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Publication Date

2004-03-01

Institute of Transportation Studies
University of California at Berkeley

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Douglas Cooper, David Gillen, Frank Atkins

RESEARCH REPORT
UCB-ITS-RR-2004-1

March 2004
ISSN 0192 4095

IMPACTS OF CALIFORNIA'S GRADUATED LICENSING LAW OF 1998

An assessment by the Institute of Transportation Studies at UC Berkeley
of the effects of the law on fatal and injury crashes of 16 year-old drivers

Douglas Cooper

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Sponsored by

California State Automobile Association (CSAA)

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EXECUTIVE SUMMARY

In July 1998 California changed its graduated driver licensing laws (GDL) for new drivers under the age of 18 to include restrictions on hours of driving, carrying teen-age passengers, and requiring more adult supervised driving practice. With fatal and injury crash data from California's Statewide Integrated Traffic Records System, this study, sponsored by the California State Automobile Association, used standard regression analysis as well as the Bai-Perron stochastic multiple structural break model to determine the effect of the law on teen-age passengers and crash rates of 16 year-old drivers. We found that in the three years following implementation of the new law, crashes caused by 16 year-old drivers decreased by 17% and the average number of teen-age passengers carried by 16 year-olds decreased by approximately 25%. The combination of these two decreases resulted in the saving of 25 lives and the prevention of 1,910 injuries.

To test the specific effect of the restrictions on driving between midnight and 5 AM, regression analysis was performed on the quarterly percentage of curfew crashes for 16 year-old drivers. Quarterly data was used due to the relatively small number of curfew crashes. The percentage of curfew crashes have been in a nearly significant long term down trend since 1996. There was a small, non-significant lessening of the long-term downward trend at the time of the implementation of the new law. The new law does not appear to have had a material effect on the percentage of driving done by 16 year-olds during curfew hours. This percentage was in a downtrend prior to the law and continued after the law took effect.

1. INTRODUCTION

Young drivers (ages 16 to 20) are different from both older, experienced drivers and from older novice drivers, often with fatal consequences. Nationally, motor vehicle crashes are the leading cause of death for this age group. Even though they comprise less than 7 percent of licensed drivers, they made up 14 percent of all drivers involved in fatal crashes and 17 percent of all drivers involved in police-reported crashes in 2000.

In California, teen drivers are over-represented in every category of traffic crashes. While they make up only 4% of all licensed drivers in the state, teens are responsible for 15% of the state's fatal and injury crashes. Sixteen year-olds are six times more likely to cause a fatal and injury crash and nine times more likely to be involved in single vehicle crashes than adult drivers age 25 to 54.

1.1 Background

While the differences in crash involvement rates between age groups are obvious, their basis is not. Numerous articles and studies have attempted to sort out the reasons and to propose solutions that would save lives. The most direct method would be to remove young drivers from the road entirely. However such a policy obviously involves tradeoffs and fairness issues (Williams, 1994). If teens are not allowed to drive, or have their driving severely restricted, what effects will it have on their ability to work, go to school, socialize, and run family errands? Additionally, since inexperience plays a part in crashes of new drivers of all ages, how do we decide the age at which people may begin driving?

Teenage crashes differ in type as well as quantity from those of older drivers. In a 1998 article involving a detailed analysis of 16 year old drivers in California during 1989-1994, Williams et al., observed that the crashes of 16 year olds are more often single-vehicle events, involve speeding and higher passenger occupancy rates (often other teenagers), and are more likely to result from driver error. Similarly, the IIHS listed inexperience, risk taking behavior/immaturity, and greater risk exposure as the three factors that combine to make the teen years so deadly for young drivers.

Disentangling inexperience and risk taking behavior (i.e., separating the effects of age and experience) is very difficult because the two are highly correlated. Additionally, most of the research in this area involves comparisons of crash rates in the first, second, and subsequent years of licensure of those who obtained their initial license at various ages, although people who obtain their initial license at, say, age 20, are likely to be a substantially different population than those obtaining a license at age 16. Such groups may have different patterns of driving experience in the first few years of licensure that could limit the extent to which age and experience factors can be sorted out via this method (Williams 1994). Nevertheless, both immaturity and lack of driving experience have been shown to contribute to the higher crash risk of young drivers (Mayhew and Simpson 1990).

Immaturity is manifested in riskier driving practices such as speeding drinking and driving, and following too closely. Because of their inexperience, young drivers are less able to detect imminent hazards and less able to cope with them when they occur. These factors are compounded by a tendency of young drivers to overestimate their capabilities and to drive at higher risk locations and times, such as at night (Ferguson et al., 1996).

