UM-HSRI-82-13

A REVIEW OF

The Effect of Truck Size and Weight on Accident Experience and Traffic Operations, Volume III: Accident Experience of Large Trucks by BioTechnology, Inc.

Robert E. Scott

Highway Safety Research Institute
The University of Michigan

May 1982

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1.0 INTRODUCTION

This is a report on my technical review of the large truck safety study conducted by BioTechnology, Inc., for the Federal Highway Administration under contract DOT-FH-11-8835. Specifically, the review is directed to the accident experience of large trucks, with emphasis on the relative safety of doubles and singles. The volumes of the BioTechnology report relating to accident experience have been reviewed, as well as the critique conducted by the Transportation Systems Center for the Federal Highway Administration. A number of critiques from the staff of the American Trucking Association (ATA) have also been reviewed.

BioTechnology had a difficult and formidable task. No truck safety study of as large a scope as was undertaken by BioTechnology had been conducted, and the investigators faced many difficult research problems. The fundamental project plan adopted was excellent and innovative, but did involve many potential operational problems. Some of the problems are reflected in the final report, with the result that the report has several shortcomings.

Following the introduction, this review is organized into five sections. They are: sample selection, data reliability, analysis, and potentially confounding variables, followed by a summary. There is a good deal of interrelation between these subjects, so some of the issues are difficult to place in one versus another. As a result, some of the discussion to follow has elements appropriate for several sections.

The other critiques I have reviewed have been thorough and broad in their coverage, and in general, I agree with many of the concerns they have raised. Consequently, much of the ground I will cover here has been touched before. Nevertheless, in concentrating on what I perceive to be the more serious problems, I hope to add perspective to the findings of the report.

A general comment on the volumes relating to accident experience (Volume III: Accident Experience of Large Trucks, and Volume III:

Accident Experience of Large Trucks; Appendices A, B, C, D, and E) is that little detail is given on the design, conduct, and analyses of the project. So little detail is given that it is difficult to critique the project. The general project description is brief, with little discussion of the data collected. In some cases, the details of the analysis method are not clear, and one is tempted to replicate the results to clarify the analysis and add insight. Unfortunately, the data necessary are not available from the report. Specific examples of insufficient explanation will be evident in the discussion that follows.

The results and findings are largely presented as individual discussions of 47 research questions or "issues." They are listed in the Appendix. This review is not directed at each individual issue, but concentrates on the "doubles" versus "singles" question. However, the comments are rather fundamental and hence are generally applicable to the entire study of accident experience.

2.0 SAMPLE SELECTION

The selection of study sites for the collection of accident and exposure data followed a rather elegant sample design. This is described very briefly in Volume III, and in somewhat more detail in the volume containing Appendices. A still more thorough explanation was given in a presentation at the 56th Annual Convention of the Transportation Research Board.[1]

The purpose of the review given here is to examine the design with regard to its ability to represent any population larger than the sample. Ordinarily the purpose of drawing a sample of anything is to allow a concentrated survey of only a limited portion of a total population to be used for making inferences to the entire population. In addition, one should ordinarily be able to compute the variance of any estimates which arise from the sample, again with respect to the total population. For example, a simple random sample of truck

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[1] Chang S. Yoo and Martin L. Reiss, "Sampling Procedure Using Multistate Traffic Records to Select Accident and Exposure Data-Collection Sites," Transportation Research Record 643, Transportation Research Board, Washington, D.C. 1977.

accidents could conceivably be drawn by making a complete list of all the truck accidents in California each day, then choosing some subset of these by a random process such as throwing dice, and conducting detailed investigations of the chosen cases. If this were done each day for some longer period of time, such as a year, the resulting data would represent the total truck accident population of California for that year. If the total number of accidents sampled and investigated in detail were 1000, then the variance of an estimate of a simple proportion p (such as the proportion of doubles in the population) would be given by p(1-p)/1000. The one-sigma error would be given by the square root of this. For example, if the proportion of doubles in the sample were 0.2, the one-sigma error would be a little larger than 0.01. Thus we could state that the probability is about two-thirds that the true value of p would lie between 0.19 and 0.21. This illustration assumes a simple random sample in which each accident has an equal probability of being in the sample (an equal probability sample). The discussion is restricted to sampling errors, and neglects the effect of any bias error. Such a sample is conceptually simple and the statistics are relatively straightforward. In addition, they are also self-weighting, i.e., estimates based on the aggregated sample are valid estimates of the population.

There are alternative strategies however, which can also yield valid estimates. Cluster or multistage sampling methods are examples. Various estimates obtained from multistage samples are related to both the number of observations (interviews, accidents, traffic counts, etc.) <u>and</u> the number of clusters or primary sampling units. The error of an estimate is not that given by the simple random sampling formula, but contains an additional factor called the "design effect." The total variance in effect is the sum of the within cluster term plus the between cluster term. The magnitude of the design effect depends on the homogeneity of the clusters, and for some estimates can be quite large. Values of the order 5 to 10 are not unusual.

The multistage sample design used by BioTechnology is described briefly by the following eight steps:

1. First, six states were chosen (from 50) because these particular states had truck types or numbers of truck accidents which were of interest in the study. There was no attempt to make these six states representative of the U.S. in a statistical sense, although they do represent different geographic regions of the country. If similar findings are reported in each of these states, there is some justification in assuming that the findings <u>might</u> extend to other areas.

2. Next, each state was divided into three to five regions--evidently to insure broad geographical coverage within the state.

3. Within each region, a list of counties (or highway districts--the report is not clear which method was used in which state) was prepared, and a random sample of counties selected.

4. Within each selected county, the complete federal-aid road network was identified by class (rural versus urban, and freeway/primary/secondary). Each of these road classes was divided into n-mile long segments (the value of n differing by road type).

5. These segments then became (stratified by road class) a sampling frame or list--essentially a group of candidates for site selection.

6. By reviewing the state records, a distribution of number of accidents for a number of segments (presumably of equal length) was defined for each road class, and from this distribution a range established for low, medium-low, medium, medium-high, and high accident counts. This tag was appended to each of the road segments in the list or frame of [5] above.

7. Next, a controlled selection process was used to ensure that, for each road class, both region (from [2] above) and accident count (from [6]) were used as weighting factors in producing a subset of the list derived in [5]. On the example given in Appendix A to Volume III, this step reduced the number of potential rural-freeway sites in one state from 62 to 30.

8. Last, the 30 candidate sites were inspected by the field team to judge whether they would produce useful data, and five of these were selected (these five being in classes determined by the controlled selection process of [7]. The final selection (of five sites in the example) was made on the basis of six criteria that include such factors as truck volume, maximize site length, potential for photographic collection of exposure data, proximity of weigh station or truck stop, etc.

Although the sampling plan is elegant and complex, involving a great deal of effort, it does have several fundamental shortcomings. The selection of the six states was not based on probability sampling technique, but was a judgmental sample. Likewise, the final selection of sites--5 from among 30 in the example used in the report--was also a judgmental, or purposeful sample. Judgmental samples can be and are useful. However, they are not necessarily self-weighting, and the computation of variances is more complex than for simple probability samples.

The selection of the six study states was done without establishing how each should be weighted in order to provide national estimates. The results that have been reported (both by BioTechnology and TSC) use simple aggregates when the data from more than one state are used. Non-weighted aggregates cannot represent the nation unless self-weighting samples are used, and this was not done by BioTechnology. Furthermore, there are no data provided in the report, nor do they seem to have been collected, which could be used to develop appropriate weights. Thus it is not possible for the BioTechnology data to be used to make national estimates, nor can any estimates from the data be interpreted as national. This was stated on page 25 of Volume III (September 1980)[2], but deserves a more prominent place in the report.

Presumably, the intent was to have a design which would provide state-wide estimates of truck accident statistics. There are two problems with this extrapolation. The final step in the site selection process (from 30 down to 5 sites in the example given in the report) also results in a judgmental sample, with no way of establishing the weighting necessary to represent the state. This lack of representation extends to each road class in the study. Thus the sampled rural-freeway sites in California do not properly represent all rural freeways in that state.

The distribution of sites by road class in each state is shown in Table 4, page 13 of Volume III (September 1980). I have found no discussion of how these numbers were derived. There is a statement on page 12 that the allocations "very approximately reflect the percentage of miles of each of those roadway types" in each state. The numbers are

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[2] Other problems with use of these six states as a national sample are cited in the discussion of accident rates by roadway type and state on page 75 of Volume III.

so small that the approximation might have been by accident, and must be crude in any case. Actually, it would be more appropriate if the distributions represented either the vehicle miles traveled by trucks, or the accident experience of trucks by road class. Without any discussion of the selection of the number of sites by road class, there is no reason to believe that the unweighted aggregation of sites within a state can provide statistics representative of the state.

3.0 DATA RELIABILITY

Appropriately designed and executed sampling plans reduce sampling errors. Even the best sampling plans, however, are still sensitive to non-sampling errors because of errors in data collection. Such errors may result from observational errors, lack of coverage of the sample, or a number of other sources, any of which may lead to biased results.

Two probable problems have become evident to me. Both relate to lack of coverage, one of accidents and the other of exposure variables.

