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ANALYSIS OF EJECTION IN FATAL CRASHES

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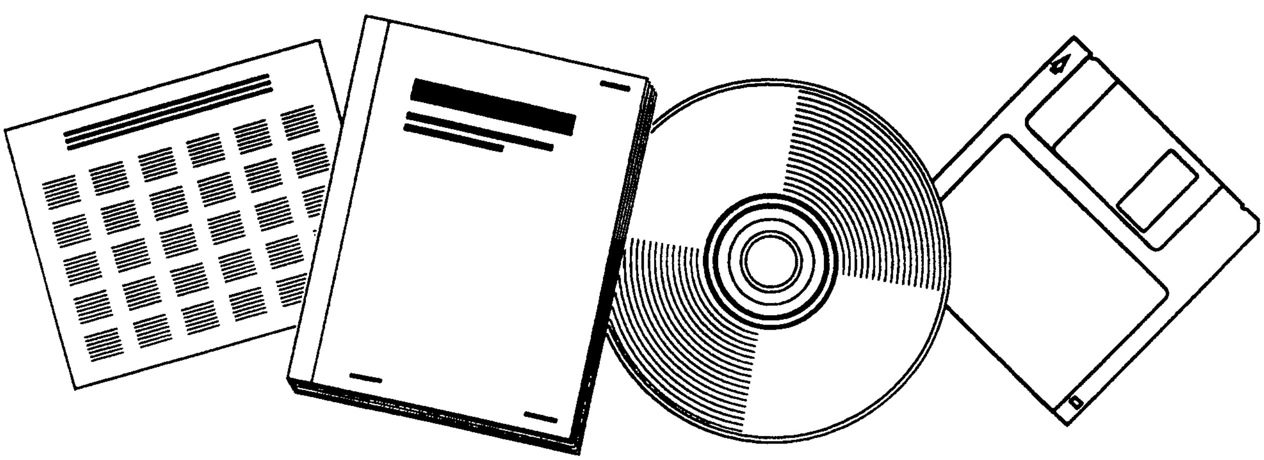

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Analysis of Ejection in Fatal Crashes

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16. Abstract

Data from NHTSA's Fatality Analysis Reporting System (FARS) show that the ejection rate among fatally injured passenger vehicle occupants has remained about 20% since the early 1980's. While belt use among fatally injured occupants increased from 2.7% in 1982 to 35.2% in 1996, there has only been a slight decline in the rate of ejection (23% in 1982 to about 22% in 1996). In addition, the overall rate of total ejection in fatal crashes was 2.4% for belted occupants in FARS and 29.3% for unbelted occupants in FARS during the same time period. This study focused on unbelted occupants in FARS to identify factors associated with the rate of ejection. The study found that rollover, speed of the vehicle prior to the crash, the age of the driver, and whether or not the unbelted occupant was a passenger of a light truck to be associated with the prevalence of ejection. Based upon the analysis, the increase in the prevalence of ejection among unbelted occupants in fatal crashes from 1982 to 1996 can be explained by the increased severity of crashes, as evidence by the increase in rollover rate and speed, together with an increase in the proportion of light trucks in those crashes. Younger drivers were found to be more likely to be involved in ejection crashes. In spite of the increase in the average age of fatally injured persons, the average driver age in rollover and ejection crashes has not substantially increased during the period 1982 - 1996. These findings lead to the conclusion that unbelted drivers are those most likely to engage in risky driving behavior associated with more severe crashes and higher probability of ejection.

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Executive Summary

Data from NHTSA's Fatality Analysis Reporting System (FARS) show that the ejection rate among fatally injured passenger vehicle occupants has remained at over 20 percent since the early 1980's. Because the risk of fatality in a crash is over three times as great for an ejected occupant compared with a nonejected occupant (i.e., person retained in the vehicle), ejection remains a significant traffic safety problem.

While the safety belt use rate among fatally injured motor vehicle occupants has increased from 2.7 percent in 1982 to 35.8 percent in 1996, there has been only a slight decline in the occupant ejection rate during the same period. The fraction of totally ejected fatalities was about 23 percent in 1982, and it was about 21 percent in 1996.

For the period 1982 to 1996, the overall rate of total ejection in fatal crashes was 2.5 percent for belted occupants and 29.4 percent for unbelted occupants. Because safety belt use largely eliminates the possibility of ejection in a crash, the fact that the ejection problem does not appear to have diminished, in spite of the increase in safety belt use, must be explained by ejections in the population of motor vehicle occupants who remain unbelted.

Focusing on the unbelted individuals, the analysis finds that their ejection rate has increased from 25 percent to about 33 percent during the period 1982 to 1996. The main factor contributing to ejection among the unbelted individuals is the occurrence of rollover during the crash, which increases the odds of ejection over five times. The average fraction ejected in rollover crashes is 51 percent compared with the ejection rate of 11 percent in fatal crashes not involving rollover.

A time trend analysis shows an increase in rollover rate among the unbelted individuals from about 28 percent in the early 1980's to over 37 percent in 1996. Thus, the increase in ejections among unbelted individuals was accompanied by an increase in rollovers, which indicates that unbelted individuals tend to be involved in more severe crashes.

Another factor that the analysis found to be strongly associated with ejection, particularly in rollover crashes, is the speed of the vehicle prior to the crash. The average police-reported speed in fatal crashes for the unbelted population has increased from about 50 mph in the early 1980's to almost 55 mph in 1996, while it has remained between 46 and 47 mph for the belted population. This provides further evidence that unbelted individuals are involved in more severe crashes.

The analysis further shows that the odds of ejection are about 1.4 times as great in a light truck (including vans and sport utility vehicles) compared with a passenger car. This estimate of the relative odds of ejection is adjusted for such factors as safety belt use and the occurrence of rollover, which leads to the conjecture that it is due to an intrinsic difference in the dynamics of being involved in a crash in a light truck compared to a crash in passenger car. Since the fraction

of light trucks involved in fatal crashes has increased from about 21 percent in the early 1980's to about 31 percent in 1996, this factor also contributes to explaining the increased prevalence of ejection.

Finally, the driver's age was found to be an important predictor of the probability of ejection. Younger drivers are more likely to be involved in ejection crashes. The average age of unbelted individuals in fatal crashes is about 35 compared with the average age of about 45 for the belted individuals. The average driver age in rollover crashes is about 33, while the average driver age in ejection crashes is about 32. In spite of the general increase in the average age of fatally injured individuals, the average driver age in rollover and ejection crashes has grown very little from 1982 to 1996.

This analysis leads to the conclusion that the increase in the prevalence of ejection among the unbelted individuals in fatal crashes during the 1980's and 1990's can be explained by the increased severity of crashes

in that population, as evidenced by the increase in the rollover rate and speed, together with the increase in the presence of light trucks in those crashes and the young age of drivers involved.

The unbelted population consists of individuals who remained unbelted in spite of the enactment of safety belt use laws and public information and education campaigns. This analysis shows that they are the population more likely to be involved in the type of crashes which result in ejection when safety belts are not used compared with the population of individuals who started using safety belts during the 1980's and 1990's.

Introduction

Occupant ejection in a motor vehicle crash is an event associated with the most severe consequences. NHTSA has estimated that the relative risk of fatality for an ejected individual compared to a non-ejected individual is 3.55 for drivers and 3.15 for passengers. The relative risk of incapacitating injury (given survival) has been estimated to be 2.39 for drivers and 1.95 for passengers [1].

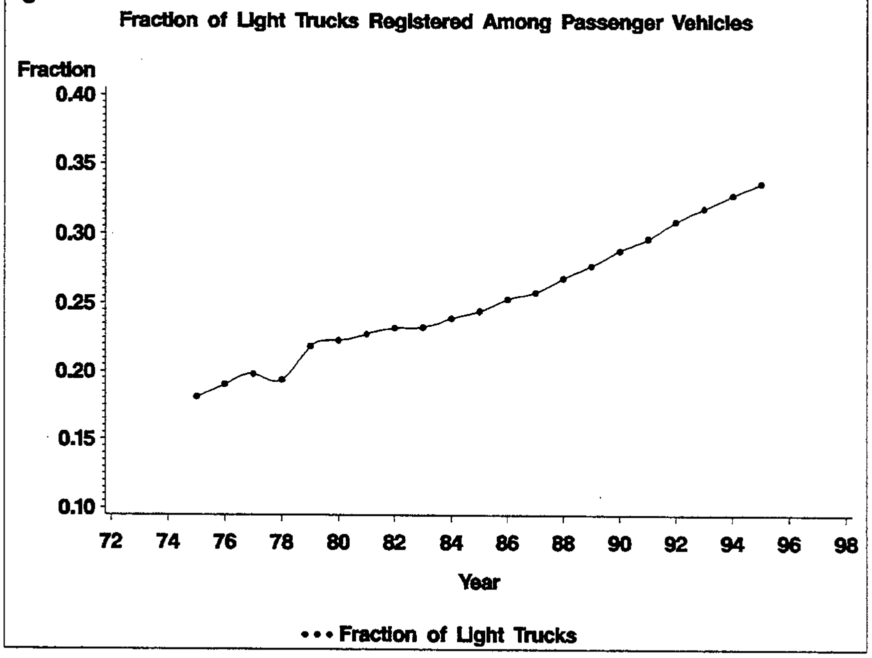
According to NHTSA statistics, in 1995 there were 9,257 ejected fatalities (including partial ejections), which is about 28 percent of all fatally injured motor vehicle occupants. Of these, 4,837 were occupants of passenger cars, which is 21.6 percent of all passenger car fatalities, and 4,069 were occupants of light trucks (including vans and sport utility vehicles), which is 42.7 percent of all light truck fatalities [2].

It is apparent that ejection is a serious traffic safety problem. The above numbers show that ejection is much more common among light truck occupants than among passenger car occupants. The following data show a recent trend in light truck registrations.

Table 1. Percentage of light trucks among passenger vehicles (based on the numbers of registered vehicles).

Year	Percentage of light trucks
75	18.11
76	19.03
77	19.80
78	19.35
79	21.84
80	22.29
81	22.76
82	23.20
83	23.26
84	23.91
85	24.46
86	25.32
87	25.81
88	26.85
89	27.74
90	28.82
91	29.68
92	30.91
93	31.84
94	32.78
95	33.66

Figure 1



The fact that the presence of light trucks among passenger vehicles on our highways is steadily increasing, together with the fact that ejection is more common among light truck occupants raises additional concerns about the ejection problem.

In order to devise effective strategies to reduce the occurrence of occupant ejection, it is important to understand the factors that are associated with ejection in a crash. The analytical tool convenient for this type of investigation is the logistic regression model. This study is limited to the analysis of ejection in fatal crashes. Consequently, the appropriate database to use is the Fatality Analysis Reporting System (FARS). Ejection is coded in FARS as either complete or partial. The FARS coding manual states that "ejection refers to persons being completely thrown out from the compartment of the vehicle during the course of the crash", but does not further elaborate on the difference between complete and partial ejections. The data are coded based on information in the police accident report. For the purposes of this analysis, by an ejection we mean a complete ejection as recorded in FARS. Partial ejections are relatively much less frequent, and may pose interpretation problems. On the other hand, the definition of total ejection is quite unambiguous.

In the first part of the study, the probability of ejection in a fatal crash is modeled as a function of several variables (covariates) to determine which factors appear to be significantly related to ejection. It is well-known that the use of safety belts almost eliminates the possibility of complete ejection. This fact is confirmed by a preliminary run of the logistic regression model. It appears then that it is appropriate to focus attention on the population of unbelted occupants. Another factor that dominates all other factors in the model is the occurrence of rollover. This indicates that the population of rollover-involved occupants may have different characteristics than the non rollover-involved population and has to be analyzed separately.

Once the analysis is restricted to a population homogeneous with respect to safety belt use and rollover, the accuracy of the model estimation is decreased due to a smaller sample size, but several interesting conclusions can be drawn. It allows one to delineate a number of factors most closely correlated with ejection. These findings help to guide the second part of the analysis, which deals with the time trends in factors relevant to ejection in fatal crashes.

As is well documented in NHTSA's research (e.g., [4]), safety belt use in fatal crashes has increased from almost zero in 1980 to over 30 percent in 1996. One would expect a corresponding decrease in the number of ejections. For example, if belt use were near 100 percent, there should be almost no ejections. It may then appear surprising that the fraction of ejected fatalities has apparently remained constant over the period in question.

Since the fraction ejected is negligible among the belted occupants, it had to increase in the unbelted population, as is readily confirmed by the data. This finding raises the question whether the increasing trend in ejection among unbelted occupants is associated with changes in other factors identified earlier as relevant to ejection. In order to answer this question, time-trends were analyzed for such variables as the fraction of rollovers, average speed, the fraction of trucks involved in crashes, and the average occupant age. These were analyzed in different populations determined by belt use and ejection status. The final section of the report discusses the conclusions that can be drawn from the analysis.