The third item listed by IIHS as making the teen years so deadly, greater risk exposure for teenagers, is supported by evidence that the accident involvement rates of young drivers vary by day of week, time of day, and the presence/absence of passengers. While the accident involvement rates of 16-19 year old drivers are higher than those of 20-24 and 25-59 year olds in all situations that were examined, they were disproportionately high on weekends, at nighttime and with passengers. In 1990, even though only 18 percent of the miles driven by 16-19 year olds took place between the hours of 9:00 PM and 5:59 AM, they accounted for 45 percent of their fatal crashes. The nighttime fatal crashes of 16 year olds are patterned differently than those of older teens, occurring more often between 10:00 PM and midnight and are concentrated on Friday and Saturday evenings (Williams 1996). The results for the passenger variable are particularly interesting because, unlike weekends and nighttime (which affect all driver groups negatively), the negative effect of passengers on overall accident rates was evident only for 16-19 year old driver groups (Doherty et al., 1998).

Over the years, states have addressed the issue of teenage drivers by variously requiring driver education, enacting curfews, changing the age of licensure, granting licenses in stages, and making it easier to suspend a license for traffic violations or drinking and driving. Some plans have produced unexpected benefits while others have had an overall effect that was opposite to that which was intended. Robertson (1980), for example, found that the elimination of high school driver education reduced the young driver licensure rate and thereby reduced young driver crashes. Preusser et al. (1984), in a study of teenage night driving curfews, found that states issuing curfew restricted licenses had substantially fewer teenage crash involvement during the curfew hours as well as during other times of the day. They suggested that curfew restricted licenses were less desirable than the full privilege licenses granted in other states and thus fewer teens became licensed and total teen exposure was reduced. (Preusser 1988)

In recent years, states have begun to embrace the concept of graduated licensing, summarized by IIHS as “a system for phasing in on-road driving that allows beginners to obtain their initial experience under lower risk conditions. There are three stages: a supervised learner’s period, an intermediate license (once the driving test is passed) that limits unsupervised driving in high-risk situations, and a full-privilege driver’s license available after completion of the first two stages. Beginners must remain in each of the first two stages for set minimum time periods.”

1.2 California's Graduated Licensing Law

While a form of graduated licensing has existed in California since 1983, a new, more stringent law took effect on July 1, 1998. In addition to conditions and restrictions already existing under the old law, the main provisions of the new law require that:

- Teens under 18 years of age hold their instructional permit for six months before they can take a drive test for their provisional license. Previously the law specified 30 days.
- During the instructional permit period the prospective driver must have 50 hours of adult-supervised driving practice (an increase of 20 hours), 10 of which must be at night.
- Provisional license holders cannot drive between midnight and 5 a.m. for the first year they hold the license unless supervised by a parent, guardian, driving instructor or adult age 25 or older.
- Provisional license holders may not transport passengers under 20 years of age for the first six months, unless supervised by a parent, guardian, driving instructor or adult age 25 or older.

2. METHODOLOGY

Perhaps the most basic problem when conducting research is the selection and presentation of descriptive statistics. How does one meaningfully compare different types of data while avoiding the impression that the data are the same? This is often achieved by what is known as normalization of the data through the use of some form of common divisor such as “per unit time” or “per licensed driver.” This does not completely solve the problem, however. If Town “A” has 20 traffic fatalities a year while Town “B” has 40, it would seem fair to say that Town “B” is twice as dangerous as Town “A” since both are given in the form “fatalities per year.” Obviously, more information is needed before such a conclusion can be drawn, such as the amount of driving done in each town or their respective driving populations. If Town “B” has four times as many drivers as Town “A”, it would actually have the better driving record in spite of having twice as many accidents. Similarly, one cannot compare the number of crashes in one year to the number in another year without knowing something about the number and driving habits of the drivers on the road in each year.

An illustration of this problem is the comparison of the crash rates of various age groups. While most accept as incontrovertible the higher comparative crash risk of young, inexperienced drivers, there is a great deal of argument today about older drivers and whether or not they should have their driving skills tested on a regular basis. One of the favorite statistics used by those

opposed to testing is the relatively benign “crashes per licensed driver” which shows only a slightly elevated risk for older drivers. This is a false picture.

Table 1 contains data from the latest (1995) Nationwide Personal Transportation Survey. As can be seen, older drivers tend to drive less, so their potential to cause crashes is reduced. If we adjust for “exposure,” i.e., the actual amount of time spent driving, using a technique called Induced Exposure (discussed below) the picture changes dramatically, with 75-79 year-olds at the same level as 17 year-olds and drivers 80 year and older being the most dangerous group of all.

Table 1: Annual Estimated VMT By Age Group

Age	Mean Annual VMT	Age	Mean Annual VMT
16	2,891	45-49	15,527
17	5,503	50-54	14,169
18-19	10,057	55-59	12,509
20-24	13,648	60-64	11,354
25-29	15,667	65-69	9,054
30-34	15,510	70-74	7,678
35-39	15,934	75-79	6,747
40-44	15,126	80+	4,469

