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FINAL REPORT

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16. Abstract

This study was directed to the comparison of several approaches to estimating exposure which can be used in evaluating the relative safety of different parts of the highway system (e.g., urban vs. rural), specific subsets of system users (e.g., trucks) or specific corridors and their specific utility in estimating relative or absolute exposure for trucks. The focus of the study is confined to estimates of truck travel for roadway segments as opposed to specific locations. Of primary interest were comparisons among survey-based, traditional vehicle-counting, and indirect methods (i.e., quasi-induced exposure). It was found that none of the three techniques currently provides all data required by different users, although vehicle-counting procedures hold the most promise if more disaggregated data are collected. Quasi-induced procedures are adequate in specific instances.

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1.0 INTRODUCTION

The indicators of highway safety most frequently used by practitioners and researchers are either measures of accident frequencies or accident rates. Although useful in certain situations, the problem with using frequencies is the lack of consideration of the opportunity for accidents to occur--there is no recognition that higher traffic volume alone may lead to a difference in the frequency of accidents. Accident rates, on the other hand, include a measure of the opportunity of an accident occurring. The base accident frequencies are essentially normalized by a measure of opportunity, or exposure to the risk, of an accident. While numerous measures of exposure have been investigated, the most universally accepted is vehicle miles of travel for roadway segments and "occurrences" for specific roadway locations. The validity of accident rates as a basis of comparison is, of course, based on the ability to accurately determine the measure of exposure.

This study was directed to the comparison of several approaches to estimating exposure which can be used in evaluating the relative safety of different parts of the highway system (e.g., urban vs. rural, interstate vs. state-numbered routes), specific subsets of system users (e.g., trucks), or specific corridors. The focus of the study is confined to estimates of travel for roadway segments as opposed to specific locations. Of primary interest are comparisons among survey-based, traditional vehicle-counting, and indirect methods (i.e., quasi-induced exposure) for estimating exposure of trucks (versus passenger vehicles). The project was funded by the Michigan Department of Transportation (MDOT) and the Great Lakes Center for Truck and Transit Research.

2.0 LITERATURE REVIEW

In reviewing the literature, the initial focus is on techniques used to estimate vehicle miles of travel (VMT) and, specifically, that portion of the VMT that is attributable to trucks. In addition, quasi-induced exposure and case-control methods of examining accident involvement rates are evaluated.

2.1 ESTIMATION OF TRUCK VMT USING TRAFFIC COUNT DATA

One of the most common methods of estimating VMT is to count vehicles at selected sites and to assume that the observed traffic is characteristic of some length of roadway upstream and downstream from the site or of some category of roads. If counts are available at several sites along a roadway, data from sequential sites can be interpolated to provide an estimate of volumes between the observation sites. Two typical procedures are reviewed below, and MDOT's procedure is discussed in a later section.

<u>Individual Road Segments</u>

In a study done by the University of California (1), VMT was used as a measure of exposure in determining accident involvement rates of trucks and buses in California. To estimate VMT, short term traffic counts were conducted at a large number of locations, with a few sites counted continuously. Using the continuous count data, the spot studies were calibrated for seasonal influence; hourly, daily, and weekly variation; and other relevant variables. The system-wide truck VMT was then estimated by multiplying specific volume counts by the length of the road segments for which they were assumed to be characteristic. The basic equation used to estimate the annual truck VMT for a specific roadway segment is given by:

$$VMT = t \times (MP_{i+1} - MP_i)[(V(2)_i + V(1)_{i+1})/2] \times 365$$

where: t = proportion of trucks;
$V(1)_{i+1}$ = adjusted 24-hour volume counts in "ahead" leg of count location;
$V(2)_i$ = adjusted 24-hour volume counts in "back" leg of count location;

$MP_{i+1}-MP_i$ = mileage between locations; and
$[(V(2)_i+V(1)_{i+1})/2]$ = average daily traffic.

Summing over all roadway segments yielded a system-wide estimate. This report did not provide information on the magnitude of errors associated with the calibration process on the number of short term counts used to estimate VMT. It seems clear that the accuracy of the estimate of VMT will increase with an increasing number of continuous count stations and also as distances between sample counts become shorter. These issues would need to be known before the accuracy of this technique for determining exposure could be evaluated. A more detailed description of the use of traffic count data was given during the "Symposium on Commercial Truck Exposure Estimates" in 1979. Here, Philipson explained how commercial vehicle exposure is estimated by two general procedures used by the California Department of Transportation. In the first procedure, 6-hour volume counts are conducted, and visual observations are made of the different categories of trucks. These 6-hour volume counts are then adjusted on the basis of experience for trends in traffic volume and certain vehicle classes and, subsequently, expanded to 24 hours.

In the second procedure, truck volume counts are performed at weigh stations for three different 8-hour periods with the periods combined to cover a 24-hour period. Linear expansion coefficients were defined for each weight class as ratios of the 24-hour truck volume counts to the aggregation of 8-hour truck weight study data for that weight class. Similar to the above, VMT is estimated using the volume counts at two weigh stations and the distance between them. Once again, no estimates of the accuracy of these procedures was presented in the reports.

System Estimates

On a national level, the Federal Highway Administration (FHWA) has developed the Highway Performance Monitoring System (HPMS) which is a data collection effort directed to providing statistics on the performance and usage of highways. Typically, a state has between 30 and 50 continuous traffic counting stations distributed over the US- and state-numbered network. In addition, one-day counts are conducted on additional selected road sections. Vehicle classification counts are used to calculate the "average number of axles per vehicle," called the "axle correction factor," and to obtain percentages of each vehicle type in a given stratum (a volume group within a functional system and an area type). To expand sample data to represent the entire stratum, an expansion factor is used. This factor is the ratio of the total vehicle mileage in a stratum to the total sampled vehicle mileage in that stratum. The total daily VMT of given sample sections in a given stratum is calculated by summing the products of the estimated number of vehicles in that stratum and the length of that road section or a percentage of all road sections in that stratum.

Although HPMS focuses on the use of individual road sections, it does provide information on the amount of travel by vehicle type. Thirteen vehicle types, based on FHWA's classification scheme, are included. The use of continuous and short term counts, as well as the basic equation of multiplying the traffic volume by the distance between counts, is common. However, compared to the California report, the HPMS procedure is much more explicit on the use of expansion factors. Specifically, procedures for adjustment, such as the modification of axle counts to volume counts, is given. Once again, however, there is no estimate of the error provided in the report.

Sample Size Determination

Other issues of concern in estimating exposure include accuracy and sample size--the determination of how much data to collect. This has been addressed by several investigators. In the *Guide For Estimating Urban Vehicle Classification and Occupancy* (2) a technique for obtaining statistically valid estimates of total VMT was described which could then be factored by the proportion of trucks to estimate truck VMT. Sampling plans for regional surveys required to accurately estimate the proportion of truck travel were also described. The sample size required is a function of the variance in traffic volume and the level of accuracy desired. The referenced guide provides data on the variance (standard deviation) of trucks in the traffic stream across time periods in a day, days in a season, and seasons in a year. With this information, estimates of annual truck VMT can be obtained from short-term counts. The composite standard deviation of the proportion of trucks (ST below) must be estimated before the minimum sample size can be computed, and is defined as:

$$ST = (STL^2 + STS^2 + STW^2)^{.5}$$

where:
STL = standard deviation of proportion of trucks across link-days within a season;
STS = standard deviation of proportion of trucks across seasons; and
STW = standard deviation of proportion of trucks across time periods during the day.

The range of values for each of these standard deviations reported were 0.021 to 0.054, 0.008 to 0.022, and 0.009 for STL, STS, and STW, respectively. Recommended values of 0.040, 0.014, and 0.009 were given for the variation for a location in a day (STL), across seasons (STS), and within a day (STW), respectively. This leads to a value of 0.043 as an estimated ST. After the composite standard deviation has been estimated, the number of link-day counts (N) needed to estimate the proportion of trucks is defined as:

$$N = (Z^2 \times ST^2)/DTR^2$$

where:
Z = the normal variate for the specified level of confidence, two-tailed test; and
DTR = acceptable difference between estimated proportion of trucks and the true value.

The number of link-day counts, N, of field data needed to estimate truck miles of travel (TRMT) is then defined as:

$$N = (Z^2 \times ST^2)/((ETRMT^2 - EVMT^2) \times TR^2)$$

where:
ETRMT = acceptable relative error between estimated and true TRMT;
EVMT = acceptable relative error between estimated and true VMT; and
TR = estimated regional proportion of truck travel.

Using an example from the guide, consider an agency that wants to estimate the regional proportion of trucks within a tolerance of ±.02 with a 95% level of confidence. Assume the estimate will be developed from a short-term data collection method and cover only one season. Also, assume no previous similar survey has been conducted. Thus, the default standard deviation terms are used to estimate the composite standard deviation. These assumptions can be summarized as:

DTR = 0.02 (objective)
Z = 2.0 (objective)
STL = 0.045 (judgment, based on default values)
STS = 0 (objective)
STW = 0.009 (judgment, based on default values)

The sample size of link-day counts can then be computed as follows:

$$ST = (0.045^2 + 0^2 + 0.009^2)^{.5} = 0.046$$
$$N = (2.0^2 \times 0.046^2)/(0.02^2) = 21$$

To determine the number of link-day counts required for each stratum of the HPMS, the coefficients of variation of average annual daily traffic (AADT) for each stratum are used. The following formula were presented:

$$n = A/(1 + (1/N)(A - 1))$$

and

$$A = (Z^2(CV)^2)/(d^2)$$

where:
Z = standard normal deviate for a confidence interval,
n = required sample size ($n \geq 3$) for a stratum,
CV = AADT coefficient of variation from state's AADT data,
d = desired precision level, and
N = stratum population size (i.e. the number of road sections available for sampling in a stratum).

In the *Guide for Estimating Urban Vehicle Classification and Occupancy* (2), limited field surveys are recommended to estimate vehicle classification. Likewise, HPMS provides for a breakdown by classification of vehicle types. With these data collected, the classification counts can be used to complement the more extensive vehicle traffic counting programs that most agencies conduct with mechanical traffic counters.

Site Selection

Another issue related to "how much" data to collect is "where" to collect them--i.e., the selection of data collection sites. While not concerned with the collection of VMT data directly, some insight can be gained from the Federal guidelines for collecting National

Maximum Speed Limit (NMSL) compliance data (4). The purpose of NMSL monitoring (at the time) was to derive system-wide estimates of the proportion of vehicles travelling in excess of the NMSL. The monitoring program was to include samples from all major types of state highways during all or part of any 24-hour period (e.g. peak, off-peak, day, night). The highway system was stratified based on FHWA's functional classification scheme. The sample was to cover the full range of state highways having a 55 mph speed limit, with the state highways grouped according to significant similarities and differences in speed characteristics and reflecting approximate length by type. The groupings were as follows:

urban--interstates
    other freeways and expressways
    other principal arterials and minor arterial street systems

rural--interstates
    other principal arterial and minor arterial street systems
    major collectors

An adequate number of samples from each type of highway were needed for valid estimation of each statewide statistic. A significance level of 5% was required for all statistical estimates, and the individual sampling sessions were to be large enough to estimate the proportion of vehicles exceeding the NMSL at that location to within 5%. Statewide estimates for the proportion on each type of highway were also to be within 5%. Field studies were to be performed quarterly to identify statewide trends, and the number of locations were to reflect the mileage of that highway type. For HPMS data collection, a similar road classification scheme was devised. All highway systems in each rural, small urban, and individual urbanized area were included in the target population. Combining the area type and functional systems, the following eight classes were identified:

1) urban interstate and other freeway and expressway,
2) urban other principal arterials,
3) urban minor arterials,
4) urban collectors,
5) rural interstate,
6) rural other principal arterials,
7) rural minor arterials, and
8) rural collectors.