Logistic Regression Analysis

The logistic regression model is designed for an analysis of a binary response as a function of one or more covariates. That is, the dependent variable takes two values, say 0 and 1, indicating the occurrence or non occurrence of an event such as ejection. The covariates, or explanatory variables, may be either discrete or continuous and serve as predictors in the model. If $x_1,\ldots,x_n$ are the covariates and $p(x_1,\ldots,x_n)$ denotes the probability that the event (ejection) occurs, then the model has the form $\log\frac{p(x_1,\ldots,x_n)}{1-p(x_1,\ldots,x_n)}=a_0+a_1x_1+\ldots+a_nx_n$, where $a_1,\ldots,a_n$ are constant coefficients [5]. Given a collection of data on fatally injured occupants, including the indicator of ejection status y and the covariates $x_1,\ldots,x_n$, the coefficients $a_1,\ldots,a_n$ are determined so

that the likelihood function $L(\{y,x_1,\ldots,x_n\}) = \prod_{\{y,x_1,\ldots,x_n\}} [p(x_1,\ldots,x_n)]^y[1-p(x_1,\ldots,x_n)]^{1-y}$, where

$\{y,x_1,\ldots,x_n\}$ symbolizes the collection of all (n+1)-tuples in the database and $\prod_{\{y,x_1,\ldots,x_n\}}$ denotes a

product over all such (n+1)-tuples. The above likelihood function means that we model ejection status of individuals under consideration as independent random variables taking value 1 with probability $p(x_1,\ldots,x_n)$ and value 0 with probability $1-p(x_1,\ldots,x_n)$, where $x_1,\ldots,x_n$ are the individual's covariates.

In our application, the covariates are such variables as indicator of weather conditions when the crash occurred (precipitation) (PRECIPIT), whether it occurred during weekend (WEEKEND), whether it occurred at night (NIGHT), whether it occurred on a curve (CURVE), whether it occurred on a slope (GRADE), whether it occurred in a rural area (RURAL), whether the vehicle was speeding (SPEEDING), whether the vehicle was a light truck (including sport utility vehicles and vans) (TRUCK), whether rollover occurred (ROLLOVER), vehicle age (VEH_AGE), whether the driver was under the influence of alcohol (DR_DRINK), whether the driver was sleepy (SLEEPY), posted speed limit (SP_LIMIT), traveling speed of the vehicle at the time of the crash (TRAV_SP), whether a collision with another vehicle occurred (COLLIDED), driver's age (DR_AGE), driver's sex (DR_MALE), occupant's seating position (FRONT), and safety belt use (BELT).

The analysis utilizes FARS data from 1982 to 1996. Earlier years of FARS were not used because it appears that the coding of some relevant variables in those early FARS files may not be as reliable. In particular, there is a large percentage of cases with ejection coded as unknown in the mid-1970's. Although most likely these were nonejected occupants, the percentage of ejections becomes substantially higher for those years. In 1982, several changes were made to the system, including introduction of edit checks for the ejection variable. Consequently, the analysis restricted to post-1981 files appears more reliable.

Only fatally injured motor vehicle occupants (drivers and passengers) over the age of 12 were included in the analysis. The restriction to fatally injured occupants is again made in the interest of uniformity and reliability of the analysis. For example, the crucial variable indicating safety belt use is believed to be overreported in cases which rely on information provided to the investigating police officer by crash-involved occupants. On the other hand, it is also believed that the information on belt use among the fatally injured occupants is subject to much less overrreporting because it is usually based on direct observation by emergency personnel arriving at the scene of the crash rather than survivor's testimony.

Presented below are the results of estimation of the model when all of the covariates listed above are included.

Table 2. Logistic regression analysis: all fatally injured individuals in FARS 1982 to 1996.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-2.9567	0.1869	250.2678	0.0001	.	.
YEAR	1	0.00736	0.00195	14.1885	0.0002	0.016834	1.007
PRECIPIT	1	-0.2724	0.0278	96.3747	0.0001	-0.048576	0.762
WEEKEND	1	-0.00435	0.0164	0.0701	0.7912	-0.001148	0.996
NIGHT	1	-0.0843	0.0177	22.8041	0.0001	-0.023224	0.919
CURVE	1	-0.0544	0.0174	9.7296	0.0018	-0.013989	0.947
RURAL	1	-0.0176	0.0204	0.7496	0.3866	-0.004301	0.983
GRADE	1	0.0547	0.0167	10.7495	0.0010	0.014396	1.056
SPEEDING	1	0.1125	0.0202	31.0882	0.0001	0.030191	1.119
TRUCK	1	0.3663	0.0175	437.7185	0.0001	0.088914	1.442
DR_DRINK	1	-0.0163	0.0181	0.8126	0.3674	-0.004428	0.984
VEH_AGE	1	-0.00742	0.00138	29.0717	0.0001	-0.023161	0.993
SLEEPY	1	0.0695	0.0380	3.3426	0.0675	0.007282	1.072
ROLLOVER	1	1.6741	0.0178	8825.8326	0.0001	0.430497	5.334
SP_LIMIT	1	0.0129	0.000976	174.6793	0.0001	0.067951	1.013
TRAV_SP	1	0.0102	0.000573	317.2725	0.0001	0.118915	1.010
COLLIDED	1	-0.3859	0.0207	346.5448	0.0001	-0.106371	0.680
BELT	1	-2.7403	0.0431	4042.0035	0.0001	-0.620951	0.065
FRONT	1	0.0904	0.0505	3.1983	0.0737	0.007654	1.095
DR_MALE	1	-0.1283	0.0197	42.5089	0.0001	-0.031566	0.880
DR_AGE	1	-0.0115	0.000528	474.2339	0.0001	-0.122831	0.989

It is apparent that the use of safety belt and the occurrence of rollover are by far the most significant variables in the model. The odds of ejection for unbelted occupants are about 15.38 times as great as the odds of ejection for belted occupants. The odds of ejection in rollover are about 5.33 times as great as the odds of ejection without rollover.

The next group of variables in the full model that appear very significant are an indicator of whether the vehicle was a truck (1.44 times higher odds of ejection for trucks), driver's age (odds decrease by a factor of 0.989 with every year of age), and an indicator of a collision with another vehicle (1.47 times higher odds in single-vehicle crashes).

Other variables with quite significant coefficients in the full model include vehicle's traveling speed (odds increase by a factor of 1.010 per 1 mph increase in speed), posted speed limit (odds increase by a factor of 1.013 per 1 mph increase in posed speed limit).

Of special interest for this study is the variable indicating a time-trend (YEAR). It turns out to be significant, but with relatively low chi-squared value. Its positive coefficient indicates that there is an increasing time-trend left after adjusting for all the variables in the model, presumably accounting for some factors not represented by those variables.

The full model utilizes about 125,000 observations out of a total of about 450,000 available in the FARS database for 1982-1996. Only the observations for which there were no missing values for any of the variables were included in the calculation. A large number of observations were not used because a single variable - traveling speed - had a missing value. The number of observations with missing traveling speed is about 260,000 out of 450,000. Consequently, it is useful to estimate the model without this variable, so that the number of observations used is more than doubled.

Table 3. Logistic regression analysis: all fatally injured individuals in FARS 1982-1996, variable traveling speed omitted.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-3.4608	0.1237	783.0973	0.0001	.	.
YEAR	1	0.0145	0.00129	126.6185	0.0001	0.033667	1.015
PRECIPIT	1	-0.2630	0.0179	216.3749	0.0001	-0.048450	0.769
WEEKEND	1	0.00132	0.0111	0.0143	0.9050	0.000348	1.001
NIGHT	1	-0.0749	0.0120	38.9532	0.0001	-0.020652	0.928
CURVE	1	-0.00938	0.0119	0.6228	0.4300	-0.002362	0.991
RURAL	1	-0.0257	0.0132	3.7860	0.0517	-0.006603	0.975
GRADE	1	0.0295	0.0115	6.5257	0.0106	0.007517	1.030
SPEEDING	1	0.2703	0.0120	510.9172	0.0001	0.070113	1.310
TRUCK	1	0.3628	0.0117	961.4333	0.0001	0.087531	1.437
DR_DRINK	1	0.0443	0.0121	13.3674	0.0003	0.012052	1.045
VEH_AGE	1	-0.00679	0.000934	52.8717	0.0001	-0.020899	0.993
SLEEPY	1	0.0326	0.0250	1.7005	0.1922	0.003524	1.033
ROLLOVER	1	1.6966	0.0120	20125.5809	0.0001	0.425219	5.455
SP_LIMIT	1	0.0207	0.000623	1109.1086	0.0001	0.112796	1.021
COLLIDED	1	-0.4167	0.0136	944.0258	0.0001	-0.114871	0.659
BELT	1	-2.6729	0.0286	8758.3909	0.0001	-0.608895	0.069
FRONT	1	0.0598	0.0352	2.8859	0.0894	0.004870	1.062
DR_MALE	1	-0.1015	0.0131	59.6179	0.0001	-0.024944	0.903
DR_AGE	1	-0.0130	0.000346	1407.1733	0.0001	-0.139450	0.987

The results of estimation of the model without the traveling speed variable confirm the findings based on the model with all variables present. Characteristically, the most significant variables, i.e., safety belt use and rollover, are almost unaffected. This shows that the estimates of odds ratios are quite stable with respect to changes in the set of observations used. It might also be noted that the relative significance of the variable indicating speeding increases to about the rank that traveling speed had in the full model.

Furthermore, stepwise logistic regression was used to eliminate from the model the variables that are not significant. This procedure also tends to eliminate collinearity problems. The stepwise method consists in incorporating variables into the model one at a time, starting with the most significant one. At each step, the most significant variable not currently in the model is added to the variables present in the previous step, while any variables which at that point turn out not significant (at a predetermined significance level, say 0.05) are deleted. The process continues until no significant variable is left out.

The results of stepwise logistic regression analysis are presented next.

Table 4. Stepwise logistic regression: all fatally injured individuals in FARS 1982-1996.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-2.8742	0.1784	259.5122	0.0001	.	.
YEAR	1	0.00738	0.00195	14.3434	0.0002	0.016886	1.007
PRECIPIT	1	-0.2730	0.0277	97.0727	0.0001	-0.048684	0.761
NIGHT	1	-0.0882	0.0169	27.2677	0.0001	-0.024289	0.916
CURVE	1	-0.0583	0.0173	11.3052	0.0008	-0.014979	0.943
GRADE	1	0.0539	0.0166	10.4989	0.0012	0.014179	1.055
SPEEDING	1	0.1075	0.0200	28.7975	0.0001	0.028860	1.113
TRUCK	1	0.3670	0.0174	442.7537	0.0001	0.089096	1.443
VEH_AGE	1	-0.00756	0.00137	30.3778	0.0001	-0.023599	0.992
ROLLOVER	1	1.6732	0.0178	8850.7439	0.0001	0.430265	5.329
SP_LIMIT	1	0.0128	0.000916	195.5030	0.0001	0.067475	1.013
TRAV_SP	1	0.0102	0.00057	317.3029	0.0001	0.118315	1.010
COLLIDED	1	-0.3902	0.0205	363.4738	0.0001	-0.107556	0.677
BELT	1	-2.7345	0.0430	4043.1280	0.0001	-0.619617	0.065
DR_MALE	1	-0.1307	0.0195	44.7848	0.0001	-0.032159	0.877
DR_AGE	1	-0.0115	0.000526	473.5612	0.0001	-0.122412	0.989

The above results show that the use of safety belts dramatically changes the probability of ejection in a crash. This is consistent with intuition, and can be illustrated by a simple comparison of ejection rates among belted and unbelted occupants.

Table 5. Ejection Rates Among Belted and Unbelted Motor Vehicle Occupants in Fatal Crashes

	Ejected	Not ejected
Belted	2.49%	97.51%
Unbelted	29.43%	70.57%

As mentioned earlier, the use of safety belts is subject to overreporting in traffic crash databases, including FARS. However, even if the above estimates of ejection rates are biased, the bias would tend to increase the estimated ejection rate among belted individuals, which would be an even stronger indication that ejection is primarily a problem among unbelted occupants. It is then proper to focus the analysis of ejection on this latter population as the actual population at risk. The first step in a study of the characteristics of this population is to restrict the logistic regression model to the unbelted population to delineate the factors that are determinative of ejection among them.

Table 6. Logistic regression analysis: unbelted fatally injured individuals in FARS 1982-1996.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-2.8715	0.1897	229.1421	0.0001	.	.
YEAR	1	0.00613	0.00198	9.5806	0.0020	0.014035	1.006
PRECIPIT	1	-0.2728	0.0283	92.9033	0.0001	-0.047522	0.761
WEEKEND	1	-0.00564	0.0168	0.1132	0.7365	-0.001503	0.994
NIGHT	1	-0.0876	0.0180	23.6673	0.0001	-0.024128	0.916
CURVE	1	-0.0570	0.0178	10.2547	0.0014	-0.014854	0.945
RURAL	1	-0.0162	0.0208	0.6043	0.4369	-0.003905	0.984
GRADE	1	0.0535	0.0170	9.8882	0.0017	0.014134	1.055
SPEEDING	1	0.1168	0.0206	32.2007	0.0001	0.031811	1.124
TRUCK	1	0.3862	0.0179	468.0202	0.0001	0.096412	1.471
DR_DRINK	1	-0.0259	0.0184	1.9826	0.1591	-0.007130	0.974
VEH_AGE	1	-0.00739	0.00140	28.0195	0.0001	-0.023682	0.993
SLEEPY	1	0.0816	0.0392	4.3384	0.0373	0.008643	1.085
ROLLOVER	1	1.6957	0.0181	8753.7173	0.0001	0.447431	5.450
SP_LIMIT	1	0.0131	0.000995	172.7916	0.0001	0.069088	1.013
TRAV_SP	1	0.0102	0.000584	303.1359	0.0001	0.115878	1.010
COLLIDED	1	-0.3891	0.0212	338.2160	0.0001	-0.106638	0.678
FRONT	1	0.0802	0.0511	2.4673	0.1162	0.007223	1.084
DR_MALE	1	-0.1284	0.0202	40.3622	0.0001	-0.030380	0.880
DR_AGE	1	-0.0111	0.00054	422.4293	0.0001	-0.112649	0.989

One finds that rollover remains the dominant factor. In fact, the results are remarkably similar to the results of the analysis utilizing all observations. This is not surprising in view of the fact that there are relatively few ejections among the belted individuals, so the analysis is primarily driven by the unbelted cases. This can also be seen from the results of estimating the logistic regression model for the belted individuals, which is shown here for illustrative purposes since it is not the population of main interest.