Source: 1995 NPTS

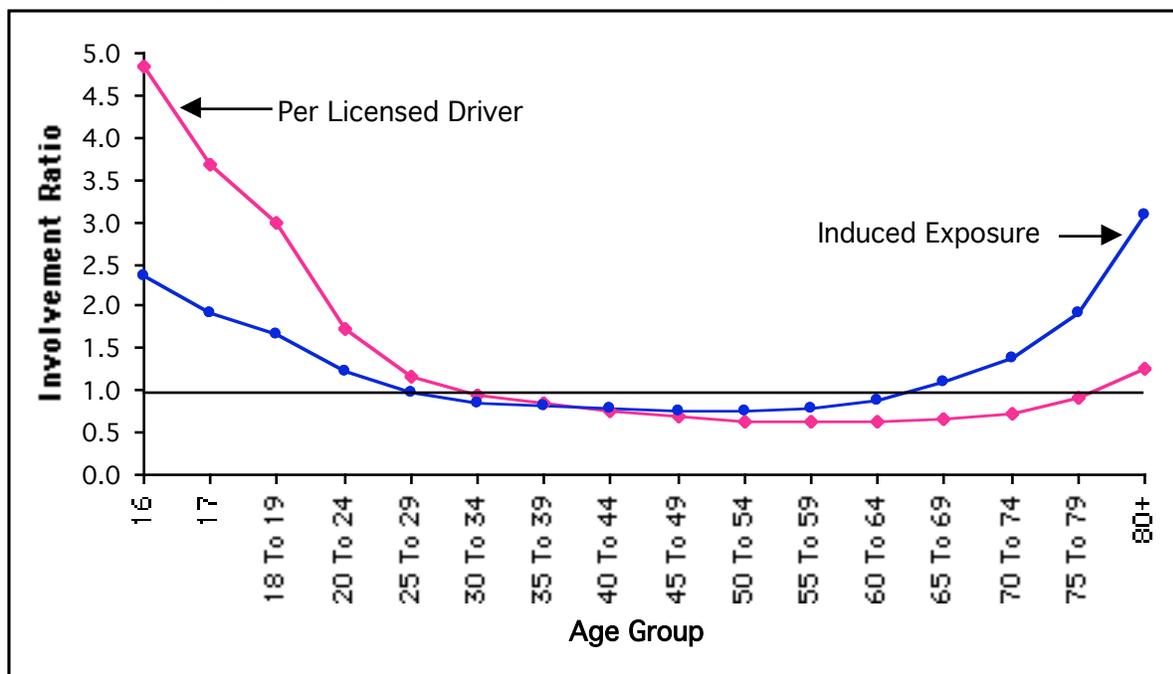
Ideally, we would like to know the actual measured annual average vehicle miles of travel for each age group in California. Such knowledge would make crash risk comparisons quite straightforward. Unfortunately, such information is virtually impossible to obtain, with only survey data such as the previously mentioned NPTS available as a crude substitute. A better, though still not perfect, technique is induced exposure (IE) which is based on the premise that the “innocent victims” of crashes (i.e., the drivers determined not to have been at-fault in a crash) represent a random sample of the drivers on the road. If it was found, for example, that teenagers were the innocent victims in 8% of two-car crashes, this group could be said to make up 8% of the drivers on the road. When using this technique, it is customary to use only two-vehicle crashes, in which fault was assigned (Massie et al. 1995, Lyles et al. 1991).

While there are a number of legitimate questions regarding IE, including assignment of fault in a crash and whether victims are truly "selected" at random, the question of validity basically comes down to the question of whether there exists an “unqualified true measure” of exposure for differentiated driver, vehicle, and environmental characteristics. The answer would seem to be that there is not, so that even if there are some errors in the induced exposure estimates, as long as they

are comparable to those from other methods, it represents an improvement since the required data are more readily available for this method than they are for others (Lyles et al, 1991).