Seventeen of the sites were in Michigan, and HSRI has an on-line file of all Michigan accidents. However, the accident location in our file is not identified by a milepost locator as used to describe the sites in Appendix B of Volume III. Our files give the location by state control section number and miles into the control section. However six of the sites can be described, at least approximately, in terms of descriptors in the HSRI file. The sites and the methods I used to describe them in our state accident file are listed in Table 1. The number of large trucks--larger than pickup and panel trucks--in our copy of the 1977 Michigan State Police file, and the number listed in Appendix B of the BioTechnology report for 1977 is shown in Table 2. It should be noted (page 25 of Volume III, September 1980), that the numbers used in the BioTechnology study are truck involvements, even though they may be labeled as accidents. The figures of Table 2 indicate that the BioTechnology data seriously undercount the trucks at these sites. Both end points of site 343 are near interchanges. This raises the possibility that a small uncertainty in defining the end points may have erroneously included high accident locations in the counts from the Michigan file. If one-half mile were dropped from each end of the site, the count would be reduced from 187 to 156, with the BioTechnology data still accounting for only 65 percent of the involvements at the six sites.

This check only included data from Michigan. I do not have any way of checking other states, so I have had to use indirect methods to look for evidence that the lack of coverage of accident involvement might be unique to Michigan. A relative involvement rate was computed for each site using information from Appendix B of Volume III. The average truck ADT (averaged across the six quarters) was multiplied by the length of the segment, giving a mean truck vehicle miles. This was divided into the number of truck involvements at each site to obtain a relative involvement rate. The range of involvement rates (times 10^5 for convenient scaling) is shown in Figure 1. The top of each vertical line is the highest rate among the sites in the respective state; the bottom is the lowest rate. The mean rates for each state are shown by the intersections of the vertical lines with the line joining states. Rather than having the lowest involvement rates in the BioTechnology data, Michigan has the highest.

Figure 2 compares the distribution of truck involvements across states in the BioTechnology data with the 1977 Bureau of Motor Carrier Safety (BMCS) data and large truck involvements in fatal accidents in the 1976 and 1977 FARS data. For each of the three data sets shown, the percentages for the six states add to 100, thus giving the distribution among the six study states. Again, Michigan is overrepresented in the BioTechnology data relative to the BMCS and FARS data.

The comparisons shown in Figures 1 and 2 do not prove accident data are missing in the other states as well as Michigan. The reporting thresholds differ in the six states and this, along with other state-to-state differences, may provide the variation shown in Figure 1. Similarly, there is no reason to expect that the three distributions of Figure 2 should all be identical. The distribution of fatal involvements certainly might be different from non-fatals. Nor is there any reason to anticipate that truck use in all states would be so uniform that reporting to BMCS would be similar to the BioTechnology data. Nevertheless, there is no evidence that the substantial

TABLE 1

Approximate Description of Six Michigan Sites

Site	BioTechnology Description	Approximate Description	Notes
311	Milepost 0.0-24.0 of I-94 in Berrien County	I-94 in Chikaming, Lake, Lincoln, New Buffalo, and St. Joseph Townships of Berrien County	Lincoln Township includes up to approximately Milepost 25 so accidents in the last mile of the township were excluded.
313	Milepost 123.0-147.27 of I-69 in Calhoun County (All of I-69 in the County	All of I-69 in Calhoun County	
314	Milepost 80.0-105.67 (north county line) of I-75 in Oakland County	I-75 in Groveland, Holly, Independence, and Springfield Townships in Oakland County	The site used by BioTechnology was 25.67 miles long. The segment used for comparison by including the four townships excludes the southern five miles of the site.
331	US-12 in St. Joseph County. White Pigeon East limits to Sturgis West limits - 9.9 miles.	US-12 in White Pigeon and Sturgis Townships in St. Joseph County.	Since Village of White Pigeon is on west township boundary and city of Sturgis is on east township boundary, the segment defined by the two townships is the same 9.9 miles.
342	Milepost 0.0 - 7.9 of M-39 in Wayne County (Ford Avenue to north city limits)	M-39 (Southfield Freeway) in City of Detroit	That portion of M-39 which is in the city of Detroit is between Ford Avenue and the north city limits.
343	Milepost 37.00-45.10 of I-75 in Wayne County	I-75 in Wayne County from 10.25 to 13.95 (end) of control section 82191 and from 0.00 to 4.38 of control section 82194	The control section designations for structures nearest Mileposts 37 and 45.1 were obtained from the Michigan Department of Transportation

TABLE 2

Comparison of Truck Involvements for Six Michigan Sites

Site	Involvements		
	Michigan State Police Files	BioTechnology Study	Percent
311	89	73	82.0
313	19	12	63.2
314	18 (partial)	10	55.6
331	13	3	23.1
342	96	33	34.4
343	187	102	54.5
Aggregate:	422	233	55.2

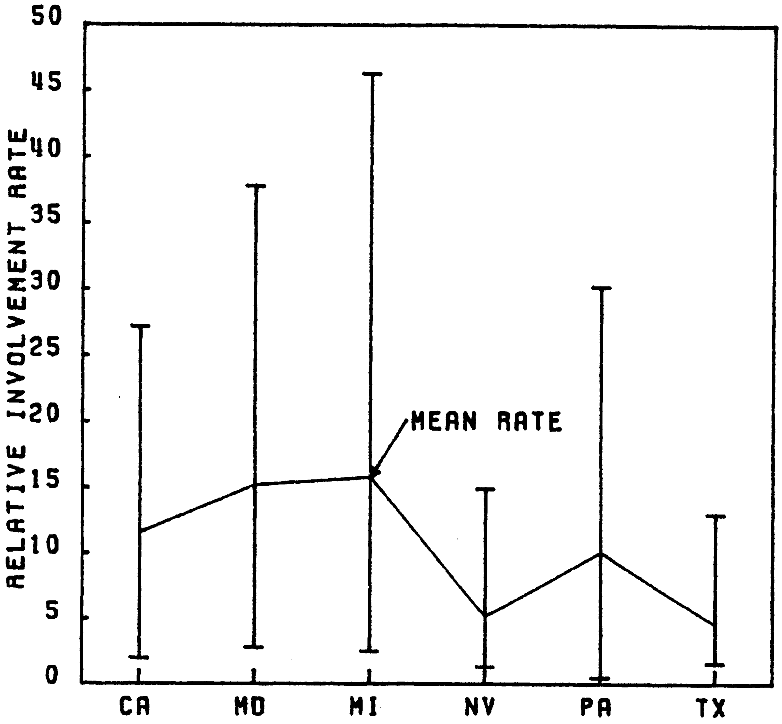

FIGURE 1
Range of Truck Involvement Rates Among Sites for Each State of the BioTechnology Data

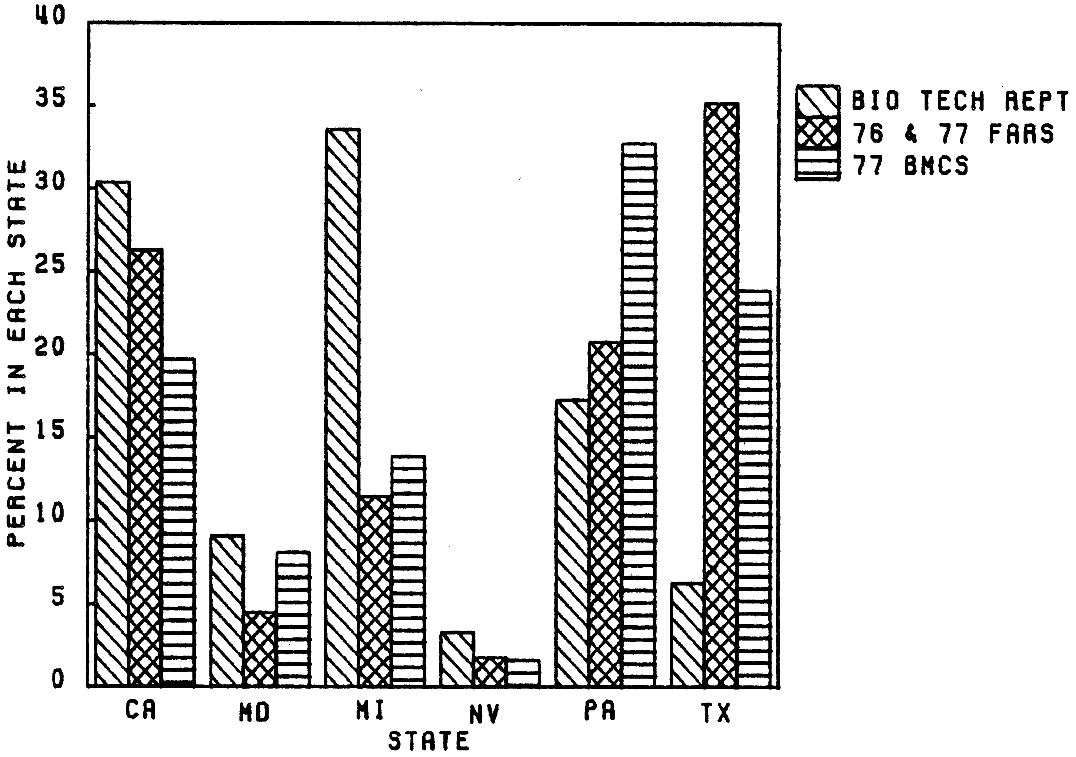

FIGURE 2
Comparison of BioTechnology Involvements With Other Data Sets

undercoverage in Michigan is unique to that state. Based on these comparisons, one would at last suspect undercoverage of accident data in all six study states.