Table 7. Logistic regression analysis: belted fatally injured individuals in FARS 1982-1996.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-9.0819	1.2774	50.5487	0.0001	.	.
YEAR	1	0.0499	0.0130	14.7235	0.0001	0.092446	1.051
PRECIPIT	1	-0.2885	0.1474	3.8310	0.0503	-0.055419	0.749
WEEKEND	1	0.0209	0.0879	0.0563	0.8124	0.005235	1.021
NIGHT	1	-0.0439	0.0946	0.2151	0.6428	-0.011417	0.957
CURVE	1	-0.0355	0.0941	0.1419	0.7064	-0.008512	0.965
RURAL	1	-0.0964	0.0992	0.9456	0.3308	-0.024392	0.908
GRADE	1	0.0742	0.0878	0.7137	0.3982	0.019310	1.077
SPEEDING	1	-0.0305	0.1093	0.0780	0.7801	-0.007323	0.970
TRUCK	1	-0.2368	0.1086	4.7566	0.0292	-0.049292	0.789
DR_DRINK	1	0.2778	0.1003	7.6761	0.0056	0.061968	1.320
VEH_AGE	1	-0.00635	0.00864	0.5406	0.4622	-0.016722	0.994
SLEEPY	1	-0.0167	0.1840	0.0082	0.9278	-0.001671	0.983
ROLLOVER	1	1.0535	0.0984	114.5414	0.0001	0.228150	2.868
SP_LIMIT	1	0.00945	0.00517	3.3447	0.0674	0.049253	1.009
TRAV_SP	1	0.0139	0.00304	20.8628	0.0001	0.168256	1.014
COLLIDED	1	-0.3764	0.1085	12.0407	0.0005	-0.097880	0.686
FRONT	1	0.3738	0.4197	0.7931	0.3732	0.022801	1.453

DR_MALE	1	-0.1333	0.0910	2.1464	0.1429	-0.035773	0.875
DR_AGE	1	-0.0215	0.00271	63.0483	0.0001	-0.255418	0.979

In comparison with the results for unbelted occupants, one notices very low chi-square values and only five significant variables (including the time-trend), in spite of over 26,000 observations.

Returning to the analysis of ejection in the unbelted population, presented below are the results of estimation of the model when the traveling speed variable is omitted (and consequently the number of observations is more than doubled from about 97,000 to over 220,000).

Table 8. Logistic regression analysis: unbelted fatally injured individuals in FARS 1982-1996, no traveling speed variable.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-3.3635	0.1256	717.6596	0.0001	.	.
YEAR	1	0.0131	0.00131	100.3773	0.0001	0.030429	1.013
PRECIPIT	1	-0.2662	0.0183	212.1926	0.0001	-0.047960	0.766
WEEKEND	1	-0.00156	0.0113	0.0191	0.8901	-0.000415	0.998
NIGHT	1	-0.0768	0.0123	39.2379	0.0001	-0.021117	0.926
CURVE	1	-0.00725	0.0121	0.3573	0.5500	-0.001853	0.993
RURAL	1	-0.0268	0.0135	3.9551	0.0467	-0.006848	0.974
GRADE	1	0.0278	0.0118	5.5762	0.0182	0.007130	1.028
SPEEDING	1	0.2711	0.0122	493.4275	0.0001	0.071851	1.311
TRUCK	1	0.3809	0.0119	1018.9883	0.0001	0.094555	1.464
DR_DRINK	1	0.0348	0.0124	7.9404	0.0048	0.009589	1.035
VEH_AGE	1	-0.00657	0.000949	47.9083	0.0001	-0.020739	0.993
SLEEPY	1	0.0403	0.0257	2.4612	0.1167	0.004382	1.041
ROLLOVER	1	1.7178	0.0122	19923.0750	0.0001	0.443695	5.572
SP_LIMIT	1	0.0210	0.000636	1093.6120	0.0001	0.114757	1.021
COLLIDED	1	-0.4197	0.0138	918.7379	0.0001	-0.115302	0.657
FRONT	1	0.0455	0.0355	1.6419	0.2001	0.003958	1.047
DR_MALE	1	-0.0981	0.0135	52.7568	0.0001	-0.023145	0.907
DR_AGE	1	-0.0126	0.000355	1261.1950	0.0001	-0.128723	0.987

These results confirm the conclusions based on the model with the variable traveling speed included. As expected, the relative significance of the variables speeding and posted speed limit increased substantially. Another distinctive feature of the above results is that the significance of the time-trend variable is relatively much greater than in the model incorporating traveling speed. This suggests the existence of a linear time-trend in the traveling speed variable.

Because rollover is a dominant variable in the model for unbelted individuals (as well as for the belted ones), it is useful to examine the rollover-involved population separately from the populations of individuals not involved in rollover. As far as ejection is concerned, these two populations appear to have different characteristics. Presented below are the results of estimating the logistic regression model for unbelted rollover-involved individuals.

Table 9. Logistic regression analysis: rollover-involved, unbelted fatally injured individuals in FARS 1982-1996.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-1.7122	0.2705	40.0675	0.0001	.	.
YEAR	1	0.00507	0.00280	3.2827	0.0700	0.011451	1.005
PRECIPIT	1	-0.4995	0.0437	130.8454	0.0001	-0.070780	0.607
WEEKEND	1	0.00353	0.0230	0.0235	0.8781	0.000962	1.004
NIGHT	1	-0.1255	0.0251	24.9717	0.0001	-0.034066	0.882
CURVE	1	-0.0514	0.0242	4.5146	0.0336	-0.014072	0.950
RURAL	1	-0.0228	0.0304	0.5611	0.4538	-0.004899	0.977
GRADE	1	0.0848	0.0236	12.9467	0.0003	0.022866	1.088
SPEEDING	1	-0.0354	0.0281	1.5865	0.2078	-0.009550	0.965
TRUCK	1	0.4148	0.0240	298.3916	0.0001	0.112510	1.514
DR_DRINK	1	-0.0924	0.0257	12.9081	0.0003	-0.024948	0.912
VEH_AGE	1	-0.0195	0.00190	104.6107	0.0001	-0.064601	0.981
SLEEPY	1	0.3207	0.0522	37.6860	0.0001	0.041229	1.378
SP_LIMIT	1	0.0142	0.00136	108.3162	0.0001	0.073374	1.014
TRAV_SP	1	0.0184	0.000899	420.8747	0.0001	0.166739	1.019
COLLIDED	1	-0.5966	0.0362	271.0699	0.0001	-0.109407	0.551
FRONT	1	0.4033	0.0782	26.6127	0.0001	0.032128	1.497
DR_MALE	1	-0.2305	0.0292	62.1467	0.0001	-0.051875	0.794
DR_AGE	1	-0.00867	0.000813	113.6854	0.0001	-0.070504	0.991

These should be compared with the following results for the unbelted individuals in non-rollover crashes.

Table 10. Logistic regression analysis: non-rollover involved, unbelted fatally injured individuals in FARS 1982-1996.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-2.3824	0.2701	77.7987	0.0001	.	.
YEAR	1	0.00611	0.00285	4.6038	0.0319	0.014038	1.006
PRECIPIT	1	-0.1095	0.0358	9.3643	0.0022	-0.020649	0.896
WEEKEND	1	-0.00468	0.0248	0.0356	0.8504	-0.001227	0.995
NIGHT	1	-0.0362	0.0263	1.9037	0.1677	-0.009980	0.964
CURVE	1	-0.0488	0.0268	3.3078	0.0690	-0.012088	0.952
RURAL	1	0.0197	0.0292	0.4567	0.4992	0.004960	1.020
GRADE	1	0.0278	0.0251	1.2317	0.2671	0.007235	1.028
SPEEDING	1	0.2929	0.0308	90.3716	0.0001	0.075461	1.340
TRUCK	1	0.4060	0.0273	221.0938	0.0001	0.092775	1.501
DR_DRINK	1	0.0411	0.0267	2.3788	0.1230	0.011155	1.042
VEH_AGE	1	0.00824	0.00202	16.6560	0.0001	0.025851	1.008
SLEEPY	1	-0.5004	0.0795	39.6684	0.0001	-0.045307	0.606
SP_LIMIT	1	0.00870	0.00146	35.4031	0.0001	0.045895	1.009
TRAV_SP	1	0.00312	0.00077	16.4294	0.0001	0.036577	1.003
COLLIDED	1	-0.2718	0.0271	100.6190	0.0001	-0.072623	0.762
FRONT	1	-0.1520	0.0637	5.7029	0.0169	-0.014475	0.859
DR_MALE	1	-0.0219	0.0289	0.5730	0.4491	-0.005304	0.978
DR_AGE	1	-0.0135	0.00074	335.1105	0.0001	-0.147080	0.987

It should be mentioned that once the rollover variable is dropped from the model, the predictive value of the model decreases dramatically. The c-value goes down from about 80 percent to about 65 percent. The results are quite different in the two populations now considered. For rollover-involved individuals, the most significant variable turns our to be traveling speed, followed by the indicator of whether the vehicle was a truck, and the indicator of collision with another vehicle. For the population not involved in rollover, the most significant variable turns out to be driver's age, followed by the indicator of whether the vehicle was a truck.

In addition to these main features, the two populations show a number of other striking differences: the variable indicating precipitation at the time of the accident is quite significant for the rollover-involved population (the analysis shows 0.607 times smaller odds of ejection during precipitation than in dry weather, possibly due to higher speeds in dry weather), while it is much less significant for non-rollover involved population; the variable indicating that the crash occurred at night is significant in the rollover-involved population (lower odds of ejection at night, possibly also because of lower speeds at night), but nonsignificant for the non-rollover involved population; the indicator of speeding as a contributing factor is significant only in the non-rollover involved population (this variable is affected by the traveling speed variable, which is very significant for the rollover-involved population, but much less significant for the non-rollover involved population); the indicator of driver's sex is highly significant for the rollover-involved population (showing a 20 percent reduction in the odds of ejection for male compared with female drivers), but it is nonsignificant among non-rollover involved individuals.

Interestingly, the time-trend variable is not very significant in both rollover-involved and non-rollover involved populations.

Ejection is so closely associated with rollover that the unbelted, rollover-involved population requires the strictest scrutiny. This association is illustrated by a simple comparison of ejection rates among unbelted individuals for the rollover-involved and non-rollover involved subpopulations.

Table 11. Ejection Rates Among Rollover-Involved Motor Vehicle Occupants and Non-Rollover-Involved Motor Vehicle Occupants in Fatal Crashes

	Ejected	Not ejected
Rollover	50.72%	49.78%
No rollover	11.12%	88.88%

To complete the logistic regression analysis of ejection, presented below are the results for the unbelted, rollover-involved population when the variable traveling speed is omitted, so that a much larger sample size is achieved.

Table 12. Logistic regression analysis: rollover-involved, unbelted fatally injured individuals in FARS 1982-1996, no traveling speed variable.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-2.2051	0.1823	146.2349	0.0001	.	.
YEAR	1	0.0144	0.00188	59.2272	0.0001	0.033337	1.015
PRECIPIT	1	-0.4838	0.0290	278.1804	0.0001	-0.070551	0.616
WEEKEND	1	0.0190	0.0158	1.4419	0.2298	0.005183	1.019
NIGHT	1	-0.1056	0.0175	36.3389	0.0001	-0.028371	0.900
CURVE	1	0.0150	0.0167	0.7992	0.3713	0.004071	1.015
RURAL	1	-0.0279	0.0200	1.9530	0.1623	-0.006363	0.972
GRADE	1	0.0154	0.0166	0.8658	0.3521	0.004055	1.016
SPEEDING	1	0.2308	0.0168	189.5499	0.0001	0.063394	1.260
TRUCK	1	0.3658	0.0163	505.3528	0.0001	0.099408	1.442
DR_DRINK	1	0.00299	0.0177	0.0286	0.8657	0.000803	1.003
VEH_AGE	1	-0.0220	0.00132	279.4420	0.0001	-0.072318	0.978
SLEEPY	1	0.2670	0.0345	59.8237	0.0001	0.035225	1.306
SP_LIMIT	1	0.0272	0.000894	925.6002	0.0001	0.141408	1.028
COLLIDED	1	-0.6730	0.0246	747.0550	0.0001	-0.124109	0.510
FRONT	1	0.3825	0.0572	44.7357	0.0001	0.028544	1.466
DR_MALE	1	-0.1549	0.0200	60.0239	0.0001	-0.034661	0.857
DR_AGE	1	-0.0112	0.000556	408.4208	0.0001	-0.091152	0.989

This is compared with the results for the population not experiencing a rollover.