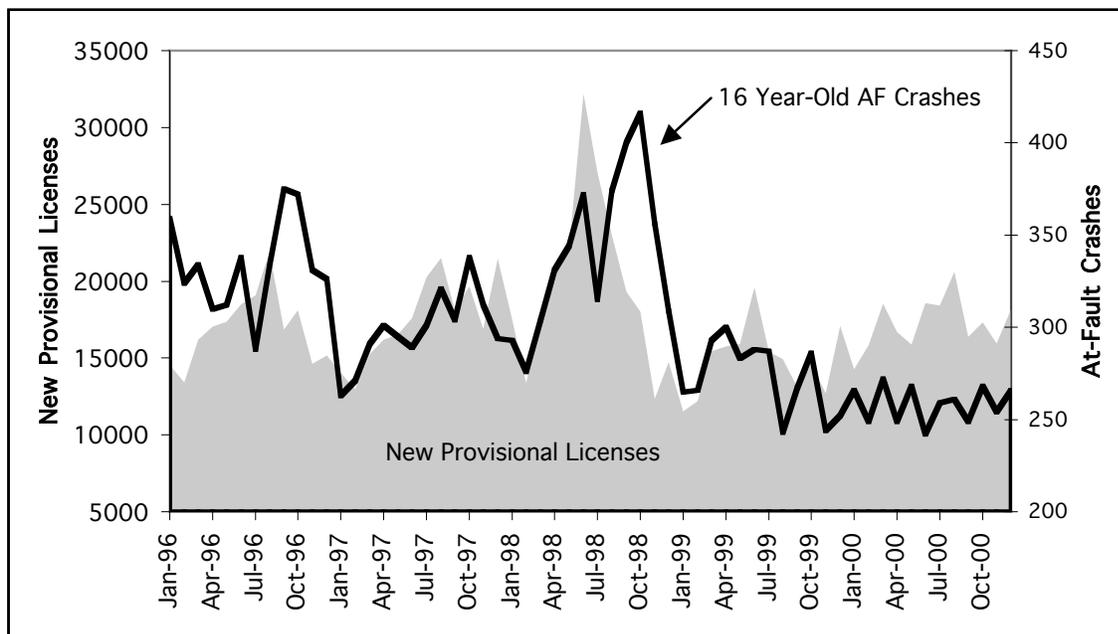
In Figure 1, the involvement ratio (IR) is the variable of interest. This is computed by dividing the percentage of crashes attributable to an age group by that group's percentage representation in the population of interest (in this figure, two populations are used: the population of licensed drivers as reported by the California DMV, and the population of all drivers on the road as determined by using IE). If a group represented 5% of the drivers on the road, for example, and was responsible for 8% of the crashes, it would mean that that group was "over-represented" in crashes by a factor of 1.6 to 1. Thus 1.6 is their involvement ratio. Figure 1 shows the IRs for all age groups involved in fatal and injury (F&I) crashes throughout the state for the period 1996 through 2000 computed on a "per licensed driver" and an "induced exposure" basis. The over-representation by drivers at both ends of the age scale is quite obvious. As previously discussed, the importance of choosing the correct population is clearly illustrated. If only total crashes or crashes per licensed driver were used, older drivers would appear to be much safer than they actually are simply because they don't drive as much as other age groups.

Figure 1: Involvement in Fatal & Injury Crashes by Age Group



One final note on the selection of data. A great deal has been made in the media regarding the large decline in the number of crashes that has occurred since 1998. While this is literally true, it is very misleading as illustrated in Figure 2.

Figure 2: New Provisional Licenses & 16 Year-Old At-Fault Crashes



In anticipation of the change in the licensing law, there was a surge in new licenses issued to 16 and 17 year-olds (roughly 70% went to 16 year-olds). With this many new drivers on the road the total number of crashes attributed to this age group also went up as shown. When compared to this obviously anomalous year, virtually any other year would look good.

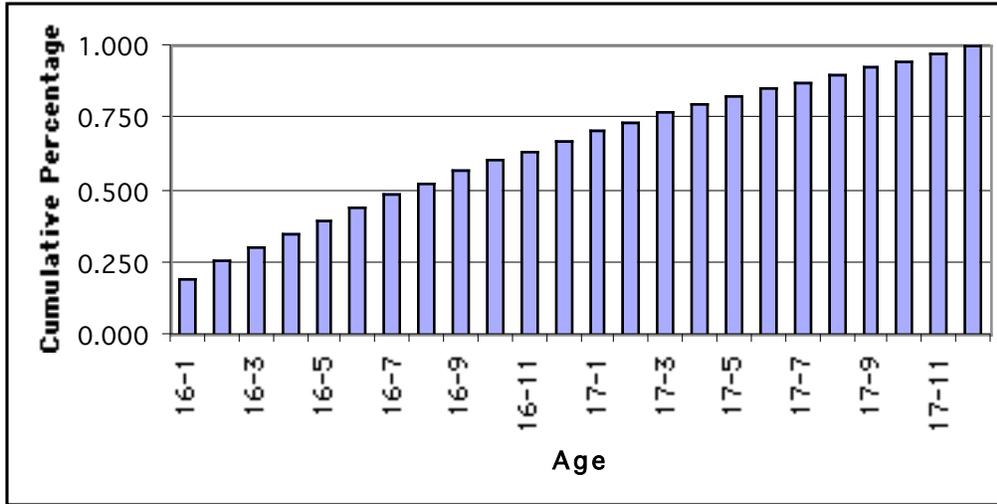
2.1 Source of Crash Data

Except where noted, all crash and passenger data included in this report is obtained from the Statewide Integrated Traffic Records System (SWITRS). SWITRS processes all reported fatal and injury collisions which occur on California's state highways and all other roadways, excluding private property. Since property damage only (PDO) crashes are not consistently reported by the various agencies throughout the state they are considered indicators of the volume of traffic collisions only and are not exact statistics (CHP 1999). For this reason, all crashes used for this study are fatal or injury crashes. Additionally, only drivers of cars, vans, or light trucks and their passengers are included.

2.2 Age Group

The focus of this report will be 16 year-old drivers. The reasons for this are twofold. First, at least theoretically, the last drivers who could still be subject to the old law will not pass out of the system (turn 18) until June 2002. Second, since the key restrictions of the new law apply for a limited time (six months for passengers and one year for curfew) and since approximately 45% of teenagers acquire their license by age 16 1/2 (Figure 3), a large segment of the 17 year-old driver population will not be subject to the laws restrictions.