This differs somewhat from the speed monitoring classification scheme and is probably more appropriate for estimating accident rates. If representative samples of VMT are combined, estimates for these classes and for an entire system can be found.

In general, estimations of system-wide as well as corridor travel can be based on vehicle count data. However, in order to undertake corridor-level analysis, data collection schemes would have to be developed specifically for the corridor(s) in question. Otherwise, disaggregation of counts made for system-wide estimates could not provide adequate detail for the (corridor) analysis. It is clear that selected corridors could be sampled with enough regularity within the context of a system-wide counting program to provide data for both purposes. The number of corridors would, however, be limited.

2.2 ESTIMATION OF TRUCK VMT USING SURVEY DATA

In addition to the traditional count-based approach, surveys of truck use can be used to estimate truck VMT. The National Truck Trip Information Survey (NTTIS) methodology used by the University of Michigan Transportation Research Institute (UMTRI) is typical of this approach (see (5) for details).

For the NTTIS, R. L. Polk and Company provided the sampling frame, and a randomized sample of trucks was selected with the objective of estimating the number of trucks registered in the United States and detailing how they were used. Four quarterly telephone calls were made over a 12-month period to the owners of the trucks (tractors). Data such as where the truck went, what was in it, and who drove it, were gathered in detail for one day in each quarter. Based on the responses, specific routes were traced, identifying the driver, freight, and weight as the trip progressed over the sampled day. The idea is that certain changes alter the exposure (e.g. different drivers, different loading). Based on the routes driven, mileage was broken down by: day and night; location (rural, small urban, and large urban areas); and roadway classification (limited access, US, State, major artery, and "other roads"). A similar procedure was also utilized for a statewide study of truck accident rates in Michigan (6).

Hu et al. (7) reviewed several approaches to estimating truck VMT including three survey-based studies. They evaluated the methods in terms of data accuracy, data item availability, and estimation precision. These data sources included the Truck Inventory and Use Survey (TIUS), the Nationwide Truck Activity and Commodity Survey (NTACS), and NTTIS. The TIUS is conducted every five years for the years ending in 2 and 7 and uses a stratified random sample. The sample is stratified by truck body type. Specifically, they are: pickup; panel truck, van, utility vehicle, jeep and station wagon or truck chassis; small single-unit truck with gross vehicle weight rating (GVWR) less than 26,000 pounds; large single-unit truck with GVWR greater than or equal to 26,000 pounds; and, truck tractor. The NTACS, conversely, was a one-time survey and consists of a sub-sample of the sample respondents to the 1987 TIUS. The NTTIS, described above, was also a one-time data collection effort, but was implemented between 1984 and 1987 and a stratified two-stage cluster design was used. Within each of 47 states (excluding Oklahoma) and the District of Columbia, three strata were formed. These strata included straight trucks, tractor-trailer combinations, and unknown truck types. The first stage was the simple random selection of trucks from each stratum in each state while the second stage was the selection of the four sample days. Although this review (7) focussed on a national level, these sources were also examined on a state level. The statewide parameters of interest were defined as follows:

1) the number of trucks of carrier type i with GVWR greater than 10,000 pounds that travelled in state k during a certain year;
2) the total VMT travelled in state k by trucks in (1) during a particular year; and
3) the average VMT per truck of carrier type i travelled in state k during a certain year.

Four indicators were determined critical to the estimation of truck VMT for a state. These were the jurisdiction of operation (interstate vs. intrastate), the carrier type (common, contract, exempt, and private), the truck weight, and the states where travel occurred. Since no one data source collected all four indicators, none by itself could provide estimates even at a state level. To obtain accurate statewide estimates, additional questions, including a list of states where travel occurred and the amount of travel that occurred in each state, would be needed on the forms. The sample size used for NTTIS would also have to be increased.

The survey approach is reasonable for developing system-wide estimates for the entire country or for a state. Such surveys were undertaken to provide a common basis for estimating exposure over several jurisdictions or to provide additional information on exposure by specific vehicle types. The latter was the case for the survey undertaken in Michigan. However, these estimates were good only on a system-wide basis. To disaggregate the exposure estimates, considerable additional sampling would have to be undertaken. Moreover, it should be borne in mind that, for Michigan, travel by non-commercial vehicles and straight trucks was not estimated.

2.3 USE OF VEHICLE REGISTRATION AND FUEL TAX DATA FOR TRUCK VMT ESTIMATES

There are some other approaches to estimating vehicle miles of travel for different types of vehicles (especially trucks). These include using data from the International Registration Plan (IRP) and fuel taxes.

VMT Estimates Based on IRP Data

The data from the IRP were also evaluated by Hu et al. (7). The IRP provides data on payment of license fees, collected annually, to the base states on the basis of fleet mileage operated in various member states. On the registration forms, carriers provide information on the total fleet mileage, number of trucks in the fleet, vehicle type, carrier operation type (interstate vs. intrastate), individual member states and non-IRP states in which the fleet will be operating, and the percentages of their operations in IRP and non-IRP states. Based on a direct extrapolation of data from such reports, IRP data could be used to provide an estimate of all statewide level information if all states were members. However, the registration for vehicles less than 26,000 pounds is optional, causing VMTs to be somewhat under-estimated. However, the data can not be used at a finer level of disaggregation. At the end of 1988, only 39 states were members. Because Michigan is a member of IRP, an estimate of VMT traveled in the state of Michigan by vehicles of IRP member states is readily available. However, similar information is not available for vehicles with a base in non-IRP states. Therefore, none of the states currently have complete estimates of VMT based on IRP data. However, under the Intermodal Surface Transportation Efficiency Act, the Motor Carrier Act of 1991 recognizes uniform vehicle registration agreements and requires states to join the IRP by September 30, 1996.

VMT Estimates Based on Fuel Tax Reports

Yet another estimate of VMT can be based on fuel tax reports which are collected in each state on quarterly, monthly, or an annual basis. These were also described by Hu et al. (7). The total number of taxable gallons of fuel reported for travel in each state during the last period is used to calculate the appropriate fees. Since fuel taxes are based on state tax rates and vehicle mileage, to convert tax revenue data to VMTs, fuel economies (MPG) for each vehicle class must be known. Frequently, the fuel economies used cannot be verified and are outdated--in addition they are fleet-wide averages. Moreover, the data are difficult, if not impossible, to assign to different vehicle types or different portions of the system. Thus, this data source is not considered to be useful for any but the least sophisticated level of estimation. It is not addressed further in this study.

2.4 MDOT COUNT-BASED PROCEDURE FOR ESTIMATING TRUCK VMT

The method currently used by the Michigan Department of Transportation (MDOT) is one of the principal techniques to be examined in this project and is described here. MDOT has developed a procedure to monitor traffic, collect and analyze vehicle classification and truck weight data, and calculate annual average daily traffic and commercial traffic for the state trunkline system--a more-or-less traditional count-based approach.

The data collected as part of the annual Statewide Traffic Count Program is a subset of the larger Traffic Data Collection Program which also includes the HPMS program, Long-Term Pavement Performance research counts, and other special counts. These different counts may also have different required durations (e.g., peak hours only, 24-hour periods) (13).

The above comments notwithstanding, MDOT's procedure generally follows the process indicated in the *Traffic Monitoring Guide* (8) presented in Appendix K of the HPMS field manual (9). The average daily traffic (ADT) is estimated from traffic counts taken at approximately 2800 locations, in a manner which is intended to account for seasonal variation. If the count is a "hose count" (a basic axle count based on vehicle interceptions of pneumatic tubes) they are adjusted for the over-count occurring from the presence of commercial vehicles in the traffic stream. The guide proposes the following adjustment:

ADT = (count)x(seasonal factor)x(axle adjustment)

However, after review of their data, MDOT developed a variation:

ADT = (count)x(seasonal factor)-(seasonally adjusted excess passenger cars)

In obtaining data to estimate traffic, three types of traffic monitoring data are collected. These are the permanent traffic recorder (PTR), basic axle counts, and vehicle classification counts. (These are referred to as axle and classification counts, respectively, hereinafter.) There are 103 PTRs which collect vehicle volume information on a continuous basis. These are the source of seasonal and day-of-week seasonal pattern information as well as vehicle counts. Axle counts range from 24 hours to 5 days in duration (48 hour counts are recommended in the *Traffic Monitoring Guide*) and are taken between April and November each year. Generally, hose counts are taken, and the device currently used for storing the count data divides the number of axle strikes by two. Finally, classification counts keep track of the type and the number of axles of each vehicle. These counts are not continuous and are taken for different durations during different times of the year. The data are typically collected on an hour-by-hour basis, consistent with the FHWA's 13 vehicle categories. For Michigan, four kinds of classification data exist. They are the 8-hour manual, 24-hour manual, hose, and toll bridge classifications. The 8-hour manual classifications are taken in December through March at over 200 locations, include the hours 8am - 12 noon and 1pm -

5pm (not necessarily taken on the same day), and are consistent with the FHWA's vehicle classification scheme. The 24-hour manual classifications are taken quarterly at each of the state's truck weight locations and contain detailed axle breakdowns for those hours of the day that an observer can distinguish the number of axles on each vehicle. For hose classifications, counts are taken throughout the year (weather permitting), last as long as the counting system remains set, and contain detailed axle breakdowns for each hour of the counting session. Lastly, the toll classifications continuously collect data on axle breakdowns at specific locations: 1) the Blue Water Bridge which connects Port Huron and Canada, 2) the International Bridge which connects Sault Ste. Marie and Canada, and 3) the Mackinaw Bridge, connecting Mackinaw City and St. Ignace. The axle breakdowns are based on toll revenues associated with different axle configurations of vehicles and are not congruent with the FHWA scheme.

For vehicle classification and axle adjustment estimates, classification counts (at approximately 350 locations) are conducted to yield totals for different types of commercial vehicles. These classifications are: single unit trucks, trucks with single trailer combinations, and trucks with two trailers. In addition, the total number of vehicles is calculated. "Excess passenger cars," representing the extra number of vehicles that would have been registered had a hose count been taken, are also estimated and are the basis for the axle adjustment later in the traffic estimation process. For the axle adjustment, the raw classification data is first aggregated from hourly to daily totals, and the number of axles per commercial vehicle is calculated. Since the total number of trucks is known, as is the number of truck axles, the axle count that would have been obtained at that location had one been taken is "estimated." The number of excess passenger vehicles is obtained by subtracting the actual number of axles from the estimated number of axles and dividing by two. In developing seasonal factors, clusters (groupings where similar travel patterns occur) from the PTR data from 1983-87 were used. These factors are reviewed annually and adjusted for count years beginning in 1991.

The years from 1983 to 1987 provided the maximum number of patterns while minimizing the number of unusual occurrences at individual PTRs--following the clustering scheme of Ward's minimum variance method. Five clusters, including factors for weekdays, Friday, Saturday, and Sunday were found and assigned to road segments. The five clusters are as follows: the Mackinaw Bridge pattern; urban, turnbacks, and local; Upper Peninsula rural; mid-state, N-S Trunklines, Houghton south to Flint; and all other rural. These clusters are geographically based rather than on functional classification as recommended by the *Traffic Monitoring Guide*. This is due to the observed variability within a functional class in Michigan. Separate seasonal factors are also determined for commercial traffic. These are developed by examining the seasonal variations at truck weight stations where quarterly counts are taken and bridge locations where continuous classification data are taken. The seasonal factors are found to have two basic patterns--one for the interstate system and another for non-interstate trunklines. The *Traffic Monitoring Guide* recommends 10% precision with 95% confidence for each seasonal group. To sample trucks for weight, the weigh-in-motion technique is used. As suggested by *Traffic Monitoring Guide*, 90 sites are sampled for 48 hours over a 3-year period, in order to achieve a 95-10 reliability. For Michigan, it was predetermined that the locations would be as follows:

30 locations on interstate routes,
41 locations on non-interstate, trunkline routes, and
19 locations on the non-trunkline system.