Such a large lack of coverage makes the analysis subject to substantial bias error. Unless it can be shown that the cases not covered are unbiased, and this has not been done, we must assume that the total error may be much larger than the sampling error, and any statistical inferences are suspect.

Apparently there is also undercoverage of exposure data, at least in the context of incomplete coverage of the time period over which accident data was collected. At a large number of sites, the proportions of the total traffic (ADT) which were truck traffic were constant across all six quarters of data collection. At each of these sites, the proportions were the same to four significant digits, an incredible coincidence. This results in the same seasonal pattern for trucks as for cars, even at sites such as 115 and 412 which have a recreational character to the passenger car travel. Figures 3-5 are from a study using a census of toll tickets for exposure data.[3] They all have the summer peak of recreational car traffic, but with nearly constant large truck traffic. The constant ratios are apparently assumptions used because of data limitations; assumptions that could lead to substantial error.

The data given in Appendix B would suggest, then, that at a large number of sites, only one measurement of the ratio of truck to total traffic was available; in effect, only one measurement of truck traffic was available to represent the 1-1/2 years of accident data. Ascribing the same seasonal or hourly pattern to truck and car traffic could lead to substantial errors not only in total truck exposure, but the correlation between truck travel and a number of potentially important variables, e.g. season and hour, as well.

Among the 78 sites used for data collection, 32 had a single ratio of truck to total traffic (ADTs). These 32 represent 50.7 percent of all the truck involvements used in the study. The undercoverage was greater in California and Nevada. In these two states, which were used for the singles-doubles comparisons, 85.7 percent of the truck involvements were at such sites.

Several reviewers have noted that the exposure data were collected on only one direction of travel at each site. This would lead to bias in the exposure data, and in turn the involvement rates, if travel and accidents were not distributed similarly in both directions.

Some information can be obtained from the accident data alone. One variable in the accident file is "General Orientation (truck direction of travel)." The coding is such that the direction of travel is characterized as increasing or decreasing in (milepost) mileage. Table 3 gives the number of involvements for singles and doubles by direction for each site, where:

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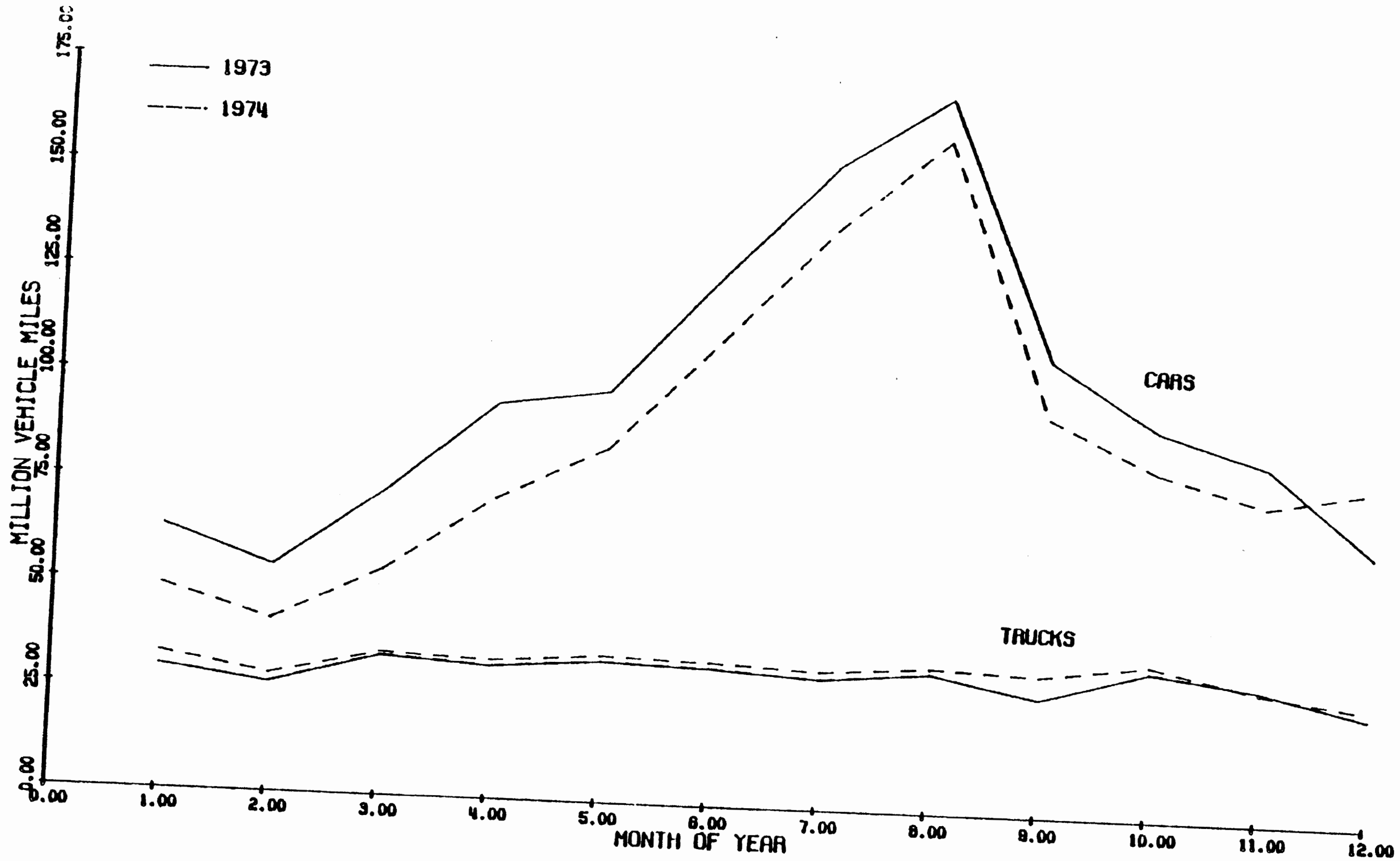
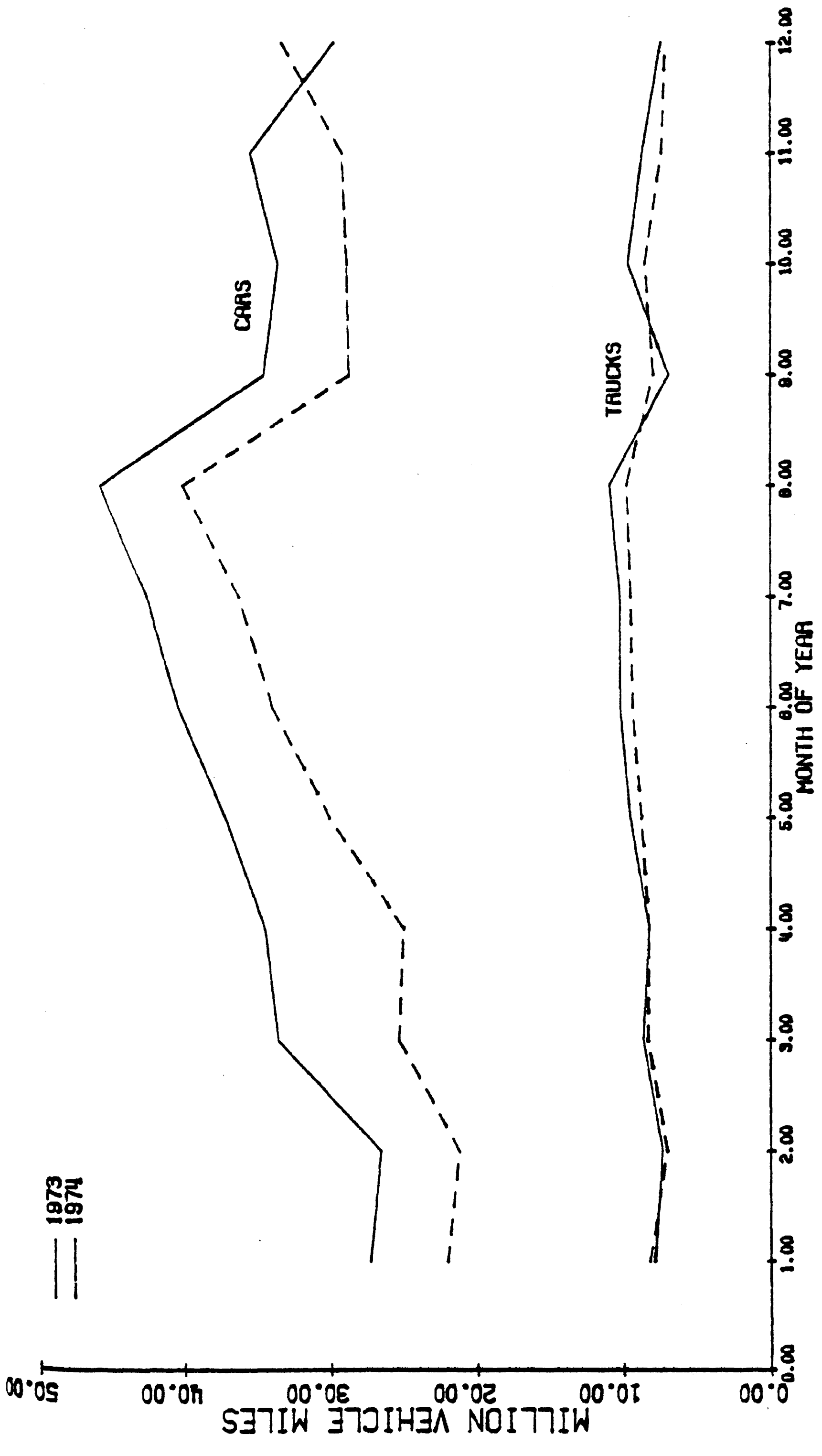
[3] K. Campbell, R. Scott, S. Tolkin, Highway Safety Effects of the Energy Crisis on U.S. Toll Roads, Report DOT-HS-801-933, Highway Safety Research Institute, The University of Michigan. June 1976.