Figure 3: Cumulative Percentage of Age At First License 7/99-6/01



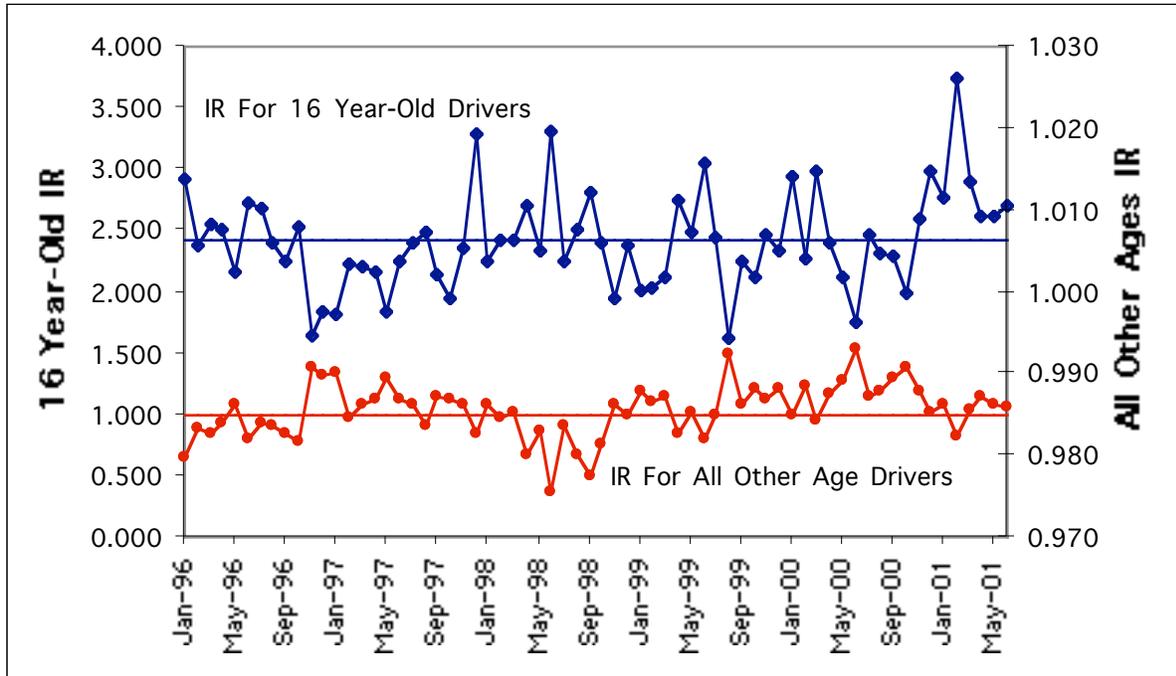
3. RESULTS

For changes in the crash rate, the challenge was to separate the effect of the new law from the long term trend in the crash rate as well as the disequilibrium created by the change in licensing behavior brought about by the change in the law. Three different metrics were investigated: involvement ratio, crashes per unit population, and crashes per licensed 16 year-old driver.

3.1 Involvement Ratio

We will begin our investigation of crashes by 16 year-old drivers by looking at the monthly involvement ratio (as defined earlier) for that group and compare it to all other drivers to see how 16 year-old's driving has changed over time. The results are shown in Figure 4. Because of the IR's extreme sensitivity for groups that comprise only a small segment of the driving population (16s are about one percent) establishing a time trend is meaningless in that it is really only telling us about the other groups. An example of this is shown for the month of February 2001 when the 16 year-olds IR spikes up to 3.7 which is caused more by an improved performance in the other age groups than a problem by the 16 year-olds. The main point to be made here is that 16 year-olds are still vastly over represented in fatal and injury crashes.

Figure 4: Involvement Ratios for Fatal & Injury Two Vehicle Crashes In California



3.2 Crashes Per Unit Population

The Journal of The American Medical Association recently published two reports, Foss et al. (2001) and Shope et al. (2001) which used a similar methodology to assess the early results of graduated driver licensing (GDL) programs in two states, Michigan (effective date April 1, 1997) and North Carolina (effective date December 1, 1997).

3.2.1 Per Unit Population Methodology

The evaluation design was a before and after comparison of the crash rate per 1,000 population during pre and post graduated licensing periods with each period represented by a single point in time. Changes in crash rates for 16 year-olds were then compared to changes in crash rates for some older group of drivers (North Carolina - 25-54 years-old, Michigan - 25 and older) to control for non GDL related influences.

First the number the number of crashes involving sixteen year-old drivers was compiled for each period and normalized by dividing that total by the state's 16 year-old population for that same period. Next a relative risk (RR) ratio was calculated by dividing the crash rate per 1,000 for the post period by that of the pre period. An RR less than one signified a reduction in the crash rate. This process was repeated for the control group. Finally, the RR for the 16 year-olds was divided by that of the control group. Theoretically, if the GDL had had no effect, both age groups would have the same RR and the ratio of the two RRs would equal one. Anything less than one would signify a net improvement by the 16 year-olds which could be attributed to the new licensing law.