The approach first uses the 300 vehicle classification sites that are distributed to each cell of the HPMS area/functional class/volume group matrix. Then, specific sites from the available vehicle classification samples from each cell are randomly selected, and permanent sensors are installed.

2.5 USE OF QUASI-INDUCED TECHNIQUES TO ESTIMATE EXPOSURE

Most exposure estimating techniques have one or more shortcomings when it is desired to estimate the exposure of some sub-group of the vehicle-driver population (e.g., small cars, older drivers) or for a specified environmental condition (e.g., rainy weather). Moreover, as implied above, most of the approaches require fairly extensive commitment of resources. Thus, other techniques have been explored. One such approach has been termed quasi-induced exposure. (See Lyles et al. (10) for additional detail.)

Briefly, this technique is based on the assumption that in two-vehicle crashes there are four possibilities for attaching the "fault" for the accident: driver-1 was at fault and driver-2 was innocent; driver-1 was innocent and driver-2 was at fault; both drivers shared in causing the accident; and both drivers were, more-or-less, innocent (e.g., adverse weather conditions, beyond the control of the drivers, caused the accident). It is the first category which is of primary interest. In this instance, the assumption is that driver-2 just happened to be involved in the accident: driver-1 randomly "chose" driver-2 from all other vehicles and drivers on the road to hit. Thus, driver-2 is termed the "innocent victim" and is assumed to represent a random sample of all drivers on the road at the time of the accident. With aggregation over appropriate time and space dimensions, the collection of driver-2s represent a measure of exposure of drivers and vehicles on the road. (Again, this is discussed in considerably more detail in reference 10.) It must be noted that this technique does not yield estimates of VMT which can be used in accident rate determination directly but rather a measure of relative accident involvement.

In the study done by Lyles et al. (10), the quasi-induced approach was reviewed and used to analyze relative accident involvement in Michigan. This method involves the calculation of the involvement ratio (IR), which determines whether a certain group of drivers are over-involved or under-involved in accident causation. The technique can be applied to different stratifications, such as cars vs. trucks on interstate highways, and, theoretically, any driver characteristic, vehicle characteristic, or combination thereof can be examined. IR is defined as the percentage of at-fault drivers in the driver group of interest divided by the percentage of that same driver group on the system. The latter is used as a relative measure of incidence and is equivalent to those categorized as innocent victims. As an example, assume males are at-fault drivers in 75% of all two-vehicle accidents and are innocent victims in 60%--the IR would equal 75/60, or 1.25. Thus, in this example male drivers are found to be overinvolved; that is, causing proportionately more accidents than their proportion on the highway system. Based only upon accident statistics, the quasi-induced method has the advantage of eliminating the reliance on traditional exposure data, such as VMT. Not only is exposure data difficult to collect but it is also often unreliable. Moreover, accident data are more readily available. The quasi-induced approach is not without disadvantages. There is concern over the consideration of one- and multi- vehicle accidents and the assignment of fault in an accident. Addressing the issue of the number of vehicles involved, the innocent victims of accidents involving two vehicles are assumed to be measures of exposure for all accidents involving one or more vehicles. This implies that the characteristics of the at-fault driver are the same for these types of accidents--which may not necessarily be true. In assigning fault for the accident, there is always potential for bias in the assignment process, the driver cited may not be the actual one responsible or even be responsible at all for the accident. Misreporting of who is at fault can occur on accident forms, although fault assignment can be validated to some extent by checking who is coded as being at fault against the hazardous action that occurred. These issues notwithstanding, Lyles et al. concluded quasi-induced estimates to be reasonably reliable and valid on at least some dimensions, but complete validation of the technique remains to be accomplished.

The question of whether the vehicle-2s represent a random sample is important. When considering accidents involving trucks, an additional issue is whether some vehicle types are simply more likely to be hit by other vehicles, all else being equal. The concerns include the facts that trucks are simply larger (and therefore more likely to be hit) and some drivers (e.g., older persons) may have problems estimating the behavior of trucks in the traffic stream. If trucks are, in fact, simply more likely to be hit (even though they were not being operated inappropriately), then their frequency as vehicle-2s would be higher than their observable frequency on the highway. This issue will be addressed further during the actual comparison of exposure techniques.

2.6 CASE-CONTROL METHOD GENERAL BACKGROUND

Another method which has been used in evaluating accidents and safety is the case-control method. Often referred to as retrospective, the case-control approach proceeds from effect to cause. It involves the comparison of subjects with a particular condition (e.g., a motorcycle involved in an accident) to a series of subjects where the condition is absent. The former are called the "cases," and the latter are called the "controls." The comparison (control) group provides an estimate of the frequency of exposure expected among subjects free of the condition and is used to support or refute an inference of a causal role for any specific factor (11). The cases and controls are compared with respect to existing and past attributes thought to be relevant to the development of the condition under study (i.e., the accident). Typically, an estimate of relative risk in terms of an odds ratio approximation is made to determine how many times more likely the condition occurs in the exposed group as compared with the unexposed group.

When examining the relative safety of trucks, the traditional mileage estimates used as measures of exposure often are hard, if not impossible, to adjust for the variation in travel patterns among different truck configurations. Truck types may also vary by length of trip, time of travel, weight of cargo, and driver characteristics as mentioned above. So, in order to adjust for differences in exposure, the case-control method was used in a crash involvement study of large trucks by configuration (12).

Conducted over a two-year period, this study investigated large truck crashes on the interstate system in Washington State. For each large truck involved in an accident, three trucks were randomly selected for inspection from the traffic stream at the same time and place as the crash but one week later. Thus, there was a match for roadway, time of day, and day of week between the case sample of crash-involved trucks and the control sample. The only criterion used for the selection of the control sample trucks was that they had to have a gross vehicle weight rating of 10,000 pounds or more. Finally, the effects of truck and driver characteristics on crashes were assessed by comparing their relative frequency among the crash-involved and comparison sample trucks. In total, the study analyzed 676 crashes involving 734 large trucks.

In determining whether particular factors were overinvolved in the crash vehicles, contingency tables were constructed using the crash and comparison samples. Involvement ratios were calculated by dividing the percentage of trucks with that particular characteristic in the crash group by the percentage of trucks with the same characteristics in the control group. If the involvement ratio was greater than 1.0, that particular factor was overinvolved in the crash sample. On the other hand, the factor was considered to be underinvolved in the crash sample if the involvement ratio was less than 1.0.

In this specific type of case-control study, it was only possible to compute relative involvements, which cannot be converted into accident rates. Therefore, the results cannot be directly compared to other studies' findings of crash involvement rates on a VMT basis. In addition, if one value of a variable (e.g., a particular truck configuration) is overrepresented in the crash sample, some other values of the same variable must be underrepresented. So, for example, the involvements are relative to the overall involvement of large trucks in crashes on the interstate system. Therefore, the results from this study cannot be compared directly with the crash involvement rates of other vehicles either. It should be noted that these problems are also shared with the quasi-induced approach.

Further problems with the case-control approach include the inability to generalize the site-based results to system-wide estimates and the lack of consideration of non-accident sites. In order to generalize the results to a system-wide basis, there must be some sort of multiplication of site results to the system level. For example, if an accident occurs at a curve, how representative of the system is that particular curve and/or how many curves are there on the system. The lack of inclusion of non-accident sites may bias the determination of how serious, say, a specific geometric condition really is in contributing to accidents.

However, the approach may provide some reasonable insight to the contribution of vehicle-related problems to the occurrence of accidents. For example, an assessment of the incidence of a vehicle defect or problem (e.g., front tractor brakes being disconnected) which contributes to an accident.

2.7 DISCUSSION AND SUMMARY

Several methods for estimating vehicle exposure to accidents have been addressed above. They include traditional procedures for estimating vehicle miles of travel based on counting vehicles (and axles), other VMT-estimating methods such as surveys, the quasi-induced technique, and case-control studies. The advantages and disadvantages of each method are summarized below.

Traditional Counting Methods

- technique is well-established and reasonably defensible from an accuracy perspective at an aggregate level
- availability of more sophisticated counting equipment will eventually allow for calculation of VMT disaggregated by vehicle type
- estimates are typically compatible with those developed in other jurisdictions (e.g., state to state)
- consumes considerable resources although some of the fixed resources (e.g., counters) are replaced only periodically
- without investment in even more resources, estimates are difficult (or impossible) to obtain for specific corridors without advance designation of corridors for extra attention
- without investment in resources, estimates are difficult (or impossible) to obtain for disaggregation by environmental variables such as time of day or ambient weather
- non-trunkline estimates are not readily obtainable (only because of limited data collection)
- estimates cannot be disaggregated by other than vehicle type variables (e.g., VMT cannot be disaggregated by driver age or sex)

Survey-Based Methods

- estimates are potentially compatible with traditional counting methods (this assumes that the same vehicle categories and system parameters are defined)
- consumes considerable, and reasonably specialized, human resources
- detailed disaggregation (e.g., vehicle types, other driver/vehicle characteristics such as age, environmental factors) is possible albeit typically with increased resource consumption
- accuracy of estimation depends on truthfulness of respondents and their ability to remember and accurately relate vehicle trip details
- there should be a definitive comparison between survey and vehicle-counting approaches (this was impossible in the context of this study because of differences in vehicle type definition)

Other Methods Used to Estimate VMT Directly

- methods such as using gas tax receipts are good only at the grossest levels of aggregation--i.e., system-wide--and are not useful for any disaggregation by vehicle type or system component (e.g., interstates)
- there is dependence on gross estimates by respondents of in-state vehicle mileage for registered trucks
- other measures of exposure such as vehicle registrations (as in accidents per 1,000 registered vehicles) make no allowances for the environment in which the vehicles are used or the miles driven

Quasi-Induced Exposure

- disaggregation of estimates by many driver, vehicle, roadway, and environmental characteristics is theoretically possible
- as long as accident data are available, it does not require additional data collection which results in low resource consumption
- exposure estimate is relative, not absolute, which makes comparison to other techniques difficult
- sample size quickly becomes prohibitively small when many disaggregations are considered (thus, for example, single corridor studies tend to be unreliable)
- methodology makes an assumption of the validity of fault determination using field-reported driver violations and contributing circumstances
- methodology is not widely accepted (although use is increasing)
- validity of method needs to be conclusively demonstrated and standard procedures for use need to be developed

Case-Control Method

- requires extensive use of resources in selecting subject vehicles to be examined
- site-based findings are not readily expandable (generalizable) to system-wide conclusions
- it is extremely difficult or impossible to disaggregate findings for other driver, vehicle, or environmental factors
- results are not easily compared to those of any other method

Based on the foregoing, in the next section three techniques are compared to one another for the state of Michigan. The survey method (using data from *The Michigan Heavy Truck Study*) is compared to the quasi-induced exposure approach and two variations of MDOT's count-based approaches are compared to the quasi-induced approach. Because of their inability to be used to give reasonable system-wide results, the case-control and fuel tax/registration approaches are not considered further.