Table 13. Logistic regression analysis: non-rollover involved, unbelted fatally injured individuals in FARS 1982-1996, no traveling speed variable.

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > Chi-Square	Standardized Estimate	Odds Ratio
INTERCPT	1	-2.7769	0.1748	252.2406	0.0001	.	.
YEAR	1	0.0101	0.00184	30.4983	0.0001	0.023635	1.010
PRECIPIT	1	-0.1381	0.0229	36.4316	0.0001	-0.026693	0.871
WEEKEND	1	-0.0198	0.0163	1.4760	0.2244	-0.005185	0.980
NIGHT	1	-0.0451	0.0173	6.7511	0.0094	-0.012427	0.956
CURVE	1	-0.0294	0.0179	2.7045	0.1001	-0.007127	0.971
RURAL	1	-0.00428	0.0186	0.0529	0.8182	-0.001128	0.996
GRADE	1	0.0433	0.0168	6.6098	0.0101	0.010950	1.044
SPEEDING	1	0.3223	0.0180	321.9003	0.0001	0.079487	1.380
TRUCK	1	0.4287	0.0178	582.1593	0.0001	0.097646	1.535
DR_DRINK	1	0.0594	0.0174	11.5986	0.0007	0.016079	1.061
VEH_AGE	1	0.0104	0.00134	60.5299	0.0001	0.032135	1.010
SLEEPY	1	-0.4515	0.0492	84.3797	0.0001	-0.042832	0.637
SP_LIMIT	1	0.0129	0.00091	201.4973	0.0001	0.071036	1.013
COLLIDED	1	-0.2711	0.0174	243.5438	0.0001	-0.072669	0.763
FRONT	1	-0.1728	0.0428	16.3144	0.0001	-0.015933	0.841
DR_MALE	1	-0.0384	0.0188	4.1589	0.0414	-0.009249	0.962
DR_AGE	1	-0.0137	0.00047	846.5352	0.0001	-0.148650	0.986

These results are consistent with the results for the model incorporating the traveling speed variable. The variables posted speed limit and indicator of speeding, which function as surrogates for traveling speed, greatly increase their significance, while the other variables generally retain their relative significance. It should be noted, however, that the time-trend variable becomes more significant in this model.

In summary, the logistic regression analysis shows that the population at greatest risk of ejection is unbelted individuals, and among them the rollover-involved individuals are at the greatest risk. In this latter population, speed is the factor most significantly contributing to ejection. In all cases, ejection is much more likely from a truck than from a passenger car. Driver's age is another factor strongly associated with ejection, particularly among individuals not involved in rollover (younger drivers are more likely to be involved in ejection crashes). Single-vehicle crashes are generally more likely to result in ejection. Finally, there is a slight but pervasive increasing time-trend in the prevalence of ejection in fatal crashes, which cannot be explained by the variables available for this analysis. It could be a result of changes in the crashworthiness of the vehicles (other than the increase in the number of light trucks, which is accounted for in this analysis), or behavioral changes, such as more frequent occurrence of aggressive or risky driving.

Analysis of Time Trends in Ejection in Fatal Crashes

The objective of the time-trend analysis in this section is to understand the changes in ejection rates in various subpopulations of fatally injured motor vehicle occupants over a period of 15 years. The fraction of ejected individuals is studied together with the main factors affecting ejection, as determined in Section 2.

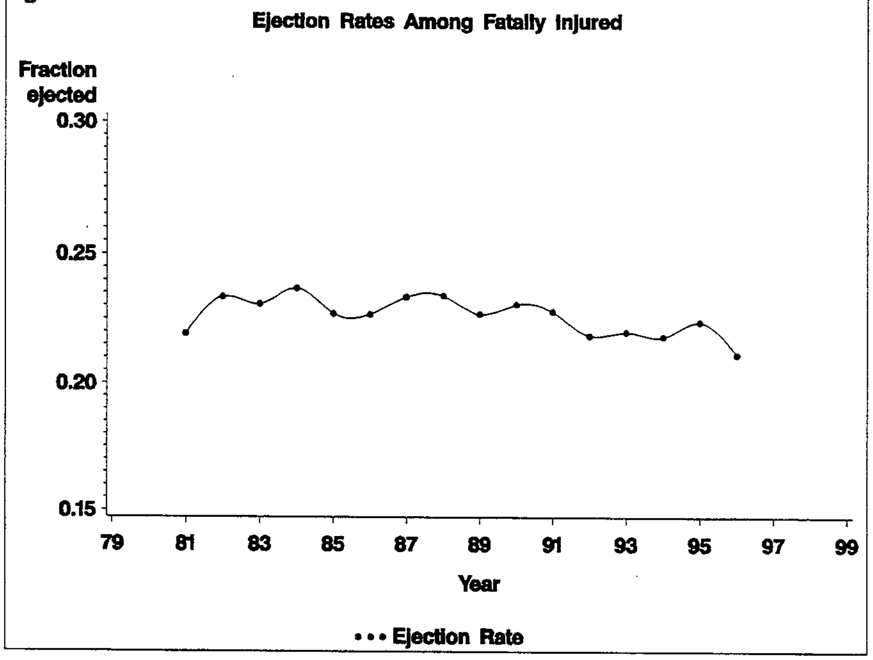
The basic methodology consists in calculating yearly averages for each of the years between 1982 and 1996, constructing time-plots of these averages, and using linear regression analysis to quantify any time-trend present in these data.

The starting point of the analysis is to examine the fraction of totally ejected in the entire population of fatally injured motor vehicle occupants at least 12 years of age. This is the same population as that considered in Section 2, except that in the logistic regression analysis, the observations with missing covariate values had to be omitted.

Table 14. Fraction ejected among fatally injured passenger vehicle occupants.

Year	Fraction ejected
82	0.23355
83	0.23079
84	0.23681
85	0.22711
86	0.22679
87	0.23343
88	0.23390
89	0.22693
90	0.23062
91	0.22788
92	0.21859
93	0.21999
94	0.21810
95	0.22395
96	0.21129

Figure 2

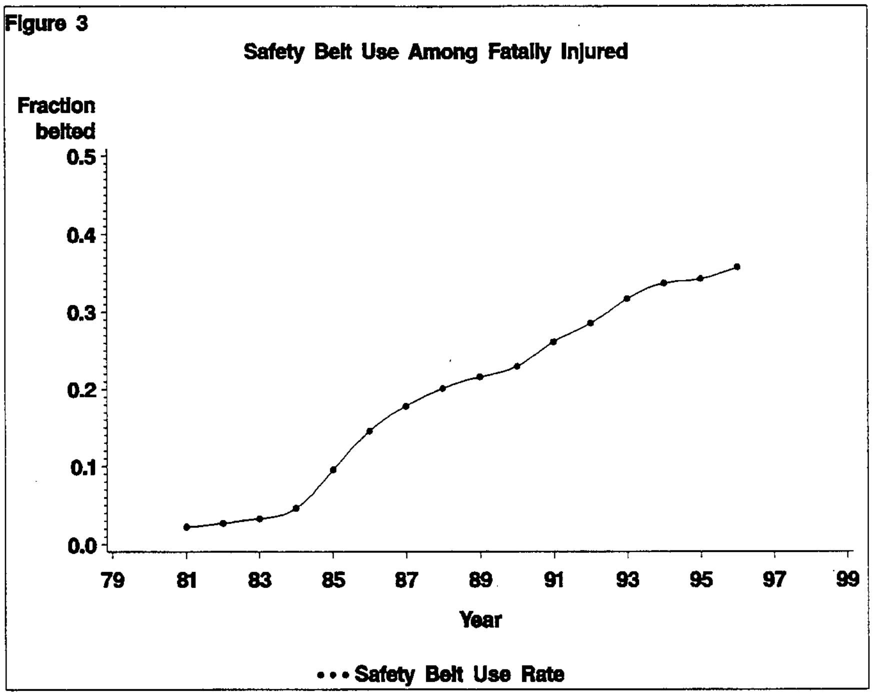


The fraction of fatalities ejected appears to be very little changed between 1982 and 1996. The linear regression of ejection rate on year shows the coefficient of the time variable to be -0.001, with a p-value of 0.0003. That is, there is an estimated 0.1 percent decline in ejection rate per year.

Next examined is the fraction of belted fatalities in the same population.

Table 15. Safety belt use among fatally injured passenger vehicle occupants.

Year	Safety belt use rate
82	0.02725
83	0.03311
84	0.04675
85	0.09560
86	0.14579
87	0.17785
88	0.20099
89	0.21599
90	0.22936
91	0.26119
92	0.28528
93	0.31686
94	0.33692
95	0.34245
96	0.35787



There is a sharp increase in safety belt use among the fatally injured from 1982 to 1996. Linear regression analysis indicates a very significant time-trend with a 2.5 percent increase in safety belt use per year.

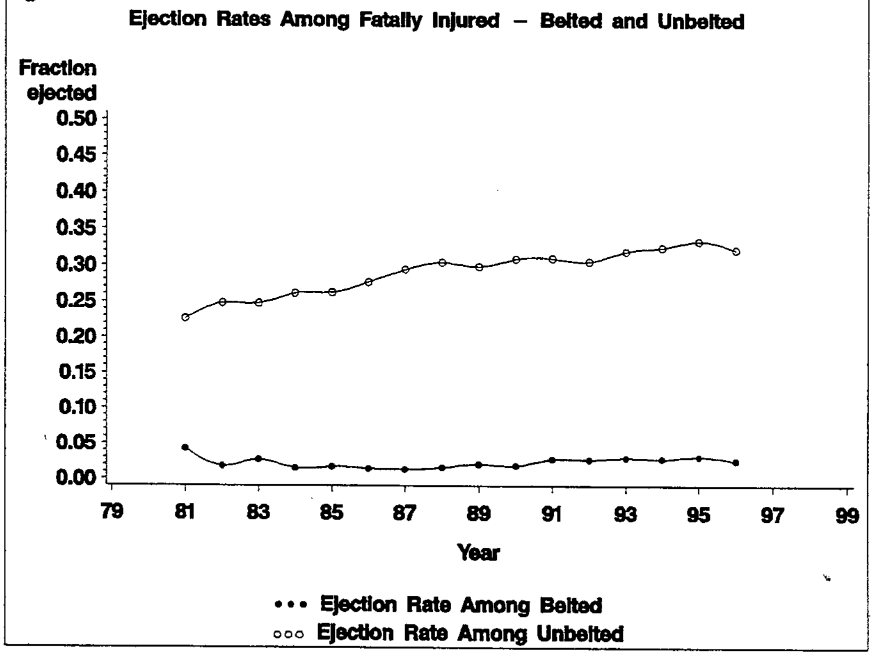
These two facts - essentially constant ejection rate and increasing safety belt use rate in the same population of fatally injured motor vehicle occupants - motivate the present study to understand why ejections did not decrease in spite of the increase in safety belt use.

Examined first will be ejection rates among the belted and unbelted occupants.

Table 16. Ejection rate among fatally injured passenger vehicle occupants (belted and unbelted).

Year	Ejection rate among unbelted occupants	Ejection rate among belted occupants
82	0.24737	0.018062
83	0.24688	0.026499
84	0.26095	0.015238
85	0.26215	0.016841
86	0.27624	0.014542
87	0.29379	0.013541
88	0.30376	0.015776
89	0.29803	0.020736
90	0.30874	0.018576
91	0.30946	0.027547
92	0.30525	0.027094
93	0.31905	0.029728
94	0.32467	0.028120
95	0.33342	0.031566
96	0.32193	0.025849

Figure 4



The above results confirm that ejection is rare among belted individuals. The linear regression shows a minimal upward trend in the fraction ejected (p-value of 0.0046 and regression coefficient of 0.001). This increasing tendency might be explained by the effect of the 'lie-factor', i.e., over-reporting of belt use as safety belt use laws were being enacted in many states in the late 1980's and 1990's. However, this hypothesis is difficult to verify. It should also be noted that ejection rate among occupants reported as restrained by automatic belts appears to be much higher than ejection rate among occupants using manual belts, possibly due to improper use of automatic belts (not using the lap belt). For example, in 1995 ejection rate among automatic belt users was 5.1 percent compared with the 2.3 percent ejection rate for manual belt users. Since automatic belts became very common in the late 1980's, this may explain the increase in ejection rate among belted occupants observed between 1988 and 1993.