The results appear to be very good with the overall crash rate declining 25% in Michigan and 27% in North Carolina.

3.2.2 Per Unit Population Results

If we accept the above methodology, the results for California 16 and 25-54 year-olds are shown in Table 2. The Involved crash type includes all age group crashes regardless of fault while AF crashes are those for which a driver of that age group was determined to have been at fault. The at fault crashes avoid the inherent problem of a change in one age group's crash rate directly affecting another age group's rate.

Table 2: California Crash Rates Per 1,000 Population For 16 Year-Olds

Crash Type	Rate Per 1000 Population			Relative Risk Per 1000 Population	
	1996	1999	2000	1999 vs 1996	2000 vs 1996
<u>16 Year-Olds</u>					
Involved	12.61	9.76	9.14	0.77	0.73
AF Fatal & Injury	9.23	7.00	6.62	0.76	0.72
AF Curfew	0.45	0.29	0.28	0.64	0.62
<u>25-54 Year-Olds</u>					
Involved	11.79	11.19	11.60	0.95	0.98
AF Fatal & Injury	5.39	5.02	5.15	0.93	0.96
AF Curfew	0.35	0.28	0.30	0.81	0.84

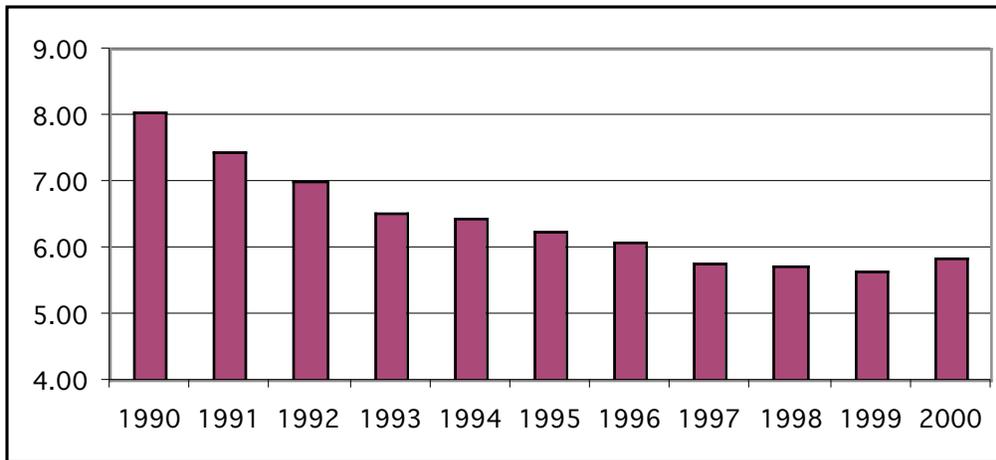
Table 3 is the final relative risk for 16 year-old drivers after the year to year, non GDL influences, have been accounted for by dividing by the appropriate RR of the 25-54 year-old group.

Table 3: Final Relative Risk For 16 Year-Olds

Crash Type	Relative Risk Per 1000 Population	
	1999 vs 1996	2000 vs 1996
Involved	0.81	0.74
AF Fatal & Injury	0.82	0.75
AF Curfew	0.79	0.74

The 1999 vs 1996 RRs in Table 6 can be interpreted as a 19% reduction in Involved and At-Fault Fatal & Injury crashes and a 21% decline in Curfew crashes for 16 year-olds as a result of the graduated licensing law and a 26%, 25%, and 26% decline for the same crash types when comparing 2000 to 1996.

We see at least two problems with this methodology, however. To begin with, fatal and injury crashes per 1,000 population have been in a downtrend in California for some time (Figure 5). By comparing two isolated points in time the long term trend is ignored. It may very well be that the improvement in crash rates is simply a continuation of the long term trend and is unrelated to the new law.

Figure 5: California Fatal And Injury Crashes Per 1,000 Population

Another serious problem is that while the population of 16 year-olds has grown each year with the exception of 1998, the number of licensed drivers is lower in the two "post" years when compared to 1996 or 1997 (Table 4). Even if driving skills remained unchanged, with fewer drivers there will be fewer crashes which, combined with a larger population of 16 year-olds, will lead to a dramatic reduction in crashes per 1,000 population.

Table 4: 16 Year-Old Population and Licensed Drivers 1996 - 2000

	1996	1997	1998	1999	2000
Population	433,523	455,083	439,628	467,899	469,009
Driver Licenses	101,381	104,244	111,757	97,871	87,914

Source: California Department Of Finance and Department of Transportation

3.3 Crashes Per Licensed Driver

While comparisons between age groups on a "per licensed driver" basis are misleading, this type of data can be used within a specific age group to look for changes over time. Specifically, we would like to look at crashes per licensed 16 year-old driver from January 1996 through June 2001 to see if the graduated licensing law has had an effect.