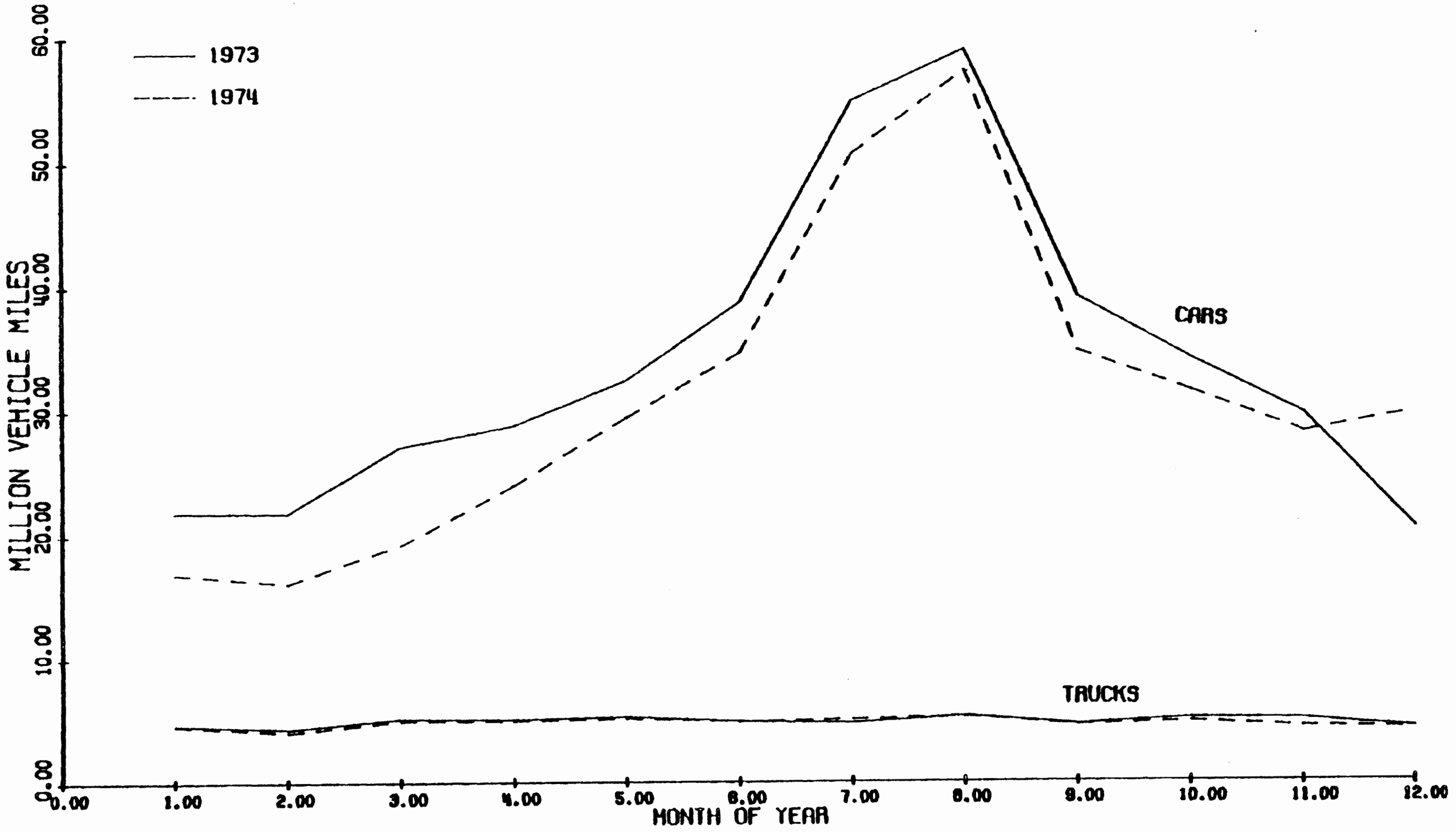
OHIO TURNPIKE
VEHICLE MILES BY MONTH
1973, 1974

FIGURE 3



KANSAS TURNPIKES
VEHICLE MILES BY MONTH
1973,1974

FIGURE 4



MAINE TURNPIKE
VEHICLE MILES BY MONTH
1973, 1974

FIGURE 5

S-I = number of single involvements in increasing mileage direction,
D-I = doubles increasing mileage involvements,
S-D = singles decreasing mileage involvements,
D-D = doubles decreasing mileage involvements,
TOT SG = total singles involvements,
TOT DB = total doubles involvements
DELTA-S = S-I/TOT SG in percent,
DELTA-D = S-I/TOT DB in percent.

Values of DELTA-S or DELTA-D different from 50 indicate unequal numbers of accidents in the two directions. A number of sites in California (those in the one hundred series) have unequal proportions.

The question is whether the unequal proportions are real, or could have resulted from chance. It would be reasonable to model accident occurrence as a Poisson process. If we hypothesize that the exposure and mean involvements are the same in each direction, the expected number would be the mean number in each direction. We can compare the observed numbers with the confidence intervals of a Poisson distribution.

Figure 6 shows the range for a number of California sites superimposed on the confidence intervals for the Poisson distribution. The triangles indicate singles, the circles represent doubles. In each case a line joins the numbers of involvements in the two directions of travel. Each site-vehicle type is plotted along the abscissa at the mean for the two directions. The combinations that are plotted are those from California and Nevada with the greatest difference in the two directions. Singles involvements at Site 114--the grapevine grade--is the only combination not within the 95 percent confidence interval. The remainder of those plotted, and thus of the 20 California and 11 Nevada sites, are all well within the 90 percent confidence limits.

Thus it is not evident that the accident experience is different in the two directions. The hypothesis of equal involvements in the two directions cannot be rejected. The only possible exception is Site 114, and even here the evidence is not conclusive. However, this examination does not include consideration of traffic in alternate directions, nor differences in empty versus loaded trucks.

TABLE 3
Accident Counts by Direction of Travel

SITE	S-I	D-I	S-D	D-D	TOT SG	TOT DB	DELTA-S	DELTA-D
111	11	7	9	3	20	10	55.00	70.00
112	2	4	4	2	6	6	33.33	66.67
113	8	5	10	4	18	9	44.44	55.56
114	54	35	27	25	81	60	66.67	58.33
115	4	2	4	2	8	4	50.00	50.00
121	5	5	3	6	8	11	62.50	45.45
122	0	1	0	0	0	1	0.	100.00
123	7	12	8	22	15	34	46.67	35.29
131	0	1	2	1	2	2	0.	50.00
132	1	2	1	1	2	3	50.00	66.67
133	0	2	0	3	0	5	0.	40.00
141	4	4	4	5	8	9	50.00	44.44
142	2	0	1	0	3	0	66.67	0.
143	8	6	5	5	13	11	61.54	54.55
144	1	0	6	4	7	4	14.29	0.
145	21	11	10	8	31	19	67.74	57.89
151	1	0	0	1	1	1	100.00	0.
152	5	7	3	7	8	14	62.50	50.00
161	0	0	0	0	0	0	0.	0.
162	0	1	0	0	0	1	0.	100.00
211	10	0	12	0	22	0	45.45	0.
231	1	0	0	0	1	0	100.00	0.
232	0	0	0	0	0	0	0.	0.
241	49	0	46	0	95	0	51.58	0.
251	5	0	4	0	9	0	55.56	0.
261	0	0	0	0	0	0	0.	0.
262	0	0	0	0	0	0	0.	0.
311	73	1	34	0	107	1	68.22	100.00
312	16	0	6	4	22	4	72.73	0.
313	13	0	8	0	21	0	61.90	0.
314	6	1	10	2	16	3	37.50	33.33
315	9	0	7	0	16	0	56.25	0.
321	6	0	5	2	11	2	54.55	0.
322	0	0	3	0	3	0	0.	0.
331	1	0	1	0	2	0	50.00	0.
332	1	0	6	0	7	0	14.29	0.
341	18	0	16	1	34	1	52.94	0.
342	18	5	18	4	36	9	50.00	55.56
343	54	1	46	4	100	5	54.00	20.00
344	43	4	45	5	88	9	48.86	44.44
351	9	0	13	4	22	4	40.91	0.
352	31	0	4	1	35	1	88.57	0.
361	3	0	3	0	6	0	50.00	0.
362	4	0	1	0	5	0	80.00	0.
411	1	1	1	2	2	3	50.00	33.33
412	2	0	1	1	3	1	66.67	0.
413	7	0	4	2	11	2	63.64	0.
421	2	0	1	0	3	0	66.67	0.
422	1	1	0	1	1	2	100.00	50.00
423	0	0	0	0	0	0	0.	0.
431	0	0	0	0	0	0	0.	0.
432	1	0	0	0	1	0	100.00	0.
441	4	2	6	1	10	3	40.00	66.67
442	1	1	2	0	3	1	33.33	100.00
451	1	0	3	0	4	0	25.00	0.
511	13	0	4	0	17	0	76.47	0.
512	8	0	17	0	25	0	32.00	0.
513	61	0	72	0	133	0	45.86	0.