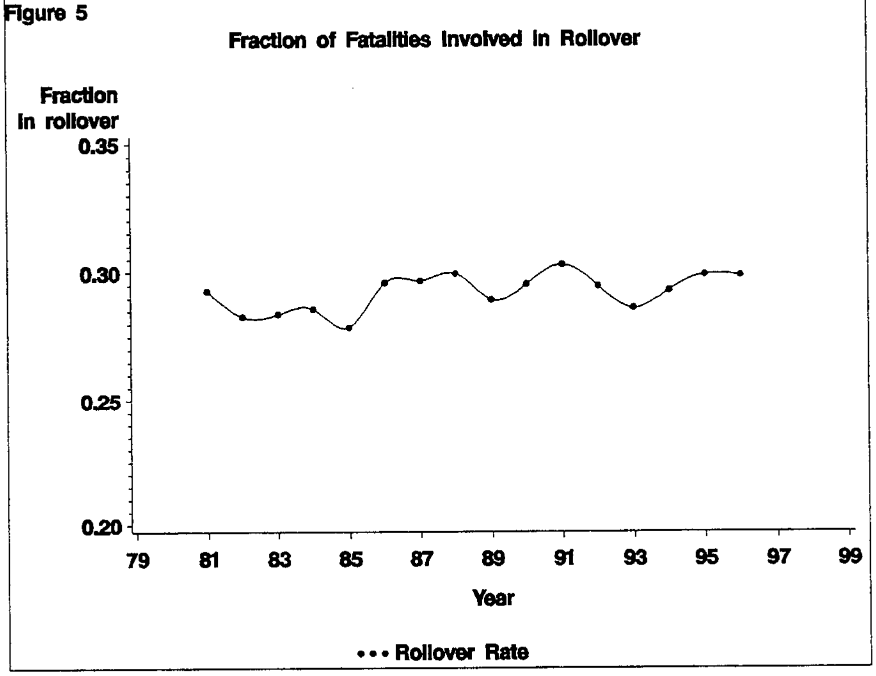
As expected, one sees a substantial increase in ejections among the unbelted individuals. The time-trend linear regression coefficient is highly significant and indicates an average increase of 0.6 percent in the fraction of ejected among fatally injured unbelted occupants.

Since rollover has been identified as the factor most strongly influencing the probability of ejection for both the belted and unbelted populations, examined next are time-trends in rollovers.

Table 17. Fraction of fatalities involved in rollover.

Year	Fraction in rollover
82	0.28292
83	0.28385
84	0.28582
85	0.27879
86	0.29600
87	0.29673
88	0.29957
89	0.28946
90	0.29538
91	0.30288
92	0.29478
93	0.28617
94	0.29301
95	0.29907
96	0.29869

Figure 5



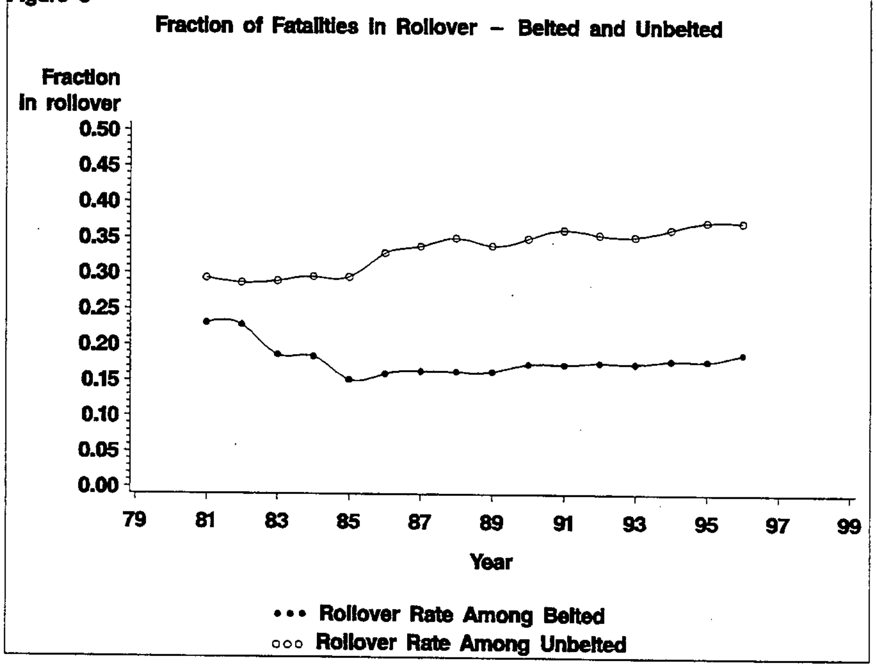
There is almost no visible trend in the overall fraction of rollovers in fatal crashes. The linear regression time-trend coefficient is 0.001 with a p-value of 0.0179. That is, it shows a slight positive trend, close to being insignificant.

One next examines the fraction of rollovers among the belted and unbelted individuals separately.

Table 18. Fraction of fatalities involved in rollover (belted and unbelted).

Year	Rollover rate among belted occupants	Rollover rate among unbelted occupants
82	0.22742	0.28652
83	0.18598	0.28892
84	0.18350	0.29494
85	0.15143	0.29456
86	0.15957	0.32818
87	0.16337	0.33826
88	0.16266	0.34991
89	0.16290	0.33929
90	0.17336	0.34940
91	0.17295	0.36143
92	0.17578	0.35474
93	0.17421	0.35228
94	0.17868	0.36226
95	0.17799	0.37252
96	0.18789	0.37221

Figure 6



For the belted individuals in fatal crashes, the rate of rollover appears to have dropped in the early 1980's. Other than a small sample size owing to the low safety belt use rates during that period, there is no apparent explanation for this drop, but after 1984 the rate follows a consistent, slowly increasing pattern. Excepting the 1982 to 1984 data, the linear regression analysis shows a statistically significant time-trend with the regression coefficient of 0.003.

For the unbelted individuals in fatal crashes, there is a clear increasing tendency in the rollover rate throughout the period under study. The linear regression analysis indicates a positive time-trend with an increase of about 0.64 percent per year.

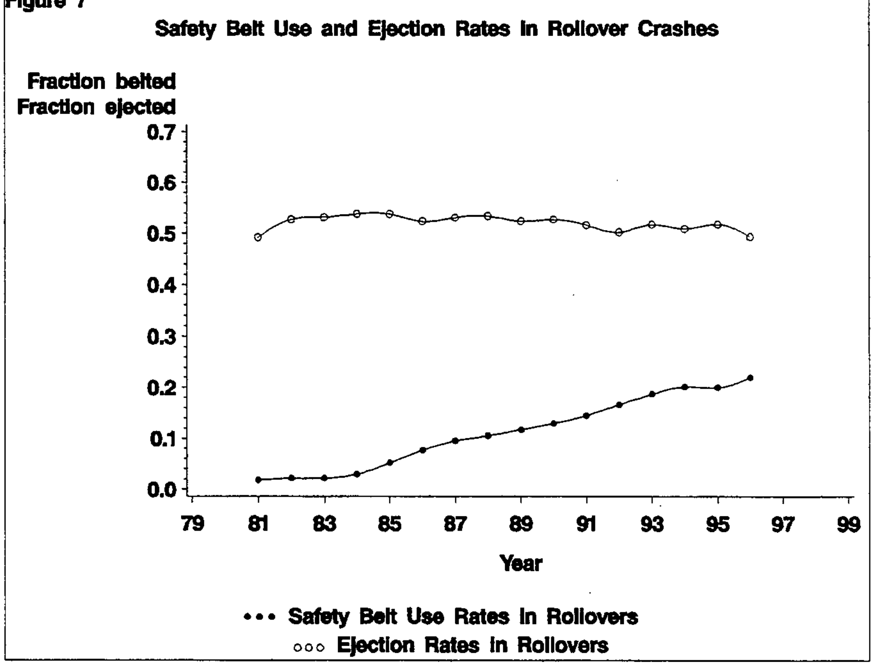
Thus, it appears that as safety belt use was increasing with the enactment of safety belt use laws, the likelihood of rollover was increasing quite fast among the population which remained unbelted compared with those who buckled-up. This is consistent with the conjecture that the population that remained unbelted were those at a higher risk of being involved in rollover (and consequently being ejected).

Focusing on the rollover-involved population, it is instructive to look at the time-trends in safety belt use in that population and at the ejection rate among them.

Table 19. Safety belt use rates and ejection rates in rollover crashes.

Year	Safety belt use rate in rollovers	Ejection rate in rollovers
82	0.02147	0.52727
83	0.02155	0.53170
84	0.02913	0.53816
85	0.05176	0.53761
86	0.07661	0.52366
87	0.09468	0.53095
88	0.10506	0.53374
89	0.11684	0.52406
90	0.12860	0.52706
91	0.14487	0.51638
92	0.16570	0.50213
93	0.18651	0.51712
94	0.20116	0.50865
95	0.19956	0.51730
96	0.21979	0.49327

Figure 7

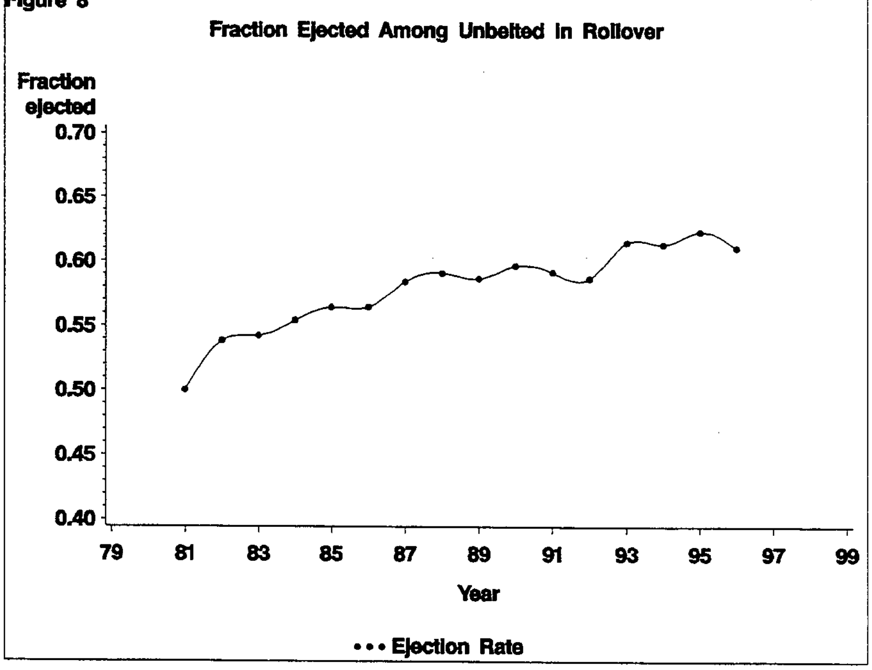


One observes an almost constant ejection rate (linear regression time-trend coefficient is -0.002 with a p-value of 0.0003), and an increasing fraction of belted individuals with the rate of increase estimated by the linear regression to be 1.5 percent per year. This suggests that there are additional factors beyond rollover that cause an increase in ejection rate among rollover-involved individuals who remain unbelted. Indeed, the following data show that ejection rate has increased in that latter population.

Table 20. Fraction of fatalities ejected among unbelted in rollover.

Year	Ejection rate among unbelted in rollover
82	0.53820
83	0.54211
84	0.55368
85	0.56417
86	0.56440
87	0.58388
88	0.59065
89	0.58632
90	0.59625
91	0.59118
92	0.58640
93	0.61432
94	0.61306
95	0.62305
96	0.61038

Figure 8



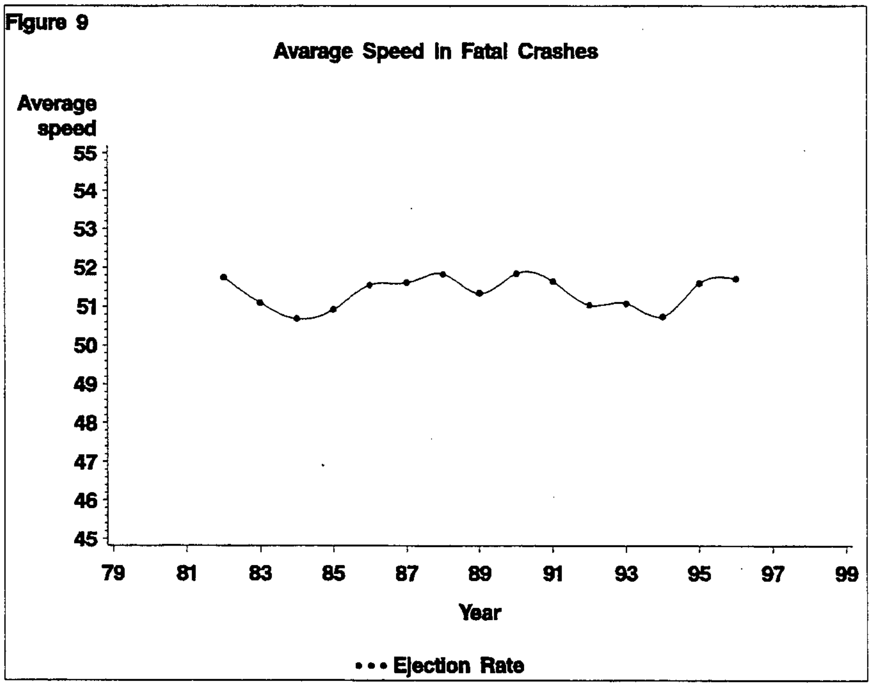
The linear regression model suggests that the ejection rate among unbelted individuals in rollover crashes has been increasing on the average by 0.6 percent per year over the period under study.