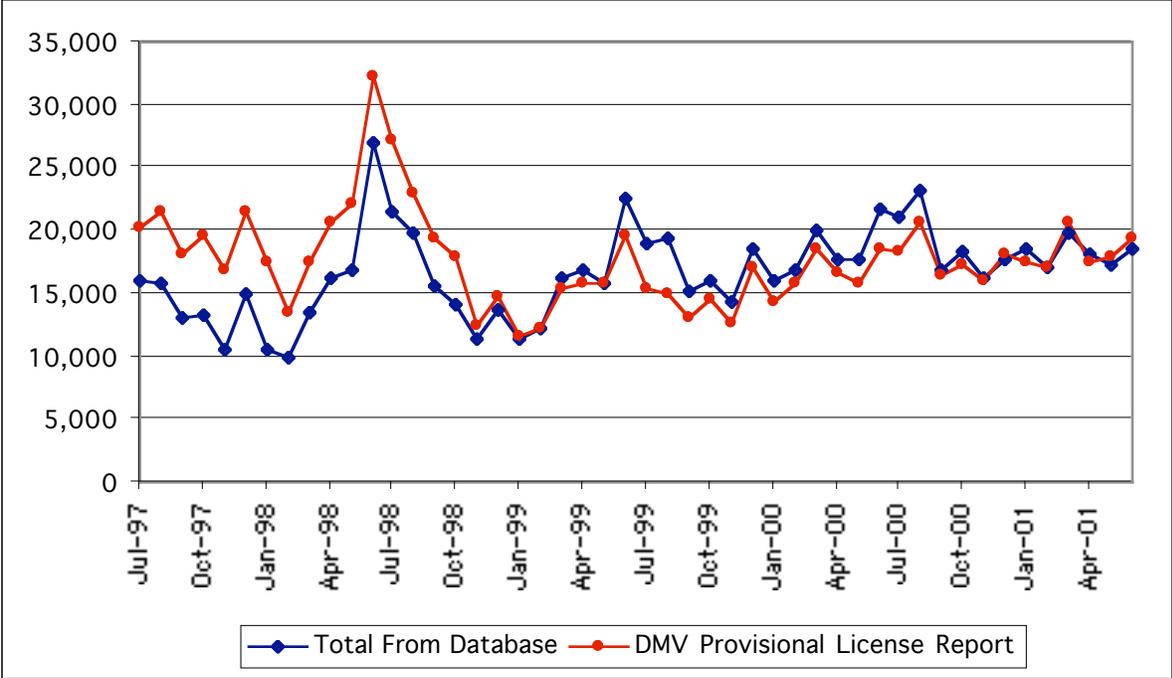
The Department of Motor Vehicles maintains a database of all licensed drivers in the state which includes type of licenses and ID cards held as well as license acquisition/change dates. Each time a license or ID card is acquired, changed or replaced, the date is added to the record. After six such entries, original data starts to be lost. Additionally, there is no way to associate a specific license action with a specific date. Thus, if a person obtained a drivers license, had it suspended, obtained an ID card, then was issued a new driver's license, there is no way to tell which date in the record pertains to which event.

On the first pass through the database (3.2 million records), on those records with multiple dates, the earliest date was assumed to be associated with a driver's license. This introduced two potential errors. First, approximately 85,000 people showed that they had been issued a license

before age 16, which is not possible. With no way to resolve this issue, these records were dropped. Second, even though the issue age was 16 or greater, it is possible that it was an ID card rather than a drivers license that was issued on that date.

With these potential errors in mind, the resulting monthly issuance of driver licenses extracted from the database was compared to the published monthly total of provisional licenses issued by the DMV. This monthly total is considered accurate in that it is automatically created as it occurs, and requires no search of past records. The comparison is shown in Figure 6.

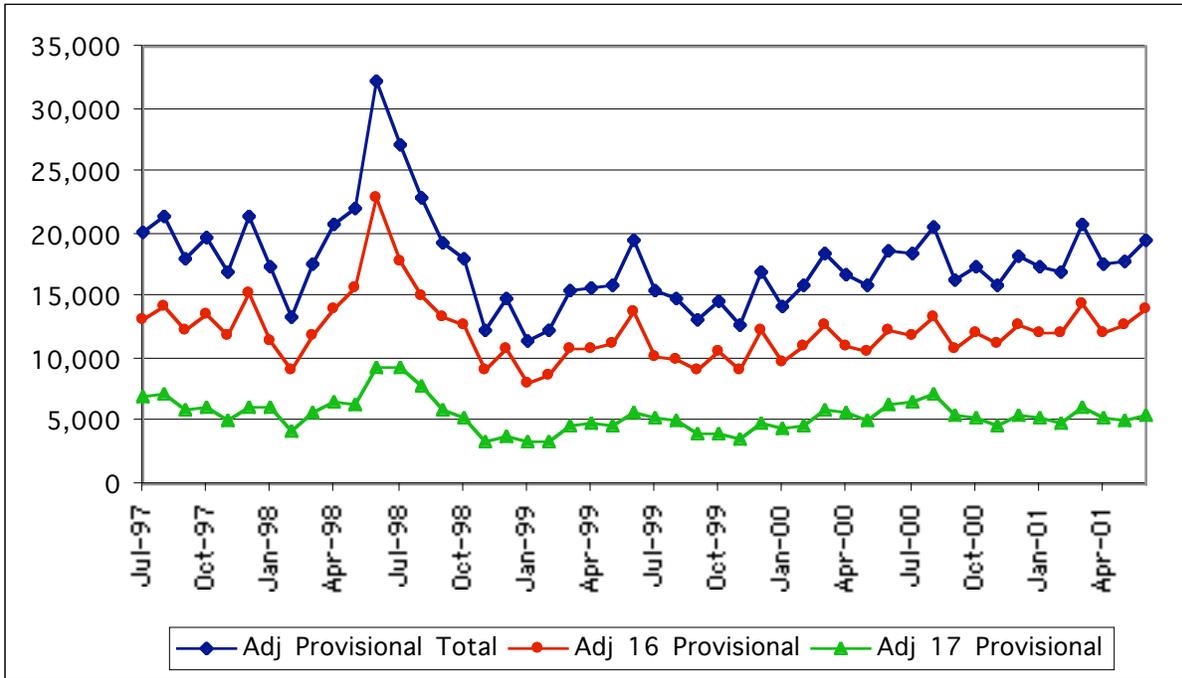
Figure 6: Comparison of Database and DMV Report of New Provisional Licenses