3.0 ANALYSIS AND COMPARISON OF ALTERNATIVE METHODS FOR ESTIMATING EXPOSURE

The basic purpose of this project was to compare several different methods for estimating exposure differentiated by vehicle type. The three methods to be compared include VMT estimates based on output from automatic data collection devices, VMT estimates based on operator surveys, and indirect estimates of exposure derived from accident records (quasi-induced exposure). Each of these methods, and how it has been used in Michigan, has been discussed in some detail in the previous section. In this section, actual estimates of VMT differentiated by vehicle type are presented and compared.

3.1 PROBLEMS WITH COMPARISONS BETWEEN METHODS

There were two principal problems encountered in comparing the three methods using Michigan data:

1. The comparisons among methods can only be made on a relative basis, there is no absolute comparison with "truth." That is, the actual exposure of different vehicle types is not known with certainty.
2. The estimates from the various methods are not consistent with one another. This occurs, in part, because the estimates examined were not always made explicitly for this study. For example, UMTRI's estimates were made for truck tractors (bobtails) and tractor-trailer combinations (singles and doubles) and disaggregated in accordance with the needs of *The Michigan Heavy Truck Study*. Thus, there is no consideration of the exposure of straight trucks. MDOT's typical exposure estimates, on the other hand, are provided for non-commercial and commercial vehicles. The latter category includes both straight and combination trucks. Thus, while comparisons can be made between quasi-induced estimates and either MDOT or UMTRI estimates, MDOT and UMTRI estimates cannot be compared with one another.

These problems notwithstanding, there are several interesting comparisons that can be made. The analysis done in this project is divided into three parts:

1. The estimates of VMT for bobtails, singles, and doubles provided by UMTRI in the joint MSU/UMTRI report, *The Michigan Heavy Truck Study*, are compared with quasi-induced estimates derived from accident records. This is done for various stratifications of roadway and environmental conditions.
2. MDOT estimates for commercial and non-commercial VMT are compared with quasi-induced estimates for various stratifications of roadway and the environment.
3. MDOT traffic count data (differentiated by several vehicle types) are developed into

VMT estimates for selected highway corridors and compared to quasi-induced estimates for the same corridors.

3.2 DEVELOPMENT OF QUASI-INDUCED ESTIMATES

Before proceeding with the several comparisons, the basic differences between the quasi-induced approach and other procedures need to be reiterated. Survey- and count-based procedures provide direct estimates of VMT which can be used, for example, in calculating an accident rate (i.e., [number of accidents] divided by [vehicle-miles of travel]). However, quasi-induced methods provide only relative measures of the over- or under-involvement of one driver or vehicle type in accidents and not a conventional rate *per se*. Thus, the comparison between these two types of exposure estimates requires consideration of the proportional distribution of VMT and not actual VMT estimates.

As indicated in the literature review, quasi-induced exposure estimates are based on the assumption that the not-at-fault vehicles (termed vehicle-2 here) in two-vehicle accidents constitute a random sample of the vehicles on the roadway at any given point in time. If this assumption is true, then the distribution of vehicle-2s provides an estimate of the vehicle mix on the roadway. For example, if the distribution of vehicle-2s by type for all two-vehicle accidents on all roadways in Michigan is determined, this is a system-wide estimate of the relative distribution of travel by vehicle type. More importantly, this distribution by vehicle type should be directly comparable to any other estimate of the system-wide distribution of exposure (i.e., VMT estimated through traffic counts or surveys).

Based on the above, what will be compared is the distribution of exposure by vehicle type, stratified by selected roadway and environmental characteristics. For the quasi-induced technique, the distribution of vehicle-2s is of primary interest.

In order to reduce the error that is introduced into quasi-induced estimates, the accident data are "cleaned" so that the random-selection assumption inherent in the approach is more likely to be satisfied. Operationally, this means that only those accidents where "fault" is clearly determined are used. For example, only those accidents where the driver of vehicle-1 is "at fault" and the driver of vehicle-2 is "not at fault" are used. This determination is made through consideration of which drivers were cited for a traffic violation and the contributing circumstances of the accident. This means, for example, that accidents where both drivers were cited (driver-1 ran a stop sign and driver-2 was speeding) were eliminated. Similarly, any accident involving a driver "under the influence" (either driver-1 or driver-2) was eliminated.

As an aside, it should be noted that this approach to determining which driver is "at fault" and which driver is "not at fault" is independent of the designation (on an accident report form) of which driver is "driver 1." Thus, the quasi-induced technique is useful as long as driver violations and hazardous actions are noted on the accident record. It should also be noted that comparisons such as those to be conducted here have been suggested as necessary steps in the validation of the quasi-induced approach (see e.g., 14)

3.3 COMPARISON OF QUASI-INDUCED- AND SURVEY-BASED ESTIMATES OF EXPOSURE

The exposure estimates based on the survey method are taken directly from *The Michigan Heavy Truck Study* (table E-1 in that report) as provided by UMTRI. The procedures for arriving at these estimates are generally described in the literature review presented earlier and in more detail in the report just noted. UMTRI's survey estimates are for a single, specific "study year" lasting from May, 1987 to April, 1988. The travel estimates are disaggregated according to the following characteristics:

truck types: bobtails (tractors operating without trailers), singles (tractor and single trailer combination), and doubles (tractors and double trailer combinations);

roadway types: limited access (limited-access highways), major artery (principal and other through highways and other four-lane divided highways not included in the limited access category), and other (all other streets and roads); and

day/night: day (6:00 AM-9:00 PM) and night (9:00 PM-6:00 AM).

The quasi-induced estimates are based on a consideration of the accidents involving the same truck types over the same time period. The truck accidents reported in the MSU/UMTRI study were further analyzed in order to "clean" the data as noted above (i.e., to ensure, to the extent possible, that driver-1 was at-fault and driver-2 represents a random sample of vehicles on the roadway). The comparable sets of numbers are presented in table 1.

Table 1. Estimates of survey-VMT and accidents by vehicle type

	survey-VMT[1]			accidents[2]		
MSU/UMTRI classification	bobtail	single	double	bobtail	single	double
rural/day/limited	2.10	204.43	23.16	1	105	13
rural/day/major	2.10	128.65	15.04	5	205	18
rural/day/other	0.26	31.77	3.21	12	144	23
rural/night/limited	0.24	41.95	9.47	2	20	3
rural/night/major	0.07	17.64	2.40	2	27	5
rural/night/other	0.06	1.29	0.22	0	6	0
urban/day/limited	2.63	177.25	21.16	12	149	9
urban/day/major	0.93	59.82	5.53	7	119	8
urban/day/other	1.44	59.73	4.95	15	221	17
urban/night/limited	0.37	29.88	3.47	0	14	1
urban/night/major	0.07	6.84	0.46	0	14	2
urban/night/other	0.09	3.78	0.34	2	14	4
TOTALS	**10.36**	**763.03**	**89.41**	**58**	**1038**	**103**

[1] VMT measured in 10^6 miles (from **The Michigan Heavy Truck Study**)
[2] accidents with vehicle-2 a truck and fault clearly assigned

In table 2, the numbers from table 1 are expressed in terms of percentages--the estimates of proportional distributions of exposure by vehicle type under different roadway and environmental conditions. For example, in the first row under VMT distribution, the total mileage from the first row of table 1 is summed for a given classification (2.1+204.43+23.16= 229.69) and then the percentages by each vehicle type are calculated (e.g., for bobtails, 2.1/229.69=.01) and shown in table 2. A similar calculation is performed for accidents (for bobtails, 1+105+13=119; 1/119=.01). The note (^{3}) indicates which accident groups had a sample size >100. This is done since small sample sizes tend to create

Table 2. Comparison of survey-based and quasi-induced estimates

MSU/UMTRI classification	survey-VMT distribution			Q-I distribution		
	bobtail	single	double	bobtail	single	double
rural/day/limited	0.01[1]	0.90	0.10	0.01[2]	0.88	0.11[3]
rural/day/major	0.01	0.88	0.10	0.02	0.90	0.08[3]
rural/day/other	0.01	0.90	0.09	0.07	0.80	0.13[3]
rural/night/limited	0.00	0.81	0.18	0.08	0.80	0.12
rural/night/major	0.00	0.88	0.12	0.06	0.79	0.15
rural/night/other	0.04	0.82	0.14	0.00	1.00	0.00
urban/day/limited	0.01	0.88	0.11	0.07	0.88	0.05[3]
urban/day/major	0.01	0.90	0.08	0.05	0.88	0.07[3]
urban/day/other	0.02	0.90	0.07	0.06	0.87	0.07[3]
urban/night/limited	0.01	0.89	0.10	0.00	0.93	0.07
urban/night/major	0.01	0.93	0.06	0.00	0.88	0.13
urban/night/other	0.02	0.90	0.08	0.01	0.70	0.20
aggregations						
rural/day/ALL	0.01	0.89	0.10	0.03	0.86	0.10[3]
rural/night/ALL	0.01	0.83	0.16	0.06	0.82	0.12
rural/ALL	0.01	0.88	0.11	0.04	0.86	0.10[3]
urban/day/ALL	0.01	0.89	0.09	0.06	0.88	0.06[3]
urban/night/ALL	0.01	0.89	0.09	0.04	0.82	0.14
urban/ALL	0.01	0.89	0.09	0.06	0.87	0.07[3]
DAY/ALL	0.01	0.89	0.10	0.05	0.87	0.08[3]
NIGHT/ALL	0.01	0.85	0.14	0.05	0.82	0.13[3]
LIMITED/DAY	0.01	0.89	0.10	0.04	0.88	0.08[3]
LIMITED/NIGHT	0.01	0.84	0.15	0.05	0.85	0.10
MAJOR/DAY	0.01	0.89	0.10	0.03	0.89	0.07[3]
MAJOR/NIGHT	0.01	0.89	0.10	0.04	0.82	0.14
OTHER/DAY	0.02	0.90	0.08	0.06	0.84	0.09
OTHER/NIGHT	0.03	0.88	0.10	0.08	0.77	0.15
TOTAL	0.01	0.89	0.10	0.05	0.87	0.09[3]

[1] number shown is percentage of total truck travel by specific truck type (see text)

[2] number shown is percentage of total truck accidents as vehicle-2

[3] number of accidents >100 for row

volatile shifts in accident distribution percentages with the addition or deletion of only a few accidents. That is, one can be more confident of the percentages which are noted (^{3}).

In the top part of table 2, the distributions are shown for individual classifications (e.g., rural/day/limited). In the bottom part of the table, the data are aggregated over one or more of the possible dimensions (e.g., rural/day/all indicates that the data are aggregated over all roadway types in rural areas for daytime accidents).

Before interpreting table 2, it is important to note that comparisons between different exposure estimating approaches must be made *within* rather than between "environments." For example, do both the quasi-induced and survey approaches estimate similar proportions of bobtails, singles, and doubles using the rural, limited-access highway system during the day? This is as opposed to making comparisons between the approaches for estimating the proportions of vehicle types *between* urban and rural portions of the system.

Comparisons of the adjacent rows indicates reasonable similarity between the distributions. In the top half of the table, the maximum difference between the row distributions (with more than 100 accidents) is 10%, with all except one case 6% or less. For example, considering the rural/day/other row (the worst case): the comparison of singles shows that the survey-VMT estimate is 90% of the truck VMT is by singles (1% by bobtail, 9% by doubles) while the quasi-induced estimate is 80% singles traffic (7% by bobtail, 13% by doubles). There is considerably more variation between the two methods where the sample sizes are small. When the data are aggregated across different dimensions (in the bottom half of table 2), greater similarity is noted between the estimates with no differences greater than 5% when there were >100 accidents in a row.