The logistic regression analysis indicates that traveling speed (the speed of the vehicle prior to the crash) is the most significant factor determining the probability of ejection in the crash among unbelted occupants in rollover. Speed is also among the most significant variables in the logistic regression model for the entire population of fatally injured motor vehicle occupants. According to the model, increased speed is associated with a higher probability of ejection. The question then arises if the increased ejection rates can be explained, at least to some degree, by an increase in the speed in fatal crashes. The analysis is based on the average speed in fatal crashes (per fatally injured individual) calculated for each year from 1982 to 1996. If the entire population of fatally injured occupants in crashes with recorded traveling speed is considered, the following results are obtained.

Table 21. Average speed in fatal crashes.

Year	Average speed
82	51.7337
83	51.0865
84	50.6823
85	50.9136
86	51.5459
87	51.6012
88	51.8249
89	51.3359
90	51.8361
91	51.6421
92	51.0311
93	51.0782
94	50.7363
95	51.5875
96	51.7010

Figure 9



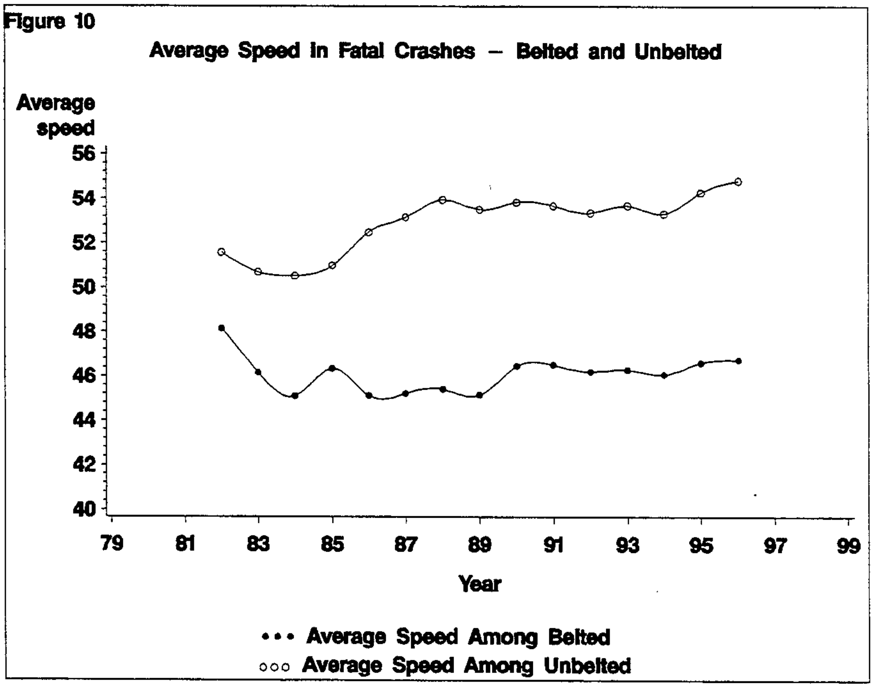
The average speed appears almost constant at about 51 mph. The linear regression time-trend analysis shows no significant trend (p-value for significance of time-trend is 0.7492).

Considered next is the average speed for the belted and unbelted fatally injured occupants.

Table 22. Average speed in fatal crashes - belted and unbelted.

Year	Average speed among belted	Average speed among unbelted
82	48.1429	51.5689
83	46.1392	50.6829
84	45.0884	50.5135
85	46.3276	50.9787
86	45.1077	52.4682
87	45.2078	53.1508
88	45.3964	53.9346
89	45.1325	53.5026
90	46.4295	53.8219
91	46.4869	53.6653
92	46.1920	53.3556
93	46.2684	53.6703
94	46.0527	53.3091
95	46.5913	54.2604
96	46.7187	54.7910

Figure 10



The results show that for the belted occupants the average speed in fatal crashes has not changed substantially from 1983 to 1996 and has remained at about 46 mph (the data for 1982 appear to be an outlier with a somewhat higher value of 48 mph). The time-trend coefficient from the linear regression analysis is not significant (with a p-value of 0.7730).

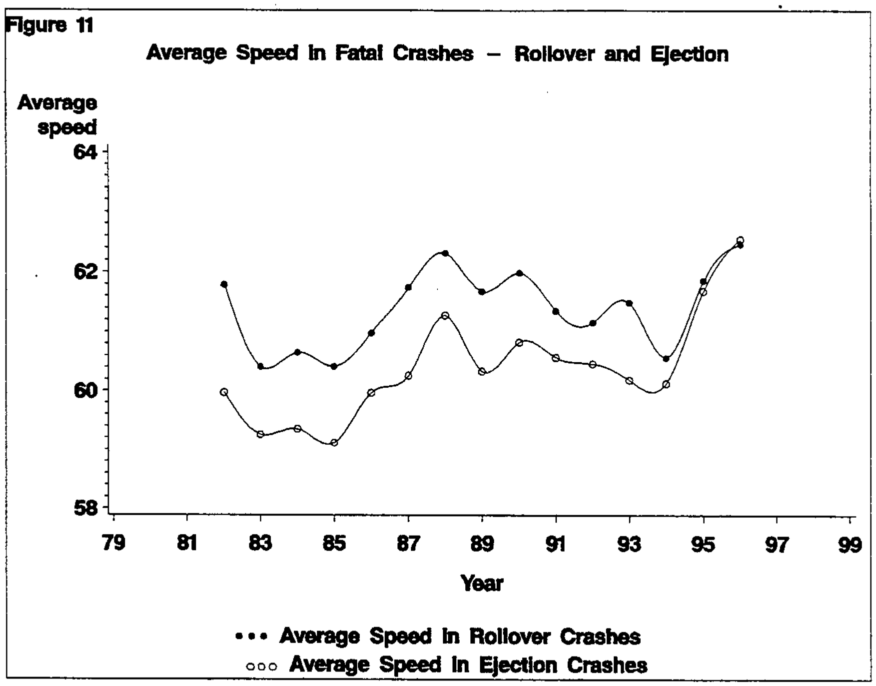
However, there is an increasing tendency in average speed for unbelted fatally injured motor vehicle occupants. It increases from about 51 mph in 1982 (when almost all occupants were unbelted), to about 55 mph in 1996. The linear regression analysis shows an average increase in speed among the belted occupants to be 0.26 mph per year (and the time-trend is highly significant).

These results may appear counter-intuitive in that one might expect that the occupants wearing safety belts are better protected and would tend to be fatally injured in more severe crashes than the unbelted occupants, who are not protected. It appears that what actually happens is that the population that remained unbelted in spite of the enactment of the safety belt use laws and the public information and education efforts, were those involved in more severe crashes at higher speeds, presumably indicating more risky driving behavior.

Turning to the population at the highest risk of ejection, that is, those involved in rollover crashes, one first examines the average speed rates in that population without regard to other factors. It is interesting to compare these rates with those occurring in ejection crashes (again looking at the entire relevant population).

Table 23. Average speed in fatal crashes - rollover and ejection.

Year	Average speed in rollovers	Average speed in ejections
82	61.7825	59.9679
83	60.4058	59.2493
84	60.6415	59.3446
85	60.4108	59.1090
86	60.9759	59.9651
87	61.7345	60.2571
88	62.3123	61.2738
89	61.6739	60.3312
90	61.9820	60.8237
91	61.3490	60.5654
92	61.1509	60.4600
93	61.4866	60.1856
94	60.5624	60.1267
95	61.8538	61.6824
96	62.4597	62.5423



One notices that the average speed in ejection crashes traces the average speed in rollover crashes remarkably closely. This reflects the fact that rollover is very closely associated with ejection (cf., Table 3). However, while there is no significant time-trend in the average speed in rollover fatal crashes (the linear regression coefficient is 0.06 with a p-value of 0.1415), there is an increasing tendency in the average speed in ejection fatal crashes, which have a time-trend linear regression coefficient of 0.152 and a p-value of 0.0017.

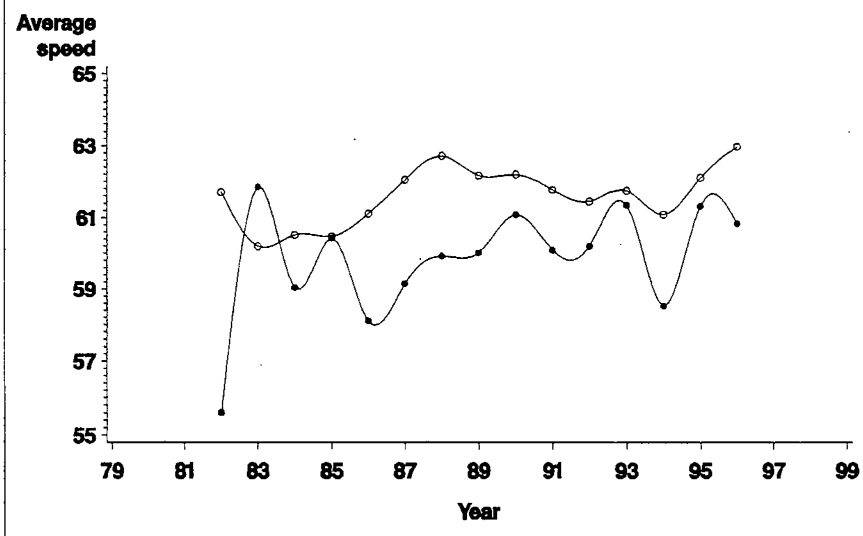
The remaining analysis for the rollover-involved population is to compare average speed in the belted and unbelted subpopulations.

Table 24. Average speed in fatal crashes - belted and unbelted.

Year	Average speed among belted in rollovers	Average speed among unbelted in rollovers
82	55.6034	61.7033
83	61.8525	60.1979
84	59.0435	60.5123
85	60.4265	60.4757
86	58.0991	61.1028
87	59.1489	62.0473
88	59.9169	62.7130
89	60.0179	62.1634
90	61.0779	62.1905
91	60.0872	61.7669
92	60.1997	61.4444
93	61.3452	61.7411
94	58.5170	61.0784
95	61.3185	62.0911
96	60.8311	62.9600

Figure 12

Average Speed In Rollover Fatal Crashes – Belted and Unbelted



These data show that given a rollover, the average speed in a fatal crash is not very different among belted and unbelted motor vehicle occupants. Except for the early years (1982 to 1985), the average speed in rollover fatal crashes for unbelted occupants appears to be between 1 mph and 3 mph higher that the average speed in rollover fatal crashes among the belted individuals. The data for 1982 to 1985 for belted occupants appear inconsistent with the rest of the data, possibly due to relatively low sample sizes in those years, when very few individuals in fatal crashes were wearing safety belts. The logistic regression analysis shows essentially that no significant time-trend is present in either the belted or the unbelted population. For the belted population, the p-value for significance of the time-trend coefficient is 0.1012. For the unbelted population, the p-value is 0.0329, which might be interpreted as showing an upward trend at the 0.05 significance level, but not at the 0.01 level (this upward effect is due to the influence of the early years data points).

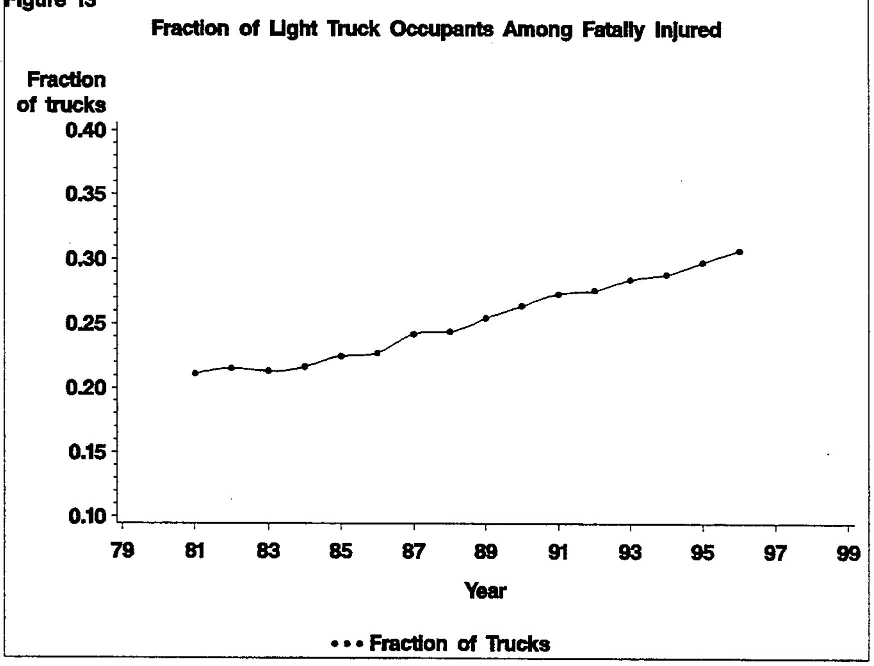
Another factor contributing to ejection probability is the vehicle type. The logistic regression models presented in Section 2 consistently show that when the vehicle is a truck the probability of ejection significantly increases. As mentioned previously, the category of light trucks in this study includes sport utility vehicles and vans.