TABLE 3 (Continued)

521	0	0	1	0	1	0	0.	0.
531	0	0	1	0	1	0	0.	0.
532	0	0	0	0	0	0	0.	0.
541	13	0	12	0	25	0	52.00	0.
542	23	0	31	0	54	0	42.59	0.
543	29	0	26	0	55	0	52.73	0.
551	2	0	1	0	3	0	66.67	0.
611	5	0	2	0	7	0	71.43	0.
612	10	0	0	0	10	0	100.00	0.
613	5	0	9	0	14	0	35.71	0.
632	2	0	0	0	2	0	100.00	0.
641	12	0	12	0	24	0	50.00	0.
642	6	0	7	0	13	0	46.15	0.
643	1	0	2	1	3	1	33.33	0.
644	5	0	6	0	11	0	45.45	0.
651	2	0	0	0	2	0	100.00	0.
661	1	0	1	0	2	0	50.00	0.

4.0 ANALYSES

The problem of incomplete documentation cited earlier applies also to the methods of analysis used by BioTechnology. Although many research questions, or "issues," are discussed in the report, very little material is devoted to describing the methods used to draw inferences. Information on which tests were statistically significant and which were not are often missing, as well as how the significance levels were computed.

Two of the first concerns on reading the report were (1) that site-to-site differences in accident rates and truck use might cause erroneous or spurious results, and (2) that sampling errors in the measured exposures were not considered in deriving variances for the inferential statistics. The first concern is but one example from a general potential problem. This is the misleading effects that are possible when aggregated data are used. The specific problem I am addressing has been called "Simpson's paradox" and can be explained most easily by a hypothetical example.

The aggregate results for the two sites indicates that doubles have a higher involvement rate. The paradox is that this higher aggregate rate results even though singles have a higher rate at <u>each</u> of the two sites. The reason for the paradox is that site 1 has a higher involvement rate for both type of vehicles, and a greater portion of doubles travel is at

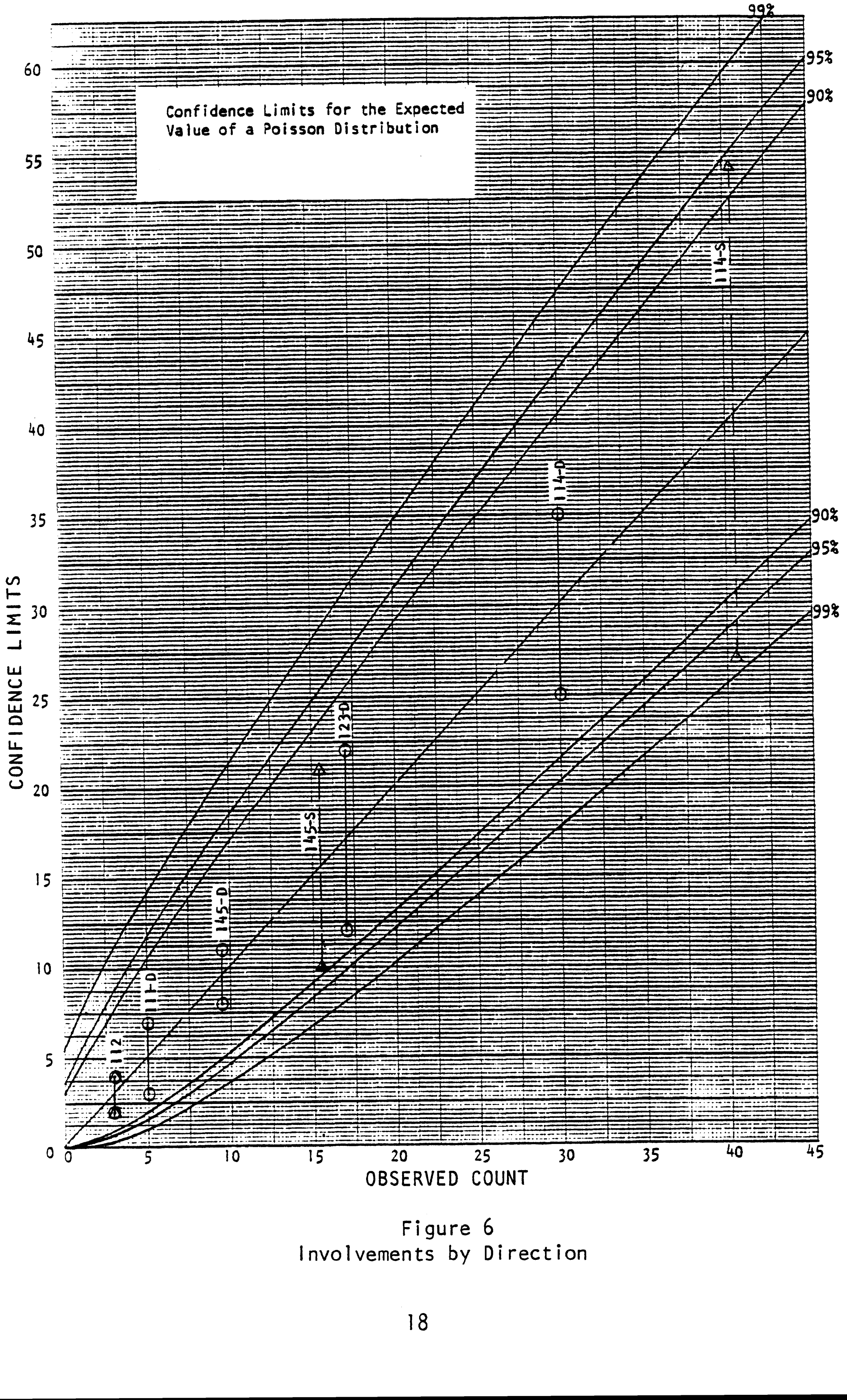


Figure 6
Involvements by Direction

Assume that the following accident and exposure data are available for singles and doubles at two sites:

Accident Involvements

	Singles	Doubles
Site 1	32	45
Site 2	108	35
Total	140	80

Exposure (in 100 mil. vehicle miles)

	Singles	Doubles
Site 1	0.2	0.3
Site 2	1.8	0.7
Total	2.0	1.0

The resulting involvement rates (involvements per 100 million vehicle miles) would be:

Involvement Rates

	Singles	Doubles
Site 1	160	150
Site 2	60	50
Total	70	80

this high-accident-rate site. Correlations between site and both accident rate and truck type are the culprit in producing the paradox. It is important to note that the erroneous result for the aggregated data is not a consequence of biased, missing, or otherwise faulty data, nor of sampling error. Such an error can only be avoided by including the pertinent variable--site in this case--in the analysis. A second important point is that <u>any</u> variable which is correlated with both the dependent and independent variables has the potential of causing an error in aggregated results if it is not included in the analysis. In the example cited above, the error was great enough to reverse the result. The same phenomena may occur without so dramatic an outcome. It could result in an apparent difference which is not real, or failure to detect a real difference.

An excellent example of the influence of a confounding variable in a closely related analysis is provided by Hedlund.[4] He compared the fatality rate in singles versus doubles accidents using BMCS data. Using only these variables, he found doubles had a significantly higher fatality rate. However, when he controlled for urbanization (rural, residential/business) and number of lanes (2,4), he found that the difference in singles and doubles rates were not statistically significant.

The analyses of doubles versus singles presented by BioTechnology would seem to be subject to this sort of error because of site differences. The report does state that paired t-tests were used. While they could be employed to avoid the paradox, but here is no indication of how they were used. The evaluation by TSC recognized the possibility of spurious results because of site differences and hence used disaggregated data.[5] However, the only confounding variable recognized and used in the TSC analysis was site. Other variables that are likely to be correlated with both vehicle type and accident rate are driver experience, highway type, vehicle use, time of day, and season. Since singles and doubles may be used for quite different purposes and under different circumstances, the relative day/night travel may also be different. Thus time of day, at least as a dichotomy, could be a particularly important confounding variable. The next section will examine a number of potentially confounding variables.

Passenger car travel has not been included in any of the analyses, and would appear to be a prime candidate for inclusion as an independent variable. One might expect truck accident experience to be influenced by the volume of concurrent car traffic. Philosophically, total traffic might be considered an exposure variable. Some researchers consider exposure in a broad sense to be exposure to the risk of accident. In

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[4] James Hedlund, The Severity of Large Truck Accidents, National Highway Traffic Safety Administration Technical Note DOT HS-802-332. April 1977.

[5] Edwin J. Roberts, Peter H. Mangert, Technical Evaluation of the BioTechnology, Inc. Study: The Effect of Truck Size and Weight on Accident Experience and Traffic Operations, TSC, DOT. July 1981.

this context, truck exposure might include a measure of concurrent car traffic. Irrespective of whether it is considered an accident or exposure variable, car traffic could be included as an independent variable in an analysis in which truck involvements per truck vehicle miles is the dependent variable.