This comparison generally shows that there is reasonably good agreement between the two methods for estimating the proportional distribution of "exposure" by vehicle type. It should be noted however, that there is very little row-to-row variation in the estimates. That is, for the survey method, bobtails account for 1-2% of total VMT regardless of the type of road and other characteristics, while singles account for 80-90% of the truck traffic with the doubles' percentage ranging from 6 to 18%. For the quasi-induced approach (and considering only those rows where the sample size is >100), the singles' estimate ranges from 82 to 90%, while the doubles' estimate ranges from 5 to 14%. The difference being made up in the proportion of bobtails which is typically higher than that obtained from the survey approach. The survey proportions seem logical in that doubles generally account for a higher percentage of the vehicle miles on limited versus major highways. However, this intuitive trend is not so apparent when the quasi-induced estimates are reviewed.

Notwithstanding the differences noted, based on the data from *The Michigan Heavy Truck Study*, the quasi-induced procedure produces results similar to those derived from the survey. Moreover, the differences are generally reasonable with the quasi-induced approach providing estimates which are, fairly consistently, slightly higher for singles, somewhat lower for doubles, and almost always higher for bobtails.

In summary, the results in table 2 indicate the following:

* the quasi-induced exposure approach detects differences in truck distributions for different portions of the highway system (e.g., limited versus major roadways) where sample sizes are adequate <u>and</u> these differences are reasonably consistent with those predicted by the survey-based approach;

* the quasi-induced exposure approach detects differences in the truck distributions for different highway environments (i.e., urban versus rural, day versus night) <u>and</u> these differences are roughly consistent with those predicted by the survey-based approach; and

* the quasi-induced exposure estimates are different for different types of trucks <u>and</u> the differences detected are consistent with those noted for the survey-based estimates although there were differences of up to 10%.

These results indicate that, generally speaking, the quasi-induced exposure approach performs reasonably well when compared to the survey-based approach. However, the reliability of the quasi-induced estimates is clearly linked to sample size. For the data examined, this was especially apparent for the proportion of bobtails (see table 2) which was more likely to have somewhat larger variations.

3.4 COMPARISON OF QUASI-INDUCED- AND COUNT-BASED ESTIMATES OF EXPOSURE

The second comparison was between quasi-induced estimates and those obtained from vehicle counts. The comparison here was for different stratifications of vehicles than those just used since the MDOT classifications are different from those used in *The Michigan Heavy Truck Study*. MDOT basically classifies vehicles (for their statewide VMT estimates) as either commercial or non-commercial and can provide roadway-section-by-roadway-section estimates of VMT. These sections can then be aggregated by roadway type (e.g., interstate, M-numbered route) and other variables contained in their (MDOT's) sufficiency file. Finally, these MDOT classifications can be "matched" with estimates using the quasi-induced technique. Again, the basis for comparison is the proportional distribution of commercial versus non-commercial vehicles for whatever roadway and environmental stratifications are specified. MDOT provided VMT summaries for 1989, 1990, and 1991, stratified for the following variables (MDOT sufficiency file parameters):

vehicle types: commercial and non-commercial;

roadway classification: interstate, US, M, interstate business loop (BL) and business route (BR), US-BR, M-BR, connectors, and service drives (note that these were aggregated to interstate, US, M, and other routes); and

rural/urban: rural (state population code of ≤5,000) and urban (state population code of >5,000).

Note that a limited-access versus non-limited-access differentiation was originally to be used but was deleted from consideration. Crosstabulations of this dichotomy with roadway classification showed some inconsistencies in the MDOT accident data base--i.e., there appeared to be an abnormally high number of accidents for non-limited access highways which were designated as interstates (a contradiction in terms). Since the interstate notation is considered to be reliable, the limited access designation was eliminated from further consideration. In table 3, typical data from 1989 are shown to illustrate the raw data that were used and how the relative exposure of commercial vehicles was calculated. For the count-based estimate, the calculation was straightforward: commercial-vehicle VMT is divided by all-vehicle VMT to yield the proportion of travel (exposure) attributable to commercial vehicles. A similar calculation is made to yield the quasi-induced estimate--i.e., the number of accidents involving commercial vehicles as vehicle-2 is divided by the total number of two-vehicle accidents. The two estimates of the relative exposure of commercial vehicles can then be compared: the quasi-induced technique provides an estimate of approximately 13% commercial vehicles on rural interstate highways while the count-based estimate is 15%. Similarly, the quasi-induced estimate for commercial vehicles on US-numbered highways is 6% while the comparable count-based estimate is 8%. For Michigan-numbered highways, the estimates are 3% and 5%. For all rural highways, the quasi-induced estimate is 5% while the count-based estimate is 9%. As can be noted, the quasi-induced estimates are somewhat lower (two-four percentage points) than the count-based estimates in all cases.

Table 3. Typical basis for estimates of relative exposure of commercial vehicles based on accidents and VMT counts for rural highways (1989)

road class	all accs[1]	comm accs	Q-I com%[2]	all VMT[3]	comm VMT	VMT com%[4]
interstate	2673	357	0.13	14940186	2308228	0.15
US-numbered	6150	358	0.06	14424479	1151222	0.08
MI-numbered	14755	500	0.03	19432661	1005457	0.05
Total[5]	25172	1252	0.05	49306016	4485603	0.09

[1] all "clean" 2-vehicle accidents
[2] % of all 2-vehicle accidents where vehicle-2 is commercial--the quasi-induced (Q-I) estimate of relative exposure
[3] total daily VMT (provided by MDOT)
[4] % of daily VMT by commercial vehicles--the relative exposure based on vehicle counts
[5] totals include other minor categories in addition to those shown

Summaries of comparisons of quasi-induced estimates of relative exposure and VMT-based estimates of the same quantity for all rural highways for three years--1989, 1990, and 1991 are shown in the top (rural) part of table 4. Examination of the estimates in this portion of table 4 shows the following:

1. The quasi-induced estimates are reasonably consistent across all three years. Year-to-year variation is minimal although the interstate proportion decreases by one percentage point each year.
2. The quasi-induced estimates are always somewhat lower than the count-based estimates although the year-to-year differential between the two estimates are very similar.
3. The count-based estimates are also reasonably consistent across all three years. The year-to-year variation is never greater than one percentage point.
4. The variation in estimates between roadway types is similar for both the quasi-induced and count-based approaches--e.g., the estimate of the percentage of commercial vehicles on interstate highways is on the order of two times the percentage on US-numbered routes for both methods.

Table 4. Comparison of count-based and quasi-induced exposure estimates for commercial vehicles for urban and rural highways for three years (1989, 1990, 1991)

roadway class	total-1989		total-1990		total-1991	
RURAL ROADS	Q-I	count-VMT	Q-I	count-VMT	Q-I	count-VMT
interstate	0.13	0.15	0.12	0.16	0.11	0.16
US-numbered	0.06	0.08	0.05	0.09	0.05	0.09
M-numbered	0.03	0.05	0.03	0.05	0.03	0.05
Total	0.05	0.09	0.04	0.09	0.04	0.10
URBAN ROADS						
interstate	0.08	0.08	0.06	0.09	0.07	0.08
US-numbered	0.03	0.04	0.03	0.04	0.02	0.04
M-numbered	0.02	0.03	0.02	0.03	0.02	0.03
Total	0.03	0.06	0.03	0.06	0.03	0.06

The bottom part of table 4 is the same as the top only the multi-year comparison is for all urban highways. The relationships between the two sets of exposure estimates for urban highways are very similar to those just noted for rural roads. The question arises as to whether the percentage of commercial traffic is simply so small that the similarities are due to chance. A comparison of the two parts of table 4 (urban and rural) shows, most notably, the differences in the estimates between the two parts (urban and rural) of the table and the consistency between the two methods. For example, both the quasi-induced and count-based estimates for commercial traffic on rural interstate highways are higher than their counterparts for urban highways. In general, all of the estimates for rural roads are consistently higher than for urban roads--there is a higher proportion of commercial vehicle travel on rural roads and the two estimating methods are consistent in this regard.

In summary, the estimates just presented indicate the following with respect to the estimate of relative commercial vehicle exposure:

- the quasi-induced exposure estimates are consistent over time (year-to-year) and are as consistent as the count-based estimates;
- the quasi-induced exposure estimates are different for different portions of the highway system (e.g., interstate versus US-numbered roadways) and the differences detected are consistent with those noted for count-based estimates;
- the quasi-induced exposure estimates are different for different highway environments (i.e., urban versus rural highways) and the differences detected are consistent with those noted for count-based estimates; and
- the quasi-induced estimates are consistently slightly lower than the count-based estimates for all roadway types.

These findings are generally supportive of using quasi-induced exposure to determine relative accident rates. However, it should be pointed out that while the estimates are within a few percentage points of one another in virtually all instances, the overall estimates of proportional commercial vehicle exposure is about half of that predicted by the count-based approach for non-interstate highways and for the system total. This is primarily due to the relatively low numbers and percentages of such vehicles that are present in the traffic stream and is not indicative of bias which renders the technique unusable. That is, the difference in the magnitude of percentages (e.g., 6% versus 4%) is more indicative of the error than the ratio of the estimates (e.g., 6% is 50% greater than 4%).

