in a more direct manner in the long range planning processs. The possibilities for "modeling" accidents on a systemwide basis appear to be good, notwithstanding the relatively poor predictive ability of volume-to-capacity ratio as measured in this thesis. Others have had success in predicting accidents on a systemwide basis. Snyder (1974), for example, had excellent results in using road frontage, type of road and population in the 16-24 year old age group as independent variables predicting accident rate. However, traffic volume was identified as the underlying factor having the greatest influence on predicting accidents.[3]

Considering the huge amounts of thought and money that are spent on travel behavior models, it seems perfectly reasonable to assume that given more attention, the practice of identifying potential hazardous locations on a systemwide basis could become more theoretically established and technically refined.

Footnotes: Part Four

[1]May, *Op. Cit.*, p. 28.

[2]Oakland County TSM Committee, *Op. Cit.*, p. 11.

[3]James C. Snyder, "Environmental Determinants of Traffic Accidents: An Alternate Mode," in *Traffic Accident Analysis*, Transportation Research Record 486, (Washington, D.C.: Transportation Research Board, 1974), pp. 11-18.

PART FIVE: RECOMMENDATIONS FOR FURTHER RESEARCH

The purpose of this section is to present an initial framework for continuing research on the topic of this thesis. Improvements in the statistical analysis of congestion and accidents will add to a basic understanding of how traffic flow is related to safety and may provide an important link between two fundamental measures of transportation deficiency. Improvements in theories about how safety concerns can be incorporated into long range planning will help planners address a growing concern in their plans and policies. In this way, a major objective of long range planning (and making the transportation system as safe as possible is a specific and important objective in the development of most long range plans) can be given more detailed attention.

Statistical Improvements

Although the linear regression analysis was not encouraging as far as relating congestion and accidents, there are several changes to the database that could be made that might improve the results. These include:

1. Use three-year average traffic volume and accident data. Three-year data would eliminate the chance occurrence of abnormally high or low volume or accident values which occasionally characterize one-year data.

2. Consider eliminating those locations with fewer than five accidents, as recommended by Renshaw and Carter (1980),[1] as these are not likely to be intersections of significant hazard.

3. Consider various alternatives for measuring congestion - using turning movements[2] or based on individual roadway sections. New measures of defining congestion, such as those based on delay, are continually being developed. These may be more appropriate to apply at intersections. If the volume-to-capacity ratio measure is maintained, turning movements should be incorporated into the analysis. Since turning movements are rarely collected on a systemwide basis, this recommendation may mean that a smaller sample size is necessary. In addition, it may be more accurate to analyze individual roadway sections, or intersection approaches. Each intersection would, therefore, be broken into its constituent approaches. Volume-to-capacity ratio would be analyzed against total accidents (and accident rate) for each approach, rather than for each intersection as an aggregation of approaches.

In addition to these data items, there are more fundmental options that should be considered, including:

1. Introduce other variables into the analysis (e.g., density of road development, signalization, etc.) to help explain more of the variation in accident occurrence. This has led to greater success in explaining the variance in accident occurrence in other studies.

2. Look more closely at developing variables that are directly, or indirectly, related to traffic volume. Congestion, for example, could be measured in terms of the sum of conflicting movements

(straight through plus opposing left turn). This would use the strength of relationship between volume and accidents in the prediction of accidents.

3. Stratify the analysis by various traffic categories, such as functional classification, area type, volume group, pavement width, etc. Although volume-to-capacity (V/C) ratio may not be closely related to accidents on a systemwide basis, it may be a more significant explanatory variable on a more refined level. For example, V/C ratio may be more closely related to accidents for those facilities with volumes ranging from 15,000-25,000 vehicles per day.

Improvements in Theory

The research on accident prediction model building will continue, but there is a large gap in the literature and practice with respect to how these models should be used and, more generally, how accident deficiencies ought to be treated in the long range planning process. There needs to be considerable attention paid to the development of a conceptual framework within which long range planning can aid in the identification and treatment of traffic safety hazards. This would allow for the development of plans and policies that specifically address accident deficiencies. As it stands now, many long range plans are tailored toward the expansion of the transportation system by adding more capacity. This approach is a direct result of the traditional long range planning process, which is aimed at identifying and addressing congestion problems. Funding policies and implementation programs (i.e., Transportation Improvement

Program) are heavily slanted on the side of providing additional capacity, presumably along those facilities identified on the long range plan. The way to get more money spent on safety improvements has to be based on fundamental improvements in the methods of identifying accident prone locations and in the characterization of these locations in the long range plan.

Summary

This thesis has shown that it is not reasonable to assume a close association between congestion and accidents in the development of long range plans and policies. A more acceptable approach is to consider accident deficiencies in a direct and specific manner. This will require an effort on the part of transportation planners and engineers to develop better models to predict accidents. In addition, a substantial improvement in clarifying the way that accident deficiencies should be characterized and addressed in the long range planning process is needed. Only with these two parallel developments will the objective of providing a safer transportation system be adequately met.

Footnotes: Part Five

[1]David L. Renshaw and Everett C. Carter, "Identification of High-Hazard Locations in the Baltimore County Road-Rating Project," in Traffic Accident Analysis and Application of Systems Safety, Transportation Research Record 753, (Washington, D.C.: Transportation Research Board, 1980), p. 3.

[2]The PLANPAC traffic assignment program PRINTLD, for example, produces turning movements at network intersections.

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