Neither BioTechnology nor TSC included analyses which controlled for the effects of these variables upon a doubles-singles comparison. In fact, the data necessary for disaggregate multivariate analyses are not presented in the reports. With a total of 2112 truck involvements including only 256 doubles[6], the number of variables that could be included in any analysis is limited; the quantity of data may be insufficient to incorporate the appropriate variables even if those variables were available. The limitations imposed by the quantity of data can be illustrated by example. In comparing the involvement rate by vehicle type (singles versus doubles), we might choose to include as relevant independent (or control) variables; road class with the six levels used in the study, two levels of time of day (night, daytime), and two weight classes as suggested by Table 10 in Volume III. Together, this modest number of variables results in 2x6x2x2=48 cells in the accident population, half of which are for doubles. With only 256 doubles, the average number per cell would be only 10, and no measure of driver characteristics has been included.

Possible biases resulting from incomplete coverage, e.g., exposure measured for traffic in only one direction, were also recognized by the TSC and sensitivity analyses were used to assess the possible effects. Two problems remain. The amount of bias assumed in the TSC analysis appears to be arbitrary without supporting evidence, which it must be if no attempts were made during the project to evaluate missing data. In addition, the sensitivity analysis does not address the problems that result from spurious correlations, i.e., Simpson's paradox. Note that the hypothetical example cited above demonstrated an erroneous conclusion while assuming no missing data or biases in the observations.

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[6] Tractor-Semi-full trailer.

The second analytical concern expressed in the first paragraph of the section titled "Analyses," was with regard to exposure sampling error. The methods used to compute variances and in turn significance levels are not explicitly stated in the BioTechology Report. However, it is clear that sampling errors in the exposure data were not included. This would result in unrealistically low variances and significance levels. Thus, some comparisons might be judged significant when in fact they should not. In addition, the design effects of the multistage sampling were not included, and lack of national or state representation and their impact on statistical inferences were not addressed; the validity of the significance tests are uncertain.

The authors have not always been careful in stating lack of statistical significance. On several occasions (on page 55 with regard to cab-over versus cab-behind, for example) they unintentionally imply that lack of statistical significance between levels of a variable prove the effect is the same for all levels. This is not true; it only proves a difference has not been found, not that there is no difference. Lack of significance could result from a (statistical) test of low power.

The powers of the various comparisons, i.e., the capability of the test to detect real differences if they in fact exist, are not given in the report, nor can they be calculated with the data given. There is also no indication that the experimental design incorporated consideration of the specific issues to be examined, the analytical techniques to be used, and in turn, the data requirements to achieve specific powers. As a consequence, many of the tests may have low powers.

5.0 POTENTIALLY CONFOUNDING VARIABLES

Attributes which may cause error in comparisons of singles and doubles involvement rates through spurious correlations are those which are associated with both involvement rate and type of truck. Without access to detailed exposure information, associations with involvement rates cannot be examined. However, evidence that an attribute should be included in a statistical comparison of singles and doubles can be obtained from the accident data. Attributes which are associated with vehicle type in the accident data are at least candidates for inclusion in analyses of involvement rates.

Truck type by state in the accident data collected by BioTechnology is shown in Table 4. The table is given to describe the quantity of data collected and how it was distributed among the truck types and study states, and not for inferential purposes.

TABLE 4
Truck Type by State

		Truck Type				
		Straight	Single	Double	Other	Total
California	N	132	231	204	74	641
	%	20.6	36.0	31.8	11.5	100.0
Maryland	N	63	127	0	3	193
	%	32.6	65.8	0.0	1.6	100.0
Michigan	N	95	531	39	45	710
	%	13.4	74.8	5.5	6.3	100.0
Nevada	N	14	38	12	6	70
	%	20.0	54.3	17.1	8.6	100.0
Pennsylvania	N	44	314	0	7	365
	%	12.1	86.0	0.0	1.9	100.0
Texas	N	43	88	1	1	133
	%	32.3	66.2	0.8	0.8	100.0
Total	N	391	1329	256	136	2112
	%	18.5	62.9	12.1	6.4	100.0

The grouping by truck type in the table is as follows. All single-unit straight trucks are included under straight. This includes bobtails. Tractors towing semis are classes as singles. Tractors towing semis and full trailers are classed as doubles. The "other" category includes straight trucks towing either a semi (dolly) or full trailer, and 24 Michigan doubles (combination units with 9-11 axles). Although

Nevada was included in the study because it permits triples, there are none in the accident data.

A number of variables were examined as potentially confounding variables, by comparing their distribution for singles and doubles. For these comparisons the definitions of singles and doubles are the same as used in Table 4. Only involvements in California and Nevada are used, consistent with the singles-doubles comparisons made by BioTechnology and the Transportation Systems Center. A list of the variables examined is shown in Table 5. Each comparison was done as a 2xn contingency table. The significance levels are shown for the maximum-likelihood test of independence. Each variable with significance at less than the 0.1 level is indicated by an asterisk. This level was selected to identify all variables that potentially could confound comparisons of singles and doubles.

A total of 30 variables were used in the comparisons. In two cases (multi-vehicle accidents and culpability), the original variables coded by Biotechnology were each used to generate two derived variables. This will be described in more detail later. Each of the variables with a significance level of 0.10 or less is described below. Several of the variables have a large number of levels, making tests for independence difficult to interpret, or resulting in a number of nearly empty cells. In these cases, the complete table was partitioned into independent 2x2 tables, thus partitioning the total chi-square into its single-degree-of-freedom components.[7] With these general remarks, each variable which was significant at the 0.1 level will be discussed separately.

Month of Accident

The distribution of month of accident for singles and doubles is shown in Table 6. Since the data collection period was from July 1976 through December 1977, the July-December period should be overrepresented for both singles and doubles. This would not affect the

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[7] Maxwell, A. E., "Analysing Qualitative Data," Methuen Monographs on Applied Probability and Statistics, Methuen and Co., Ltd., London, 1961 (Chapter III).

TABLE 5

Accident Variable Examined as Potentially Confounding Variables

	Significance Level*
Month of accident	0.086*
Day of month	0.717
Year of accident	0.446
Day of week	0.472
Hour, 1-Hour intervals	0.498**
Highway type	0.001*
Intersection	0.102
Number of vehicles involved	0.483
Number of trucks involved	0.106
Multi-vehicle accident:	0.096*
Object struck	0.323
Impact type	0.394
Culpability	0.123
Driver culpability	0.726
Defective equipment	0.770
Weather	0.038*
Light	0.706
Road condition	0.007*
Cab type	0.003*
Make	0.033*
GVW, bracketed	0.002*
Load factor, 10% intervals	0.025*
Cargo unit configuration	0.000*
Cargo in first trailer straight/semi	0.001*
Accident classification	0.348
Truck movement, before impact	0.123
Age, 5-year intervals	0.341
Familiarity with road	0.040*
Experience as driver	0.879
Experience with rig	0.740
Driver classification	0.152
Trip classification	0.000*
Miles since rest $\geq$ 6 hr.	0.663
Independent driver	0.021*

*Significance level for the maximum likelihood independence test. An asterisk indicates significance at the 0.10 level. Singles (tractor-semi) were compared with doubles (tractor-semi-full trailer).

**Hour in 1 hour intervals was not significant, but certain time periods are.

relative distribution for singles and doubles, however, unless there is a seasonal component in their accident experience.

TABLE 6
Month of Accident

	Single		Double	
	N	%	N	%
January	8	3.0	4	1.9
February	11	4.1	9	4.2
March	14	5.2	12	5.6
April	8	3.0	11	5.1
May	14	5.2	13	6.0
June	14	5.2	7	3.2
July	48	17.8	17	7.9
August	42	15.6	45	20.8
September	32	11.9	32	14.8
October	28	10.4	28	13.0
November	19	7.1	20	9.3
December	31	11.5	18	8.3
Total	269	100.0	216	100.0

The chi-square significance level is 0.0991 for the entire table. June and July both have a relatively higher accident frequency for singles. Using the partitioned chi-square, the difference between June-July and the remainder of the table is significant at the 0.001 level (X^2 = 11.70, d.f. = 1). There are ten remaining independent tables, each with one degree of freedom, but none are significant at the 0.001 level. Thus there is a seasonal association with singles/doubles, with doubles having relatively fewer involvements in June and July.

Hour of Day

Hour of day, in 24 one-hour intervals, does not have significantly different distributions for singles and doubles involvements (significance level = 0.50). Neither does time of day in four-hour intervals. However, doubles are overrepresented in the period from

1:00-8:59 a.m. compared to singles. The proportions for this period are shown in Table 7.

TABLE 7
Singles Versus Doubles by Period of Day

Hour		Singles	Doubles
0100-0859	N	70	86
	%	26.0	39.8
0900-2400, 0000-0059	N %	199 74.0	130 60.2
Total	N	269	216
	%	100.0	100.0

Although the results are shown as a 2x2 table, the tests of significance were conducted by partitioning the degrees of freedom of the original 2x24 table. The chi-square for the entire 2x24 table was 21.7 with d.f. = 23. The component of the chi-square for the above partition is 10.44 with d.f. = 1, and a significance level of 0.0012. Thus the distribution of involvements by hour is significantly different for singles and doubles.