3.5 COMPARISON OF QUASI-INDUCED- AND COUNT-BASED ESTIMATES OF EXPOSURE FOR SPECIFIC CORRIDORS

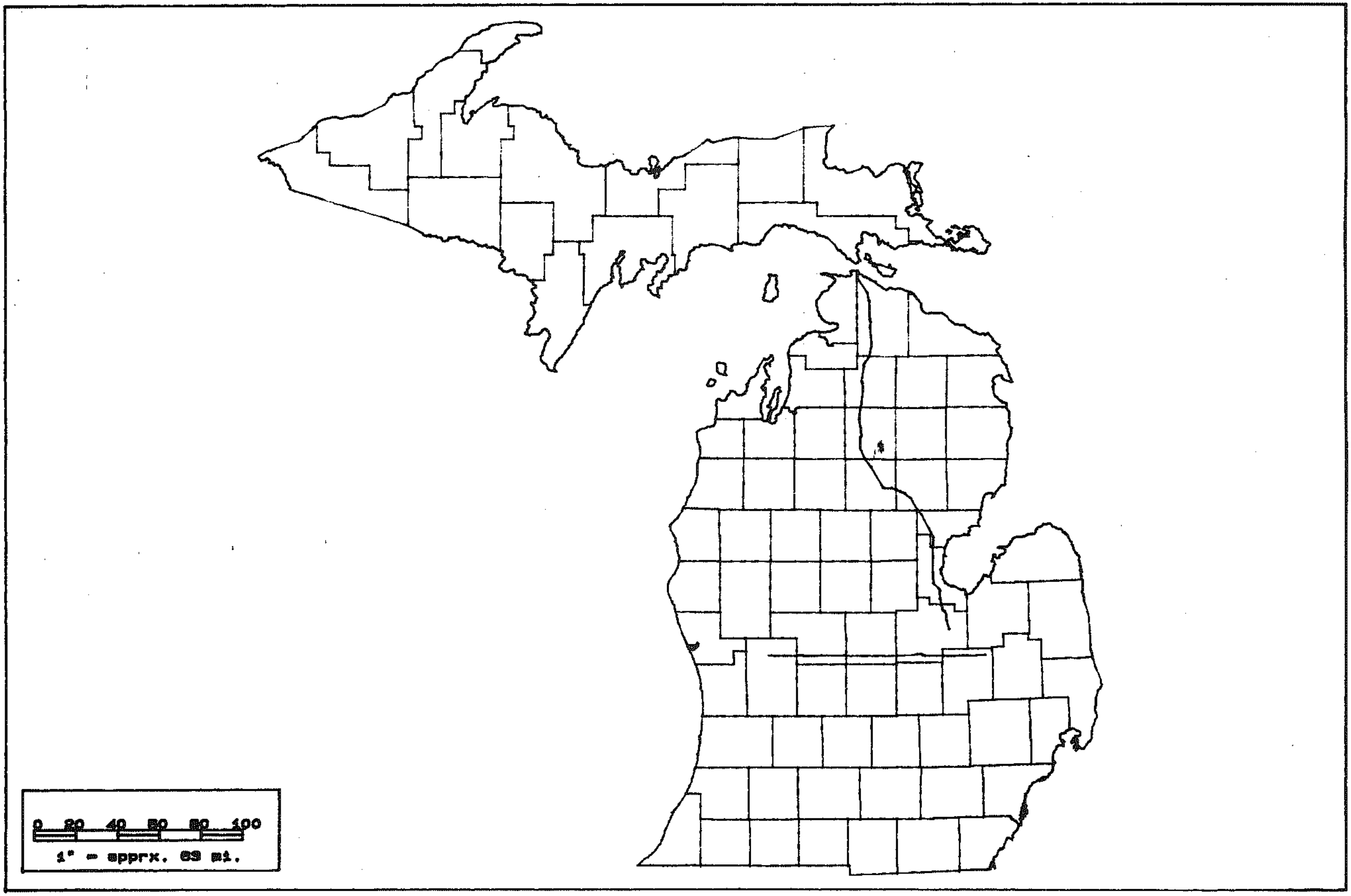
The count-based estimates of VMT discussed in the last section were based on a simple dichotomy of commercial and non-commercial vehicles on a systemwide basis. However, MDOT has embarked on a systematic improvement of their vehicle counting procedures using counters which provide significantly more detail on vehicle classification (so-called "classification counts"). These data can then be used to estimate VMT for both the commercial/non-commercial vehicle dichotomy and more disaggregated categories. Thus, part of the study was directed to using the more detailed classification-count data to estimate VMT by vehicle type and then to compare the resulting distribution by vehicle type to a comparable estimate based on quasi-induced exposure. In addition, the disaggregated VMT estimates were also aggregated and compared to published MDOT estimates of commercial and non-commercial VMT.

While the original intent had been to undertake this comparison for several test corridors, due to computational difficulties, only two were eventually used (figures 1, 2, and 3). The corridors were M-57 (figure 2), from US-131 to M-15, and I-75 (figure 3), from approximately the Mackinaw Bridge to a point south of US-23.

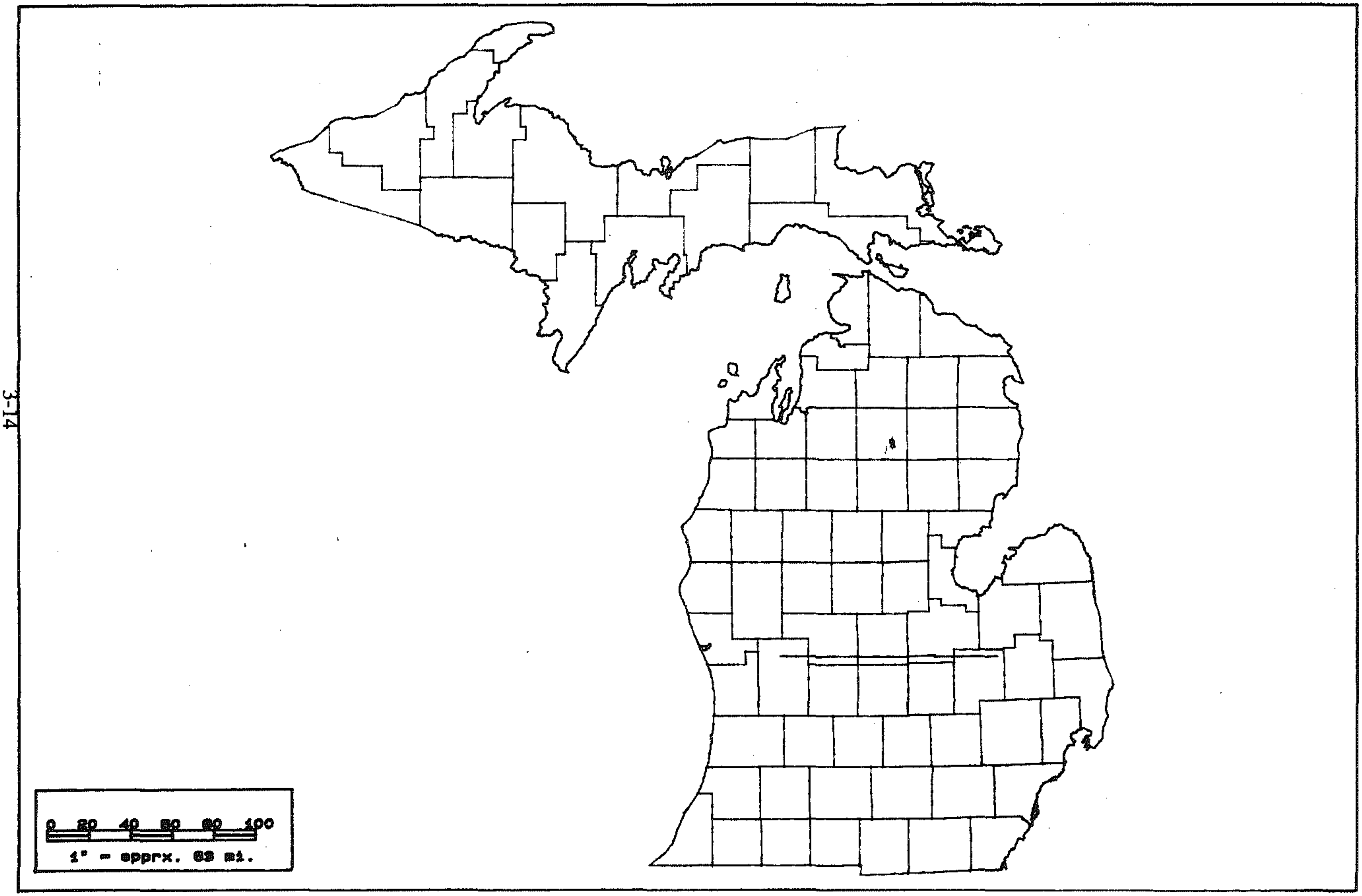
The analytical procedure for determining the exposure using vehicle counts was generally as described in the literature review. In this particular case, all available classification counts were provided by MDOT, manipulated and sorted in the SPSS environment to form files which were specific for a corridor and counting station, and transferred to a Quattro-Pro (spreadsheet) environment where they were further manipulated to provide VMT by vehicle type for roadway segments within each corridor. The raw vehicle counts were adjusted using MDOT seasonal factors, averaged over the distance between the adjacent counting stations, multiplied by the distance between the counting stations, and then aggregated to provide VMT by vehicle type for each entire corridor. More detail is provided in appendix A.

The accidents for the corridors, the basis for the quasi-induced estimates, were culled from the data file for the entire state and "cleaned" (e.g., 2-vehicle accidents, vehicle-1 at-fault, vehicle-2 not-at-fault) as discussed earlier and consistent with what was done for the system-wide comparisons. Because the sample sizes were small, data from three years, 1989,

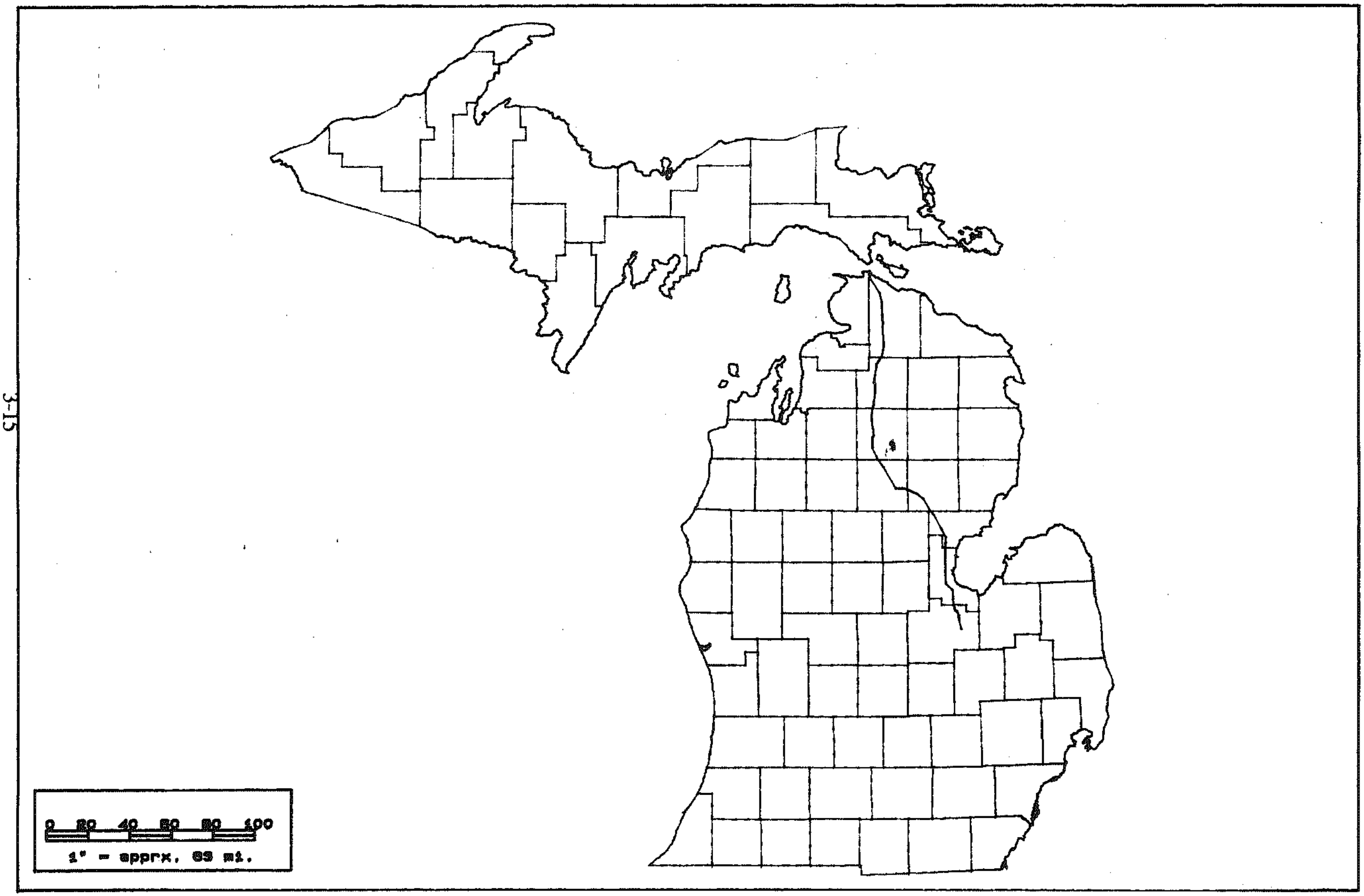
Michigan Truck Exposure Study: Selected Corridors



Michigan Truck Exposure Study: Corridor M-57



Michigan Truck Exposure Study: Corridor I-75



1990, and 1991, were combined.