In Section 1, it was pointed out that the fraction of light trucks in the fleet of passenger vehicles has been increasing. The following analysis shows how this trend is reflected in the data on fatally injured occupants.

Table 24. Fraction of light truck occupants among fatally injured.

Year	Fraction of light truck occupants
82	0.21507
83	0.21293
84	0.21627
85	0.22457
86	0.22715
87	0.24162
88	0.24356
89	0.25399
90	0.26352
91	0.27287
92	0.27559
93	0.28409
94	0.28801
95	0.29744
96	0.30652

Figure 13



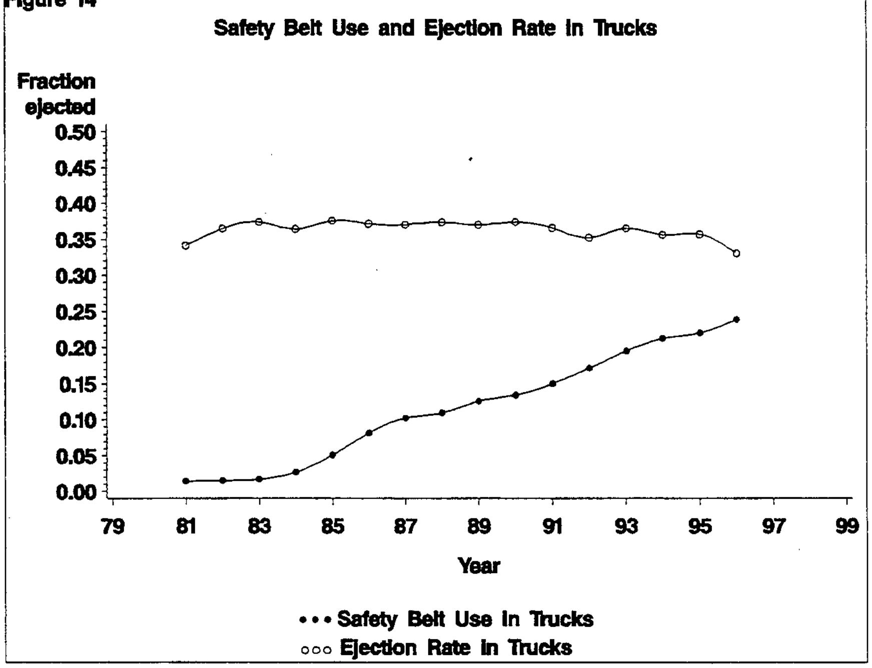
The linear regression model shows an average increase of 0.7 percent per year in the fraction of light truck occupants among the fatally injured passenger vehicle occupants.

It is of interest to see if the same time-trends relating to ejection that were identified for the entire population of fatally injured passenger vehicle occupants persist among fatally injured light truck occupants.

Table 25. Safety belt use rate and ejection rate in light trucks.

Year	Fraction belted in trucks	Fraction ejected in trucks
82	0.01499	0.36520
83	0.01693	0.37415
84	0.02679	0.36456
85	0.05081	0.37602
86	0.08154	0.37186
87	0.10273	0.37057
88	0.10974	0.37389
89	0.12616	0.37029
90	0.13457	0.37414
91	0.15021	0.36593
92	0.17155	0.35227
93	0.19500	0.36526
94	0.21250	0.35615
95	0.22009	0.35696
96	0.23899	0.33063

Figure 14



This analysis shows that the fraction of ejected occupants in light trucks changed very little between 1982 and 1996. The linear regression time-trend coefficient for fraction ejected is -0.0018 with a p-value of 0.006. Safety belt use in the same population has increased from almost zero to over 23 percent. The linear regression indicates a highly significant increasing trend of 1.7 percent per year in safety belt use rate. This is the same pattern as that observed for all passenger vehicle occupants, except that the fraction ejected from light trucks is higher (about 35 percent), and the safety belt use rate in light trucks is lower than in the general population of passenger vehicle occupants.

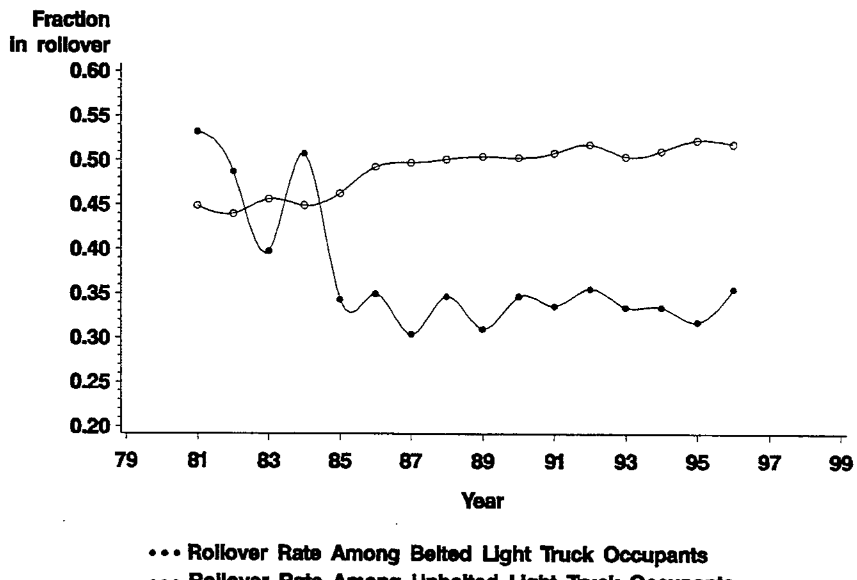
One of the key findings for the general population of fatally injured passenger vehicle occupants was that the rollover rate has increased among the unbelted occupants, but it did not increase among the belted individuals.

Table 26. Rollover rate among light truck occupants - belted and unbelted.

Year	Fraction of rollovers among belted in trucks	Fraction of rollovers among unbelted in trucks
82	0.48684	0.43955
83	0.39759	0.45612
84	0.50735	0.44895
85	0.34328	0.46266
86	0.34940	0.49252
87	0.30380	0.49735
88	0.34663	0.50107
89	0.30998	0.50405
90	0.34642	0.50258
91	0.33602	0.50799
92	0.35541	0.51769
93	0.33447	0.50371
94	0.33433	0.51013
95	0.31755	0.52238
96	0.35499	0.51814

Figure 15

Rollover Rate Among Light Truck Occupants -- Belted and Unbelted



Here again the pattern from the analysis of the entire passenger vehicle occupant population is repeated in the light truck occupant population. As in that former analysis, the years 1982 to 1984 are not consistent with the rest of the data, most likely due to the small sample sizes of belted truck occupants during that period. If those years are excluded, the linear regression time-trend analysis shows no significant time-trend in rollover rate for the belted occupants (p-value of 0.7841). For the unbelted light truck occupants in fatal crashes, there is a significant upward time-trend in the rollover rate estimated at 0.54 percent per year if the years 1982 to 1984 are included (if the years 1982 to 1984 are excluded, the estimate is 0.42 percent per year).

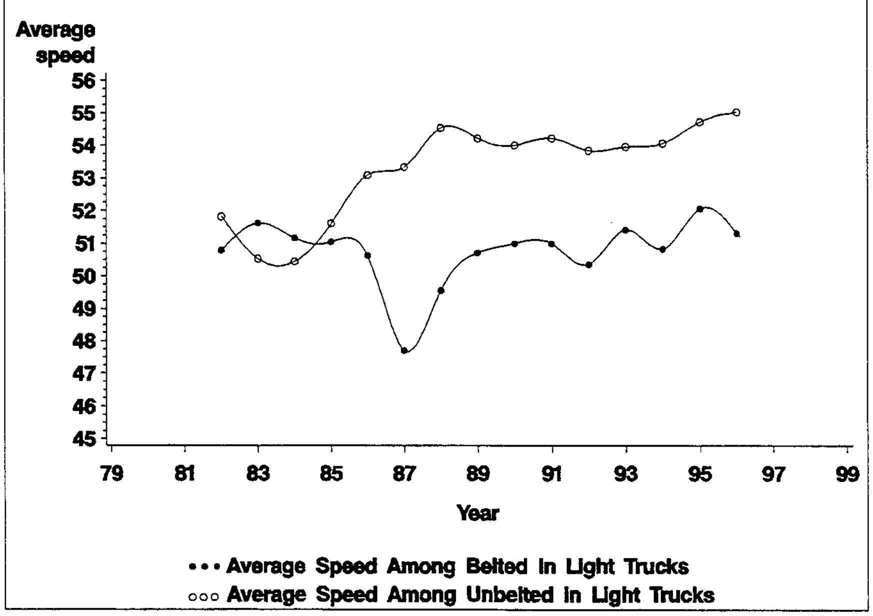
Another key finding was that the average speed in fatal crashes has remained constant among the belted occupants, but has increased among the unbelted occupants. Average speed is now analyzed for light truck occupants.

Table 27. Average speed in light truck fatal crashes - belted and unbelted.

Year	Average speed for light truck belted occupants	Average speed for light truck unbelted occupants
82	50.7805	51.8180
83	51.6176	50.5245
84	51.1552	50.4393
85	51.0326	51.6016
86	50.6235	53.0915
87	47.6869	53.3296
88	49.5509	54.5361
89	50.7099	54.2111
90	50.9911	53.9990
91	50.9835	54.2114
92	50.3507	53.8375
93	51.4041	53.9524
94	50.8173	54.0564
95	52.0522	54.7238
96	51.3011	55.0272

Figure 16

Average Speed In Light Truck Fatal Crashes – Belted and Unbelted



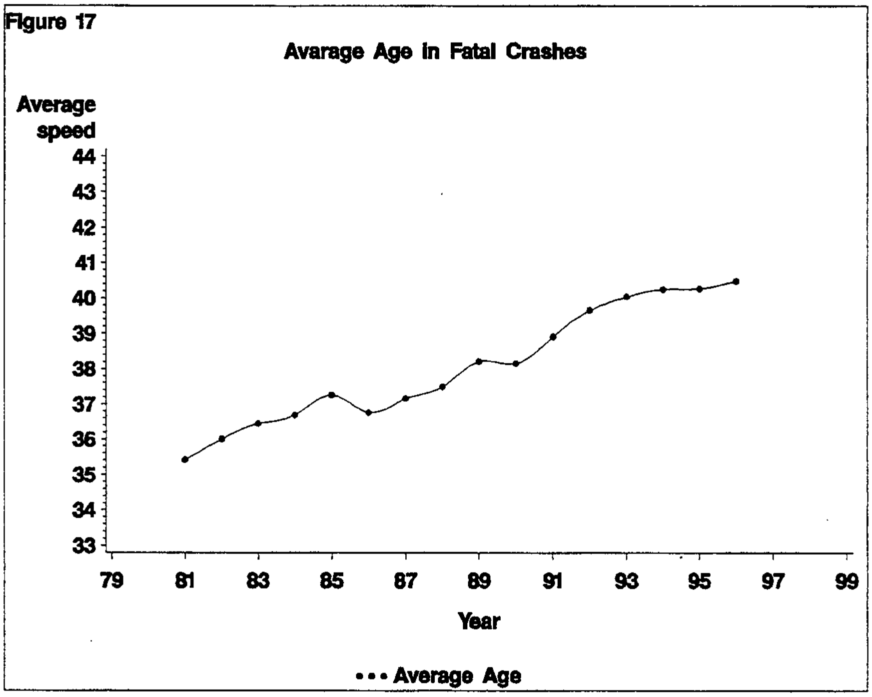
The early years' data (1982 to 1984) for the belted occupants again appear problematic. Based on the data from 1985 to 1996, the linear regression time-trend analysis shows a nonsignificant coefficient for the belted individuals (p-value of 0.0806), and a coefficient of 0.188 for the unbelted individuals with a p-value of 0.0046. If the early years are included in the analysis, the time-trend for the belted individuals remains nonsignificant (p-value of 0.4572), and the time-trend for the unbelted individuals is significant with an average increase of 0.28 percent per year. Since the sample size for the unbelted light truck occupants is quite large for all years under consideration, it can be concluded that there was an increase in the average speed in fatal crashes among the unbelted light truck occupants, while the average speed for the belted occupants has not changed significantly. However, the increase in the average speed among the unbelted occupants has taken place mostly in the 1980's.

The final variable to be analyzed as a factor determining ejection probability in a fatal crash is the occupant's age. This variable is very significant in all logistic regression models considered in Section 2, and it is the most significant variable for the population of unbelted, rollover-involved individuals.

First examined is the average age of individuals in fatal crashes.

Table 28. Average age in fatal crashes.