Highway Type

The distribution of highway type is significantly different for the two vehicle types. The maximum-likelihood-test significance level for Table 8 is 0.001.

Partitioning the chi-square indicates that doubles have relatively more of their involvements on primary and secondary roads (chi-square = 19.9, d.f. = 1). The difference between rural and urban highways is not significant. Although highway class is potentially an important confounding variable in the BioTechnology analysis, the analysis conducted by the Transportation Systems Center incorporated site in such a way that highway class should not produce errors in the singles versus doubles comparisons.

TABLE 8
Highway Type

	Singles		Doubles	
	N	%	N	%
Rural				
Freeway	149	55.4	95	44.0
Primary	27	10.0	48	22.2
Secondary	5	1.9	10	4.6
Urban:				
Freeway	75	27.9	47	21.8
Primary	13	4.8	15	6.9
Secondary	0	0.0	1	0.5
Total	269	100.0	216	100.0

Multi-Vehicle Accidents

The multi-vehicle accident variable is significant at the 0.096 level. However this significance is difficult to interpret. The variable has 42 levels, and is actually a combination of two variables describing the object struck (other vehicle type) and impact configuration. Statistical significance in the total table has little physical significance. The variable is more useful split into two variables, one for object struck and one for impact type. When this is done, neither resulting table is statistically significant, as indicated in Table 5.

Culpability is a similar variable. It is actually a multiple-response variable giving one or two factors of culpability. The complete table (in which each digit represents a factor) is not significant; nor are separate derived tables of driver culpability and defective equipment.

Weather

The distributions of weather for the singles and doubles involvements are shown in Table 9, which is significant at the 0.038 level.

TABLE 9
Weather

	Single		Double	
	N	%	N	%
Clear	211	79.0	146	67.6
Cloudy	30	11.2	34	15.7
Rain	20	7.5	30	13.9
Sleet/hail	0	0.0	1	0.5
Fog	3	1.1	2	0.9
Dust/sand	2	0.7	0	0.0
Heavy, gust wind	1	0.4	2	0.9
Combination: Dust/sand, wind	0	0.0	1	0.5
Total	267	100.0	216	100.0
M.D.	2		0	

Partitioning the table indicates that doubles involvements are less frequent in clear weather than in all other weather categories (chi-square = 8.09, d.f. = 1, significance level = 0.004). Even when clear and cloudy together are partitioned from the remainder of the table, the significance level is still 0.0024 (chi-square = 5.12, d.f. = 1).

Road Condition

Road surface condition, as shown in Table 10, is significant at the 0.007 level, with doubles having a lower proportion of their involvements on dry surfaces. Partitioning the tables into dry versus the remainder is still significant at the 0.011 level (chi-square = 6.47, d.f. = 1). The association with surface condition is not surprising given the association with weather, since one is nearly a surrogate for the other.

TABLE 10
Road Condition

	Single		Double	
	N	%	N	%
Dry	243	91.0	180	83.3
Wet	22	8.2	34	15.7
Snow/icy	2	0.7	0	0.0
Other	0	0.0	2	0.9
Total	267	100.0	216	100.0
Missing Data	2		0	

Cab Type

Cab type is associated with vehicle type as shown in Table 11. However, cab type is so closely associated with the configuration of the combination vehicle that it may not be an independent causal factor, and may not be an appropriate control variable.

It should also be noted that the amount of missing data is substantial--much greater than the number of conventional tractors. Thus the association is very sensitive to any bias that may exist in the missing data cases. The variables that have been discussed to this

TABLE 11
Cab Type

		Single	Double
Conventional	N %	42 28.6	19 14.2
COE	N %	105 71.4	115 85.8
Total	N %	147 100.0	134 100.0
Missing Data	N	122	82

point are all accident related (location, time, environment, etc.). The information is generally available on all police reports and consequently the missing data rates have been low. Those to be discussed subsequently are vehicle and driver related, often not addressed on police reports. As a result, the missing data rates in general will be much higher. This presents a dilemma. While driver and use factors may be very important to comparisons of singles and doubles involvement rates, they are among the more difficult data to collect on traffic accidents.

Tractor Make

The distribution of tractor manufacturer for singles and doubles combinations in the BioTechnology data is shown in Table 12. While the differences are significant at the p = 0.033 level, the interpretation of the table is not clear. The tractor make may be associated with more fundamental factors such as use or class of owner/operator.

Gross Vehicle Weight

The gross vehicle weight pooled in the same intervals as used in Table 10 of Volume III of the BioTechnology report is shown in Table 13. The overall table is significant at the 0.002 level. Two of the weight intervals are noteworthy because of their high incidence in the accident

TABLE 12
Tractor Make

	Single		Double	
	N	%	N	%
Autocar	1	0.4	2	1.0
Diamond Reo	2	0.8	0	0.0
Dodge	3	1.2	2	1.0
Ford	13	5.1	9	4.3
GMC	11	4.3	10	4.8
International	45	17.8	47	22.4
Kenworth	52	20.6	20	9.5
Mack	17	6.7	11	5.2
Peterbilt	40	15.8	30	14.3
White/ Freightliner	68	26.9	78	37.1
Other	1	0.4	1	0.5
Total	253	100.0	210	100.0
Missing Data	16		6	

population (column percent) and because of different proportions for singles and doubles in the two categories. These are the 21-30 and 71-80 kip groups. In both of these, doubles account for a greater proportion than do singles.

It should be noted that the numbers of involvements shown here are the numbers used to derive the rates shown by BioTechnology in Table 10. It is evident that the great variation in rates found by Biotechnology, and as published under report number FHWA/RD-80-137, July 1981, is largely a consequence of the exposure data rather than accident data, and is based on small numbers of involvements. It should also be

TABLE 13
Gross Vehicle Weight

GVW (kips)	Single		Double	
	N	%	N	%
0-20	10	7.9	0	0.0
21-30	33	26.0	43	39.8
31-40	18	14.2	13	12.0
41-50	15	11.8	8	7.4
51-60	9	7.1	3	2.8
61-70	14	11.0	8	7.4
71-80	27	21.3	32	29.6
81-90	0	0.0	1	0.9
101-150	1	0.0	0	0.0
Total	127	100.0	108	100.0
Missing Data	142		108	

evident that with more than half of the data missing on this variable, comparison of involvement rate by gross vehicle weight would be sensitive to bias in the missing data.

Load Factor

The load factor is the total vehicle weight expressed as a percentage of the total allowable weight, and is shown in Table 14. The significance level is 0.025 with a maximum likelihood ratio of 16.017, d.f. = 7. Doubles are underrepresented in the 51-90 percent categories, with a partitioned chi-square of 13.08 and a significance level of 0.0003 for this group compared to all others. All other independent partitions are insignificant at the 0.10 level.

This variable is closely associated with gross vehicle weight, at least for each restricted class of truck, and one might serve as a surrogate for the other. The amount of missing data is the same as for gross vehicle weight.

TABLE 14
Load Factor

Load Factor in Percent	Single		Double	
	N	%	N	%
21-30	8	6.3	7	6.5
31-40	38	30.2	40	37.4
41-50	6	4.8	9	8.4
51-60	14	11.1	4	3.7
61-70	9	7.1	6	5.6
71-80	8	6.3	3	2.8
81-90	23	18.3	9	8.4
91-100	20	15.9	29	27.1
Total	126	100.0	107	100.0
Missing Data	143		109	

Cargo Unit Configuration

The cargo unit configuration (type of trailer body) is shown in Table 15. The major significant differences are that tank and platform trailers are relatively more common on doubles than on singles, while fully enclosed trailers are more common on singles. These differences would seem to imply that doubles and singles are used for different purposes, at least in California and Nevada.

A comparison of the cargos in accident-involved singles and doubles is shown in Table 16.

The distribution for singles and doubles are significantly different at the 0.001 level (chi square = 39.97 with d.f. = 21). However, the large number of levels results in many empty cells, making the statistics for the total table suspect, and at least difficult to interpret. When the table is partitioned into a series of 2x2 comparisons, the difference in the proportion of empties is not significant (chi-square = 2.56, d.f. = 1, significance level = 0.11). The total sample of trucks (singles and doubles) with non-missing data on cargo is only 293, and this number is insufficient to detect the

TABLE 15
Cargo Unit Configuration

	Single		Double	
	N	%	N	%
Fully enclosed	116	61.4	59	35.5
Fully enclosed, low bed	5	2.6	5	3.0
Tank	10	5.3	19	11.4
Bulk commodity	3	1.6	8	4.8
Platform	41	21.7	67	40.4
Low-bed, heavy-hauler	7	3.7	0	0.0
Dump	3	1.6	6	3.6
Vehicle carrier	1	0.5	0	0
Platform w/sides (open)	3	1.6	2	1.2
Total	189	100.0	166	100.0
Missing data	80		50	

difference between 30 and 39 percent with high probability. The power of the test with the figures shown in Table 16, for a significance level of 0.1 is only 0.49--the probability of detecting such a difference. To achieve a power of 0.9 under the same conditions would require a total sample of 975 cases.