The comparisons that can be made between quasi-induced and classification-count-based estimates are shown in table 5. Overall, the comparison between the two approaches is not very good. One reason could be because both the number of counting stations and the number of accidents in the corridors are relatively low. This is especially true for the accidents. While there were over 1,000 total accidents in each of the corridors for the three-year period, the number of accidents involving trucks was, relatively, quite small--less than 5%, or less than 50 for each corridor.

Table 5. Comparison of disaggregate vehicle estimates with quasi-induced estimates for specific corridors.

	I-75 corridor		M-57 corridor	
vehicle type	classification count estimate	quasi-induced estimate	classification count estimate	quasi-induced estimate
autos	86.8[1] (302.1)[2]	95.7[1] (1075)[3]	93.2 (200.5)	96.0 (940)
SUs	2.3 (8.0)	1.4 (16)	2.8 (6.1)	1.3 (13)
singles	8.6 (30.0)	2.3 (26)	3.0 (6.5)	2.3 (23)
doubles	2.2 (7.8)	0.6 (7)	1.0 (2.1)	0.3 (3)

[1] percentage of travel attributed to vehicle type
[2] annual VMT (X 10^6) attributed to vehicle type
[3] accidents attributed to vehicle type

Notwithstanding the small sample of accidents, it is interesting to note that the quasi-induced estimates are similar between the two corridors. This is not, however, what would be expected *a priori*: it would be expected that there would be a lower percentage of travel by singles and doubles on M-57 than on I-75. Such a variation is present when considering the count-based estimates. Singles make up about 9% of the travel on I-75 while only accounting for about 3% on M-57--this is more consistent with the conventional wisdom regarding what kinds of trucks are more prevalent on what types of roads. However, both are estimates, and there is no way to determine which is closer to absolute "truth."

While the general variation in truck usage of different roads is encouraging (at least with respect to general wisdom), a comparison between the classification-count-based estimates developed for these corridors (table 5) and the statewide (axle) count-based estimates shown in table 4 can also be done. From table 4 it would be expected that approximately 5% commercial traffic would have been expected on rural, M-numbered highways and about 15-16% on rural interstates.

Thus, if the two corridors can be considered typical, there is reasonably good agreement between the count-based estimates: for I-75, 13.1 versus about 15-16%; and for M-57, 6.8 versus 5%. For the quasi-induced estimates only the M-57 corridor compares well with the 5% commercial estimated from the statewide axle-count figures.

A third estimate of travel in the two corridors is also possible. This estimate is derived from MDOT-published volumes of all-vehicle and commercial travel on all trunklines. These are based, in part, on "axle" counts. These estimated volumes are available from MDOT's sufficiency file and selected volumes are also displayed on statewide maps. It should be noted that the latter (the maps) are NOT complete and are for general indications of volumes only. The figures used here were provided separately by MDOT and are more detailed than those derived from the maps. The comparison of this third estimate with the other two is presented in table 6. For this table, the disaggregated VMT shown in table 5 is aggregated into commercial and non-commercial vehicles. The axle-count estimate is what was reported in 1991. These data were assumed to be reasonably representative of 1989-1991, the time period for the accidents which form the basis for the quasi-induced estimates.

Considering the estimates for I-75, the classification count estimate in table 6 is considerably lower than the axle estimate in terms of the absolute estimates of VMT: the axle estimate of VMT is approximately 27% higher than the classification count estimate. However, and more importantly, the distributions of commercial versus non-commercial travel are quite similar: the classification count (percentage) estimates are within a percentage point of the axle-count estimate. The comparison between the quasi-induced estimate and the two count-based estimates shows that the former is considerably higher for non-commercial vehicles, 95.3 versus 86-87% for the count-based estimates. The quasi-induced estimate for commercial vehicles is, necessarily, lower than the count-based estimates (4.7 versus about 13%).

Table 6. Comparison of VMT distributions for three methods for the I-75 and M-57 corridors.

	VMT estimates		distribution of travel		
I-75 corridor	class cnt VMT	axle VMT	class cnt estimate	axle estimate	Q-I estimate
non-comm	302.1[1]	387.3[2]	86.8	87.4	95.3
commercial	45.8	55.7	13.1	12.6	4.7
TOTAL	347.9	443.0	100.0	100.0	100.0
M-57 corridor					
non-comm	200.5	224.5	93.2	93.0	95.2
commercial	14.6	16.9	6.8	7.0	4.8
TOTAL	215.1	241.3	100.0	100.0	100.0

[1] annual VMT = number X 10^6

[2] annual VMT = number X 10^6; from MDOT calculations for 1991

Similar comparisons can also be made for the M-57 corridor. It can be seen that the VMT estimate based on the more detailed classification counts compares somewhat better (than I-75) with that derived from the standard MDOT-published volumes: the latter is about 12% higher. The distributions of travel estimated by the two procedures are even closer than for I-75. In the present case, the classification count commercial vehicle percentage is within 0.2 percentage points of the axle-count estimate.

Interestingly enough, the axle-count and classification distribution estimates compare favorably with the quasi-induced estimate for M-57 in spite of the relatively small sample size (i.e., number of accidents in the corridor). However, the quasi-induced estimate is based on relatively few data and turns out to be very similar for both corridors. Based on more aggregated estimates of truck travel on M-numbered versus I-numbered highways, it would be expected that the two corridors investigated here would be more likely to vary (i.e., as per that suggested by the axle and classification-count-based estimates). Thus, the quasi-induced technique is probably not reliable in this case.

Finally, the axle-count-based VMT estimates shown in table 6 are, as noted above, from more detailed MDOT data files and not simply the published volume maps. A comparison of these estimates and those that can be obtained directly from the maps was also made. In table 6 a total VMT on I-75 of $443.0\mathrm{x}10^{6}$ (387.3 non-commercial, 55.7 commercial) is shown while the estimate derived directly from the 1991 map is $432.0\mathrm{x}10^{6}$ (377.7 non-commercial, 54.3 commercial). That is, the map figures are about 2.5% lower overall, although the distributions are virtually the same. For M-57, the two estimates are, for all practical purposes, the same.

3.6 COMMENTS ON DIFFERENCES IN VMT ESTIMATES

When MDOT uses the vehicle classification data for estimating purposes, they disregard both less than 48-hour counts and those on weekends (see also Appendix A). The latter being defined as Friday noon to Monday noon. In order to have adequate data for the purposes here, both of these rules were relaxed--counts for less than 48 hours were considered and weekend data were not discarded. However, in the latter instance, estimates of ADT, AADT, and VMT were all done with and without the weekend data considered. These two estimates are discussed below. (Notwithstanding the use of weekend data, all estimates of VMT were on an annual basis.)

VMT estimates utilizing weekend data proved to be higher than those that did not include weekend data. For M-57, the overall annual estimate of non-commercial travel is about 6% higher when weekend data are used while commercial travel is lower (from 4.7 to 16% depending on type of vehicle considered). Combined VMT is about 4.6% higher when weekend travel data are included in the estimating process. For I-75, the non-commercial travel was about 5% higher when weekend data were incorporated. However, on the commercial side, only the traffic by SUs was substantially different, in this instance about 6% higher. Combined VMT is about 4% higher when weekend travel data are included in the estimating process.

Assuming that MDOT's adjustment factors for weekend traffic are appropriate, the results above imply that inclusion of these traffic data will make a difference in corridor VMT estimates and, by implication and extension, any statewide estimates. There was also disagreement between the two corridor VMT estimates (axle data versus classification data) derived from MDOT data as noted in table 6. That is, while the proportional distribution of commercial and non-commercial vehicle travel agreed quite well, the actual VMT estimates were not nearly as close. This was the case for both corridors. In order to determine why this might have occurred, the raw classification-count data were re-examined in an attempt to ascertain whether the errors occurred as a result of using the count expansion factors and the averaging techniques or whether the differences were more fundamental (i.e., in the raw count data). Note that the so-called classification counts were from any one of three years, 1989, 1990, or 1991.

For both corridors, the raw vehicle count data were re-examined as follows:

1. the hourly count (classification count) data available from files supplied by MDOT were adjusted for seasonal variation and aggregated into 24-hour counts (some counts were for lesser time periods--e.g., 20 hours); and
2. the total and commercial ADTs reported by MDOT for each segment length within a control section (and within a corridor) for 1991 were compared with the total and commercial classification count data for the same (approximate) control section (although the latter were from three years).

In making these calculations, passenger vehicles were considered to include cars and vans, motorcycles, buses, and pickup trucks while commercial vehicles included everything else (including all 2-axle, 6-tire and larger vehicles).

While this comparison is approximate, in general, the classification count data consistently show lower numbers of both commercial and non-commercial vehicles throughout both corridors. This appears to be independent of all other considerations (e.g., considering weekend counts, considering less than 48-hour counts).

According to MDOT (13), their practice of only using 48-hour counts is based on the *Traffic Monitoring Guide* (8) and AASHTO recommendations. The assertion is that 48 continuous hours provides a more reliable measurement which would have the effect of smoothing out some of the daily variation which may be on the order of 10-25% of the AADT. Moreover, similar variation in truck travel (by vehicle classification) is even more difficult to accurately estimate due to seasonal and truck use purpose variation. In this context, MDOT indicates that "...vehicle classification is best used to estimate annual average percentages of commercial vehicles for the system." Finally, MDOT hypothesizes that the differences in the corridor VMT estimates may be due to the fact that MDOT uses Permanent Traffic Recorder data and classification counts for such estimates while in the current study only classification count data were used--the "greater stratification of the data [in this study] may account for the differences in the VMT estimates...."

3.7 DISCUSSION AND SUMMARY OF COMPARISONS AMONG EXPOSURE ESTIMATING METHODS

Based on the several comparisons presented above, there are several comments that can be made. The paragraphs that follow serve both as a discussion and summary of the comparisons made. At the outset, it is useful to reiterate that there was no comparison with "truth" for any of the methods.

Quasi-Induced vs. Survey Methods

The comparison between the quasi-induced and survey techniques indicated that the two methods generally gave comparable estimates for relative exposure when there was an adequate number of accidents from which to estimate the vehicle distribution by type using the quasi-induced technique. For the most part, both estimating procedures appeared to be sensitive to expected changes in vehicle exposure by type of vehicle, roadway classification, and day-night stratifications.

Quasi-Induced vs. Count-Based Methods (system-wide comparison)

The comparison between the quasi-induced and count-based techniques on a system-wide basis has a somewhat different basis than the comparison just discussed. This is due to the definition of vehicle types and other variables of interest. Moreover, this first series of comparisons considered only a commercial vehicle vs. non-commercial vehicle dichotomy. These differences notwithstanding, the comparisons also showed that the two procedures were generally comparable to one another. There was year-to-year consistency for both approaches, and they were both sensitive to differences among roadway classes and consistent with each other. It was, however, noted that the quasi-induced estimates were consistently lower (for commercial vehicles) than the count-based estimates for all roadway types. On balance, if the count-based method is considered to be accurate, the agreement between the two estimates is interpreted to suggest that the quasi-induced exposure estimates are reasonable. However, it should be pointed out that while the estimates are within a few percentage points of one another in virtually all instances, the overall estimates of the proportion of commercial vehicle exposure is about half of that predicted by the count-based approach for non-interstate highways and for the system total. This is primarily due to the relatively low percentages of such vehicles that are observed and does not indicate any inherent bias.