Year	Average age of individuals in fatal crashes
82	35.9989
83	36.4356
84	36.6888
85	37.2490
86	36.7620
87	37.1504
88	37.4849
89	38.2060
90	38.1492
91	38.9122
92	39.6530
93	40.0326
94	40.2502
95	40.2701
96	40.4817



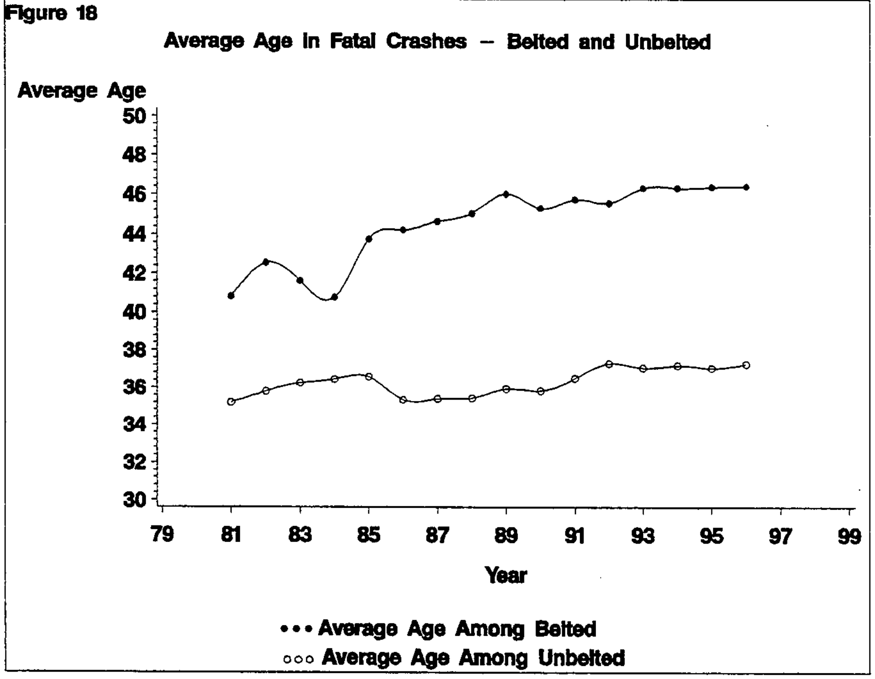
These results show that the average age of individuals in fatal crashes has been increasing. This is consistent with the well-known fact that the overall average age of the U.S. population has been increasing. According to the linear regression model, the rate of increase in the average age of individuals fatally injured in motor vehicle crashes is 0.344 per year.

Next, the average occupant age is considered separately in the belted and unbelted populations.

Table 29. Average age in fatal crashes - belted and unbelted.

Year	Average age in fatal crashes among belted occupants	Average age in fatal crashes among unbelted occupants
82	42.5500	35.7763
83	41.6159	36.2308
84	40.7683	36.4232
85	43.7585	36.5571
86	44.2154	35.3260
87	44.6626	35.3865
88	45.0651	35.4200
89	46.0425	35.9097
90	45.3084	35.8081
91	45.7498	36.4855
92	45.5767	37.2852
93	46.3199	37.0441
94	46.3413	37.1850
95	46.3855	37.0387
96	46.4188	37.2575

Figure 18



The same increasing tendency of the average age as in the population of all fatally injured occupants is observed in the data on the average age for the belted and unbelted subpopulations. The linear regression time-trend coefficient for the belted population is highly significant and the estimated per year increase in the average age is 0.36. For the unbelted population, the estimated per year increase in the average age is 0.11, but the p-value of the time-trend coefficient is 0.0073, which indicates that the trend is not very significant.

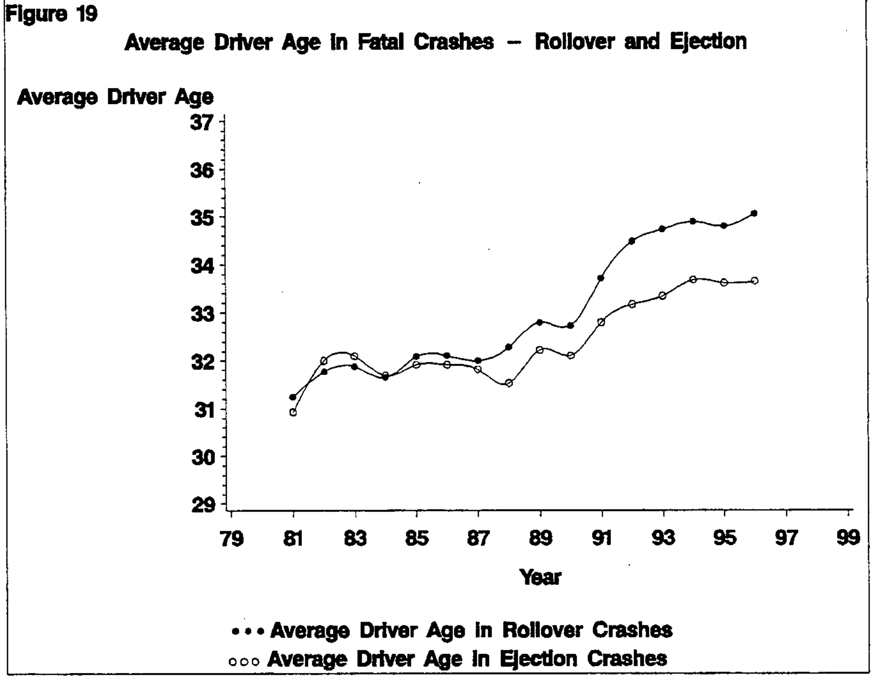
A striking feature of the data is the separation in average age between the two populations. Except for the early years (1982 to 1985), the average age among the belted individuals is consistently about 10 years higher than the average age in the unbelted population. This suggests very different characteristics of the two populations due to the age factor. However, the above results do not appear to explain the increased prevalence of ejection in the unbelted population, because the average age in both the belted and the unbelted populations follow similar increasing patterns. On the other hand, the results of the liner regression analysis show that the rate of increase in the average age in the unbelted population is about half the rate of increase in the average age in the general population, suggesting that the unbelted population was becoming relatively younger, and consequently at greater risk of ejection compared with the general population. However, because of the large standard error in the estimate of the time-trend in the unbelted population, this argument may not be conclusive.

It is also of interest to examine time-trends in the average driver age in the ejection-involved and rollover-involved populations.

Table 30. Average driver age in fatal crashes - rollover and ejection.

Year	Average driver age in rollovers	Average driver age in ejections
82	31.7652	31.9972
83	31.8758	32.0977
84	31.6476	31.6887
85	32.0795	31.9116
86	32.1020	31.9173
87	31.9983	31.8181
88	32.2828	31.5287
89	32.7967	32.2199
90	32.7266	32.1028
91	33.7128	32.7931
92	34.4802	33.1683
93	34.7335	33.3432
94	34.8877	33.6745
95	34.7974	33.6099
96	35.0487	33.6495

Figure 19



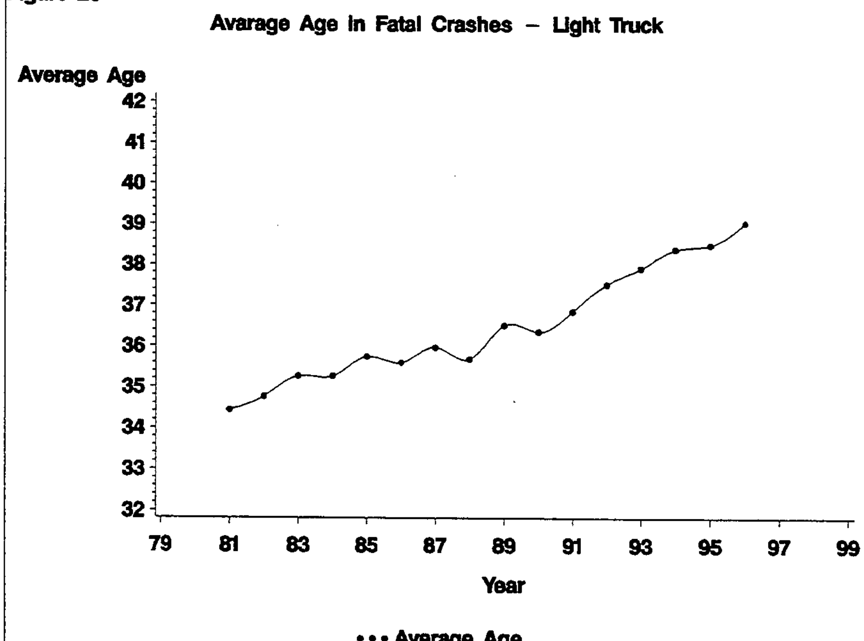
The average driver age for fatally injured motor vehicle occupants involved in rollover crashes and those involved in ejections are quite similar and follow similar patterns. The average driver age in the rollover-involved population has been increasing somewhat faster than the average driver age in the ejection-involved population. The linear regression estimates of the increase in the average driver age are 0.28 per year for fatal rollovers and 0.15 for fatal ejections. Because of the difference in the rate of increase, the difference between the average driver age in ejections and the average driver age in rollovers has grown from zero to about 1.5 years. This might suggest ejection crashes are associated with driver age factors more than rollover crashes, and is consistent with the fact that the ejection rate increased much faster than the rollover rate in the unbelted population.

Since the ejection probability is affected by vehicle type and is higher in trucks, it is relevant to consider the average age of light truck occupants in fatal crashes.

Table 31. Average age in fatal crashes for light truck occupants.

Year	Average age in light truck fatal crashes
82	34.7553
83	35.2611
84	35.2553
85	35.7401
86	35.5955
87	35.9728
88	35.6780
89	36.5146
90	36.3598
91	36.8647
92	37.5146
93	37.9121
94	38.3719
95	38.4828
96	39.0283

Figure 20



One notices the increasing trend analogous to the trend observed for the entire population of fatally injured passenger vehicle occupants. The logistic regression shows an increasing time-trend of 0.29 per year. One also notices that the average age of fatally injured light truck occupants is lower than the average age in the population of all fatally injured passenger vehicle occupants, but much higher than driver age in the population of rollover-involved or ejection-involved individuals.

In summary, the time trend analysis shows that the ejection rate has significantly increased in the unbelted population from 1982 to 1996. The unbelted population consists of individuals who remained unbelted in spite of the enactment of safety belt use laws and public information and education campaigns. It appears that they are the population at greatest risk of being involved in crashes resulting in ejection when safety belts are not used compared with the population of individuals who started using safety belts during that period. This is corroborated by the fact that the rollover rate has increased in the unbelted population, and the average speed in crashes has increased in that population. Both involvement in rollover and higher speed indicate more risky driving behavior. An additional factor increasing an occupant's likelihood of ejection in a crash is the vehicle being a light truck. The increase in the proportion of light trucks (including sport utility vehicles and vans) in the fleet of passenger cars has contributed to a greater probability of ejection, especially for the unbelted occupants. The analysis of the average age of fatally injured occupants shows that age is an important factor both in terms of safety belt use and involvement in rollover or ejection crashes. Unbelted individuals in fatal crashes tend to be much younger than the belted individuals, and the average driver age for individuals involved in rollover or ejection crashes is much lower.

Conclusions

The analysis shows that in fatal crashes only 2.5 percent of passenger vehicle occupants reported as using safety belt at the time of the crash were ejected. The actual fraction of ejections among the belted individuals may be even lower due to overreporting of safety belt use.

Safety belt use among the fatally injured has increased from almost zero to over 35 percent from 1980 to 1996. However, the ejection rate in the same population has changed very little during this period, going from about 23 percent in the early 1980's to 21 percent in 1996.

Focusing on the unbelted individuals, the analysis finds that the ejection rate among them has increased from 25 percent to about 33 percent for the same period. The main factor contributing to ejection among the unbelted individuals is the occurrence of rollover during the crash, which increases the odds of ejection over five times. The average fraction ejected in rollover crashes is 51 percent compared with the ejection rate of 11 percent in fatal crashes not involving rollover.

A time trend analysis shows an increase in rollover rate among the unbelted individuals from about 28 percent in the early 1980's to over 37 percent in 1996. Thus, the increase in ejections among unbelted individuals was accompanied by an increase in rollovers, which indicates that the unbelted individuals tend to be involved in more severe crashes.

Another factor that the analysis found to be strongly associated with ejection, particularly in rollover crashes, is the speed of the vehicle prior to the crash. It turns out that the average speed in fatal crashes for the unbelted population has increased from about 50 mph in the early 1980's to almost 55 mph in 1996, while it has remained between 46 and 47 mph for the belted population. This provides further evidence that the unbelted individuals are those involved in more severe crashes.

The analysis further shows that the odds of ejection are about 1.4 times greater in a light truck compared with a passenger vehicle. Since the fraction of light trucks involved in fatal crashes has increased from about 21 percent in the early 1980's to about 31 percent in 1996, this factor also contributes to explaining the increased prevalence of ejection.

Finally, the driver's age was found to be an important predictor of ejection probability. Younger drivers are more likely to be involved in ejection crashes. The average age of unbelted individuals in fatal crashes is about 35 compared with the average age of about 45 for the belted individuals. The average driver age in rollover crashes is about 33, while the average driver age in ejection crashes is about 32. In spite of the general increase in the average age of fatally injured individuals, the average driver age in rollover and ejection crashes has grown very little from 1982 to 1996.

This analysis leads to the conclusion that the increase in the prevalence of ejection among the unbelted individuals in fatal crashes during the 1980's and 1990's can be explained by the increased severity of crashes in that population, as evidenced by the increase in the rollover rate and speed, together with the increase in the presence of light trucks in those crashes and the young age of drivers involved in those crashes.

References

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