Although a substantial proportion of the trucks were carrying general freight, the difference for singles and doubles is not significant (chi-square = 0.541). However, a significantly greater proportion of the doubles were carrying farm products or livestock; 20.0 percent versus 9.5 percent. Partitioning the chi-square into this group versus all other cargos gives a chi-square of 6.50, d.f. = 1, and a

TABLE 16
Cargo in First Trailer

	Singles		Doubles	
	N	%	N	%
None, Empty	45	30.4	57	39.3
General Freight	25	16.9	20	13.8
Furniture	6	4.1	1	0.7
Refrigerator, Produce	8	5.4	2	1.4
Refrigerator, Frozen Goods	10	6.8	1	0.7
Farm Products	14	9.5	27	18.6
Hanging Goods	1	0.7	0	0.0
Livestock	0	0.0	2	1.4
Metal, Sheets	2	1.4	0	0.0
Metal, Coiled	3	2.0	1	0.7
Heavy Machinery	4	2.7	2	1.4
Vehicles	1	0.7	0	0.0
Bulk Solids	4	2.7	8	5.5
Bulk Liquids, Flammable	2	1.4	5	3.4
Bulk Liquids, Hazardous	1	0.7	0	0.0
Bulk Liquids, Non-Flam.	5	3.4	5	3.4
Logs, Poles	6	4.1	2	1.4
Lumber Products	5	3.4	6	4.1
Beverages	1	0.7	0	0.0
Food	2	1.4	6	4.1
Bulk Metal (scrap)	2	1.4	0	0.0
Other	1	0.7	0	0.0
Total	148	100.0	145	100.0
Missing Data	121		71	

significance level of 0.011. This variable provides further evidence that singles and doubles differed in their usage in the study areas.

Familiarity with Road

The familiarity of the driver with the road on which the accident occurred is given in Table 17. Doubles were more likely to have been on roads they traveled frequently, more often than once a week, than were singles; 63.7 percent of their involvements compared with 41.0 percent for singles. This difference is highly significant (p = 0.000).

TABLE 17
Familiarity with Road

Frequency of Use of Road	Single		Double	
	N	%	N	%
No driver	5	3.7	3	2.4
First time	4	3.0	4	3.2
Once/year	1	0.7	0	0.0
<Once/month	16	11.9	7	5.6
Once/month	13	9.7	8	6.5
<Once/week	22	16.4	10	8.1
Once/week	18	13.4	13	10.5
>Once/week	28	20.9	38	30.6
Daily	27	20.1	41	33.1
Total	134	100.0	124	100.0
Missing data	135		92	

Trip Classification

Classification of the trip by long or short haul is shown in Table 18. With the low incidence of "Variable" and "No driver," the table is essentially 2x2. The significance level for long versus short haul is less than 0.001, with doubles much more likely to have been on short trips and singles on long trips.

Independent Driver

The proportion of independent drivers in the two types of trucks is shown in Table 19. The difference in the Independent/Not independent dichotomy is significant at the 0.007 level, with doubles drivers about half as likely to be independents. Although the difference is highly significant, the number of drivers who are independent is much smaller than the number with missing data in either column. Again in this instance, the variable appears to be highly relevant, but with a missing data rate that limits its utility.

TABLE 18
Trip Classification

Class	Single		Double	
	N	%	N	%
No driver	5	3.6	3	2.4
Long haul	82	58.6	43	34.4
Short haul	53	37.9	78	62.4
Variable	0	0.0	1	0.8
Total	140	100.0	125	100.0
Missing Data	129		91	

TABLE 19
Independent Driver

Independent	Single		Double	
	N	%	N	%
No driver	5	4.0	3	2.4
Yes (independent)	35	28.0	18	14.5
No (not independent)	85	68.0	103	83.1
Total	125	100.0	124	100.0
Missing data	144		92	

Summary of Accident Variable Examination

Of the 30 variables examined above, 14 are statistically significant at the 0.1 level and 12 of these are significant at the 0.05 level. Several of the significant variables are closely related.

Consequently, they are probably highly correlated and might be considered surrogates, viz weather and road condition, GVW and load factor, and cargo unit configuration and cargo in first trailer. Each of these pairs might be treated as a single attribute. Cab type and tractor make may not be appropriate control variables for the reasons stated earlier.

There remain, then, nine variables which potentially could influence a comparison of singles and doubles accident involvement rates, and which are candidate control variables in a multivariate analysis. Four relate to environmental factors and where the accident occurred, three relate to the vehicle and its use, and two to the driver.

The BioTechnology comparison of overall singles and doubles rates did not include any control variables. The Transportation Systems Center analysis of singles versus doubles rates did use a methodology that would eliminate the effects of site differences, and consequently the effects of road type. The result is still subject to error from the confounding effects of the other attributes, however.

Without controlling for such error, it is impossible to predict, with any confidence, the safety consequence of expanding the use of doubles in another area or state to match that at the study sites in California and Nevada. Unfortunately, the exposure data evidently does not contain enough information, particularly on driver related variables, to conduct a multi-variate analysis using all of the potentially important variables, nor is the quantity of accident data sufficient to simultaneously include more than a small number.

6.0 SUMMARY

The six study states were not selected by a random process, nor do they represent a probability sample. They are a judgmental sample, and without appropriate weighting they cannot be used to give nationally representative estimates. This limitation was recognized by Biotechnology and so stated in the report.

Justification for the distribution of the number of each of the six road classes in each state is not given, and is apparently not based on a probability sample. The final choice of individual sites was also a judgmental selection by field personnel. Because of these two facets of the sample selection, the aggregate data within each state cannot be assumed to represent the state.

Comparison of the BioTechnology data with computer files from the Michigan State Police at six Michigan sites suggests that there was serious undercounting of large truck involvements in the Biotechnology data--undercounting from 35 to 45 percent. Undercounting of this magnitude in other project areas could introduce serious bias in the data, and in turn, the findings.

Although accident data were collected for a period of 18 months or six quarters, exposure data were evidently collected during only one quarter at many sites. Evidence of this is the fact that 41 percent of the sites representing 51 percent of the truck involvements had a constant ratio of truck to car ADT's used throughout the 18 months. Such sites accounted for 86 percent of the truck involvements in California and Nevada, the two states used for the singles-doubles comparisons. Incomplete exposure coverage over the data collection period could also lead to bias in the involvement rate derivations.

Computation of levels of statistical significance were not based on variances which included the sampling errors in the exposure data.

The sampling plan adopted for the study was a multistage design, but the computations for variances of estimates were based on a simple equal-probability sample, and did not include the design effects of the multistage sample.

The above two factors resulted in computed variances which are low, resulting in unrealistically low significance levels. This in turn may have led to recognizing differences, e.g., between singles and doubles, which are not real but the result of chance.

The comparisons of singles versus doubles involvement rates were based on single factor--or at the most, two factor--analyses.

Unrecognized correlation with confounding variables could have resulted in erroneous findings.

Thirty variables in the accident data were examined for correlation with vehicle type, specifically singles and doubles. Nine were found which, if also correlated with exposure, are potentially confounding variables. At least these nine are candidates for inclusion in any analysis of singles versus doubles involvement rates, or comparison of rates by gross-vehicle weight. The accident data consist of 2112 large truck involvements, and include 269 singles and 216 doubles in California and Nevada. Unfortunately, this is a quantity sufficient to include but only a very limited number of variables in any one multivariate analysis.

APPENDIX

Study Issues Addressed in Volume III: Accident Experience of Large Trucks

ISSUES FROM THE BIOTECHNOLOGY TRUCK STUDY, VOL III

ISSUE NO.	PAGE NO.	
1	37	Are accident rates affected by truck type and roadway type, and how does the accident rate of large trucks compare to the rates for non trucks?
2	39	Do accident rates vary by tuck weight?
3	43	On a ton-mile basis, does the accident rate vary by truck type?
4	45	Does the injury accident rate vary by truck type and roadway type?
5	47	Does the weight of the truck affect accident injury severity?
6	49	Do accident rates vary by overall truck length?
7	51	What are the widths of trucks involved in accidents, and are wider trucks over-involved in accidents?
8	53	What is the distribution of truck accidents by truck height?
9	55	Is there a difference in accident rates, injury rates, or injury severity between trucks with cab-over-engines(coe) and cab-behind-engines(cbe)?
10	57	Do certain trailer configurations have higher accident rates?
11	59	Is the drivers age related to accident frequency?
12	61	Is the truck drivers professional experience related to accident frequency?
13	63	Is driver experience with the rig related to accident frequency?
14	65	Are the drivers of the different truck types themselves different?
15	67	Do the accident dynamics for single vehicle truck accidents vary by truck type?
16	69	Do the accident dynamics for multi-vehicle truck accidents vary by truck type?
17	71	Is the distribution of accidents on vertical grades affected by truck type and does the degree of slope affect the distribution?

Supplemental Data

37	113	Were the truck drivers involved in accidents familiar with the roadway?
38	115	How many miles had been driven after a rest of six or more hours prior to the accident?
39	117	What was the distribution of the type of cargo carried by accident involved trucks?
40	119	Were there truck factors other than vehicle defects which contributed to the accident?
41	121	What were the truck movements immediately preceding the accident?
42	123	Do truck movements preceding a collision differ by truck type?
43	125	Where was the initial point of impact on the truck?
44	127	Does the point of impact vary by truck type?
45	129	What section of the truck was involved in the collision?
46	131	Was obstruction of the truck driver's vision a factor in accidents?
47	133	What factor (individual or agent) was most responsible for the occurrence of the accident?