Quasi-Induced vs. Count-Based Methods (corridor comparison)

Comparisons were also made among the quasi-induced method, the basic MDOT commercial vs. non-commercial dichotomy, and an estimate based on MDOT's so-called classification (detailed) counts for two specific corridors. The agreements among methods noted for the system-wide comparisons breaks down at the corridor level. Based on expectations of vehicle distributions (e.g., from aggregate estimates) and the relatively small numbers of accidents typically seen on a single corridor, it would seem that the disagreement is more likely a function of the quasi-induced approach breaking down rather than the other methods. When accident frequencies are low, the proportional distribution by vehicle type is quite variable (i.e., a few more or less accidents in a category can change the distribution by several percentage points). One estimate of the total number of accidents that would have to be considered was 3,000 (14) although that estimate seems high based on more recent investigation (10) and the estimates presented here.

Comparisons Among MDOT Methods

There are three sets of estimates based on MDOT data that were compared. The traditional axle-count-based estimates were provided by MDOT in both file and map forms with the former having a finer delineation of where road segments began and ended (i.e., more segments are defined in the computer files than on the published maps). There were basically no differences between the two methods for the M-57 corridor--for either absolute VMT estimates or the distribution of traffic by commercial and non-commercial vehicles. For the I-75 corridor, the absolute differences for VMT were small--on the order of 2.5%--with virtually no difference in the distribution of traffic.

There were some differences noted between the estimates developed using classification data and those from axle count data. The former is based only on the available classification counts in the corridors studied. In general, it was noted that the classification counts resulted in significantly lower VMT estimates both overall and for commercial vehicles. At a more detailed level (segments within the corridors), it was noted that (adjusted) ADTs from the classification counts always appeared to be lower than the ADTs reported by MDOT for the individual segments. It should be noted that this comparison did not include comparison of actual classification counts and short counts at the same or nearby locations *per se*. This latter comparison should be made to determine whether the differences noted are just a quirk of using less data for the classification-based estimate or whether there is truly a difference in the ADTs estimated by the two methods.

4.0 DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this project was to review and compare several methods for estimating absolute or relative exposure of various vehicle types on the highway system. Of primary concern were vehicle counting methods, user surveys, and the so-called quasi-induced exposure method. Other methods, such as those based on vehicle registrations or gas taxes and case-control methods, were examined in the literature search and eliminated from further consideration because of their inherent inaccuracy or bias (estimates derived from vehicle registration and gas taxes) or inability to be generalized to a system level (case-control).

4.1 DISCUSSION OF METHODS

The study was hampered by the lack of a reliable measure of "truth" although the count-based approaches are widely used and generally accepted. An additional problem was that the three principal methods could not be directly compared to each other (a three-way comparison) because of differences in the definition of vehicle types that were used and in the characterization of roadway types as well as the absence of comprehensive estimates for all vehicle types. These differences notwithstanding, several interesting comparisons were made.

With respect to the quasi-induced exposure method, it was found that at a system level, the estimates using this method compared favorably with those from both the survey approach and MDOT's statewide commercial vehicle estimates. One of the questions which had been raised in the literature search was whether certain vehicles, such as trucks, are simply more likely to be hit by other vehicles, thus invalidating the assumption that the vehicle-2s are a random sample of the vehicles on the roadway. However, there was no evidence that this was the case. In fact, if anything, the opposite phenomenon was noted, with the quasi-induced estimates being consistently lower for percent trucks in the traffic stream. It appears, however, that small sample sizes will render the quasi-induced approach unreliable. For example, to get a reasonable sample size for the corridor-based comparisons, it was necessary to aggregate accident data over a three-year period. In spite of this aggregation, the sample sizes for specific vehicle types were small and the relative estimates of exposure were quite volatile. Even if this aggregation had been successful, any year-to-year variation would have been lost due to the aggregation. The technique did, however, seem to work reasonably well at the system level.

The problems with the quasi-induced approach at the corridor level do not translate to the system level. Basically, what is being estimated is a proportion which is subject to some variation--the smaller sample size causes the proportion to vary considerably with the addition or deletion of only a few observations (accidents). The aggregation to the system level simply dampens the effect of any shift of a few accidents from one category to another. The appropriate sample size needed to use the quasi-induced can be based on traditional sampling to estimate a proportion. Empirically, the effect of sample size was seen in tables 1 and 2 where aggregations of accident- and survey-VMT-based resulted in estimates of the exposure distributions which tended to converge with increasing aggregation.

Finally, there has been some concern about whether, in Michigan, use of the quasi-induced procedure will be hindered by the lack of the investigating police officer indicating which driver is "most at fault" (i.e., driver-1). All data used in the current effort were "cleaned" (e.g., no drunk drivers) and definitions of driver-1 and driver-2 were based on analysis of violations and hazardous actions and <u>not</u> the officer's notation of which driver was recorded as driver-1. As long as officers continue to note violations and hazardous actions on the accident forms, the quasi-induced procedure should be usable.

The survey method could not be "validated" *per se* since it could only be compared, at least in this instance, with the relative estimates from the quasi-induced estimates. As pointed out, there was reasonable consistency between these two methods. The implication from the agreement of the quasi-induced technique with both the survey and count-based approaches is that each is reliable at the system level in terms of determining the distribution of vehicle travel among vehicle types if not the validity of the absolute estimate.

While there was good agreement among the different methods in estimating the proportional distribution of travel by vehicle type, consideration of the count-based methods did result in a question about the apparent disagreement between axle and classification-based estimates of total vehicle miles of travel. The classification-based VMT estimates that were developed for this project did not agree with the estimates provided by MDOT for the same corridors--the classification-based estimates were consistently lower, both overall and, as near as could be determined, for road segments within the corridor. The disagreement however, could easily be a result of the averaging of the classification counts that were required for this project. A more detailed comparison of actual axle counts with classification counts at the same or a nearby location should be undertaken in order to clarify (verify) the relationship between the relatively simple axle and the more sophisticated vehicle classification counts.

Unless it is shown that the vehicle classification counts, *per se*, are in error (an outcome that seems unlikely), they provide significant detail about truck travel in Michigan. For example, the vehicle classification counts show that a fairly large percentage of commercial traffic is due to single-unit (SU) (straight) trucks on M-57, approximately 41% of the commercial traffic is attributable to SUs with the rest being due to tractor-trailer combinations. On the other hand, on I-75, only 17% is attributable to SUs. However, the difference in total commercial traffic between the two roads is about six percentage points (7% on M-57 and 13% on I-75). The aggregation of the different types of truck traffic into the commercial category blurs the substantial differences in traffic flow composition.

4.2 CONCLUSIONS

While there could not be an overall comparison with some universal truth, it seems that each of the three methods provides reasonably comparable estimates of <u>relative</u> exposure at the system level. This conclusion is based on the general agreement of quasi-induced estimates with those produced using the other two methods and the literature review that showed that both the vehicle-count- and survey-based procedures are developed from what appear to be reasonably sound assumptions. However, no specific comparisons of actual VMT were possible: the quasi-induced procedure does not produce VMT; and the UMTRI survey and MDOT counting procedures resulted in estimates which are not comparable.

At the corridor level, no survey-based estimates of either relative or actual VMT distributions were available and the quasi-induced approach appeared to suffer from the lack of sample size. The estimates based on different uses of the vehicle count data showed that while distributions of vehicle travel were similar, VMT estimates did not agree.

4.3 RECOMMENDATIONS

The recommendations are contingent upon what is desired from exposure estimating procedures. For example, if it is desired to know conventional truck accident rates (accidents/VMT), the quasi-induced approach cannot be used. If relative rates and a general understanding of safety are sought (e.g., are singles safer than doubles), then the quasi-induced approach could be used as long as some level of aggregation is acceptable (i.e., it will not typically be applicable at the corridor level). By the same token, existing MDOT VMT-estimating procedures do not lend themselves to producing exposure estimates that are disaggregated by vehicle type--it would be impossible to estimate statewide truck VMT differentiated by vehicle type using MDOT's current estimating procedures (although they could be modified). At the corridor level, the survey procedure is also problematic since it is geared toward system-wide estimates, although it could presumably be restructured to provide such estimates at a less-than-system level.

From a safety perspective, the current MDOT practice of simply estimating VMT by commercial and non-commercial users is probably inadequate. As was shown in *The Michigan Heavy Truck Study*, accident rates within the general classification of commercial vehicles will vary significantly--not only by vehicle type *per se* but also in terms of roadway class and, presumably, interactively between roadway and vehicle. The only currently convenient method for estimating relative exposure by vehicle type is through use of the quasi-induced exposure which is recommended for providing a general indication when a determination at a fairly significant level of aggregation (e.g., road class; for a several county area) is acceptable. If more precise and traditional truck accident rates are required, the MDOT counting and estimating procedures will have to be expanded. The same may be true for estimating axle loads for pavement design purposes.

Notwithstanding that MDOT is currently collecting a substantial amount of vehicle classification and axle count data, a concerted effort should be made to reconcile the differences between axle counts and classification counts such as were found in the current study.

In summary, none of the three exposure estimating techniques currently provides all of the information that may be needed by all of the different users of the data. While the vehicle-counting procedures hold the most promise, the current product is inadequate for some users--e.g., those concerned with safety, and possibly pavement design, who need to have more detailed information by vehicle type. In lieu of having appropriately disaggregated VMT estimates, quasi-induced exposure can be used when relative estimates of exposure are acceptable with the caveat that accuracy is sacrificed as the analysis moves from the system to corridor level.

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APPENDIX A

PROCEDURE FOR ESTIMATING CORRIDOR VMT USING MDOT VEHICLE CLASSIFICATION DATA

PROCEDURE FOR ESTIMATING CORRIDOR VMT USING MDOT VEHICLE CLASSIFICATION DATA

The procedure for estimating vehicle miles of travel (VMT) in the test corridors is described below. This procedure generally follows that which MDOT uses although there are some exceptions (which are noted).

1. The raw data consist of detailed hour-by-hour vehicle classification counts at various data collection sites. These were provided by MDOT.
2. The vehicle classification data were aggregated by vehicle type as follows: passenger vehicles = cars and vans, motorcycles, buses, and pickups and vans less than 1 ton; SU trucks (3 categories based on number of axles); singles (3 categories of tractor-trailer combinations); and doubles (3 categories of tractor-double trailer combinations). The truck categories can also be aggregated to make up the "commercial" category.
3. Hour-by-hour data were assembled for the corridors of interest (in this instance, parts of M-57 and I-75) and sorted by data collection location, direction of travel, year, day of the week, data collection date, and hour of the day. Data from three years were used in order to get reasonable coverage in the corridor and because the accident data (for the quasi-induced exposure estimates) had to be aggregated over three years.
4. Seasonal adjustment factors supplied by MDOT were applied to the estimated 24-hour counts developed in step 4 above. At this point, motorcycles were dropped out since application of seasonal adjustments for them made no sense. In spite of the original data being from 1989-1991, MDOT factors for 1991 were applied to all years. While this may introduce some error, the 1991 factors were assumed to be better than the earlier factors. The correction factors were consistent with those assigned by MDOT.
5. Data were examined to obtain valid 24-counts. In a very few instances less-then-24-hour counts were used. The latter depended on when data were missing--e.g., if rush-hour data were missing, the data were not used while if 2:00 AM data were missing, the count would be considered to be acceptable. The MDOT rule of using only 48-hour counts was not followed--this was primarily to maintain adequate data for the corridor. The rule of using only 48 hour counts as valid seems to cause discarding of otherwise valid counts. MDOT also does not use weekend counts in their calculations although weekend adjustment factors are provided. It is not clear why these counts are taken if they are not going to be used. This point notwithstanding, VMT estimates were developed both with and without consideration of weekend data.
6. Adjusted counts from step 5 were converted into ADT and AADT volumes.
7. VMTs were calculated based on the distances between counting stations and the 1 volumes at the adjoining stations.