As can be seen, the two lines are very similar in shape. Given this similarity as well as the inherent accuracy of the DMV’s monthly report, we felt that it was reasonable to adjust the database numbers to that of the DMV. If this procedure introduces an error into our analysis, it will work against the case of a positive effect of the new law because this adjustment results in more licensed drivers in the “before” period (hence fewer crashes per licensed driver) and fewer licensed drivers in the “after” period, resulting in more crashes per licensed driver.

In making the adjustments to our totals, the original percentage allocations by month and age at first license were maintained. The Figure below shows the total number of provisional licenses as reported by the DMV as well as the adjusted number of 16 and 17 year-old new licensees that go to make up that total.

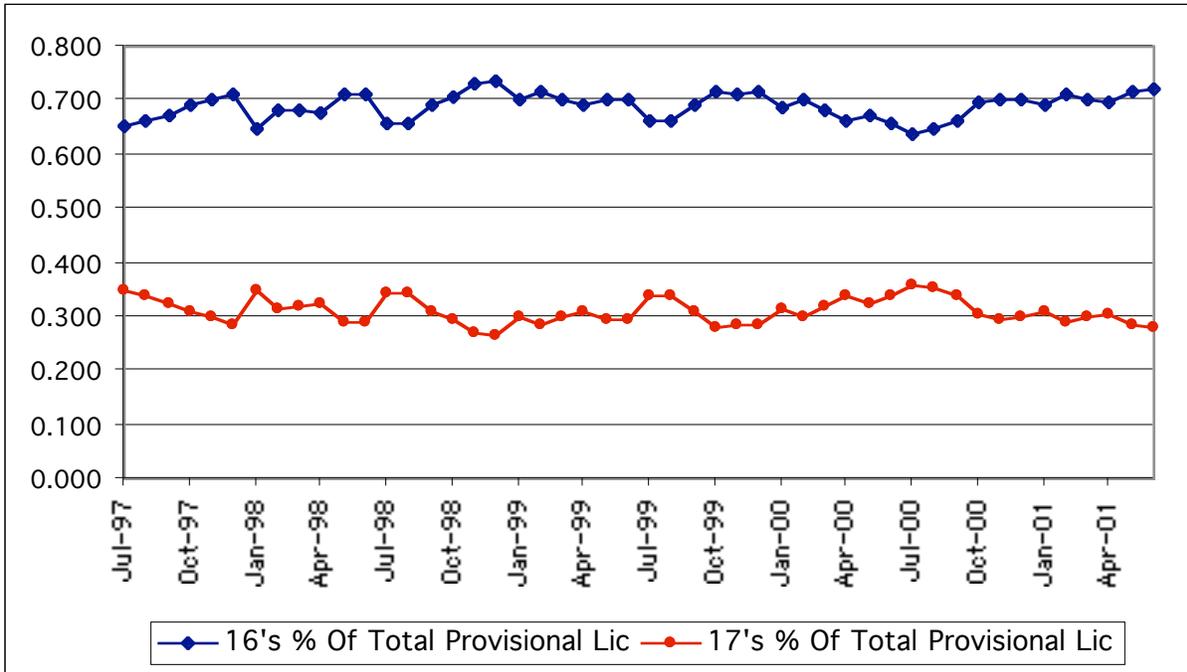
Figure 7: Monthly New Provisional Licenses by Age Group



Due to the fact that the database supplied to us begins with people born on or after July 1, 1979, we only have complete data for 17 year-olds starting July, 1997, or one year prior to the new law going into effect. If we want to go back further than that (since we have accident data going back to January 1996) we will have to estimate the number of 16 and 17 year-old licensees using known percentages established earlier and the monthly total number of provisional licenses which we have going back as far as 1989.

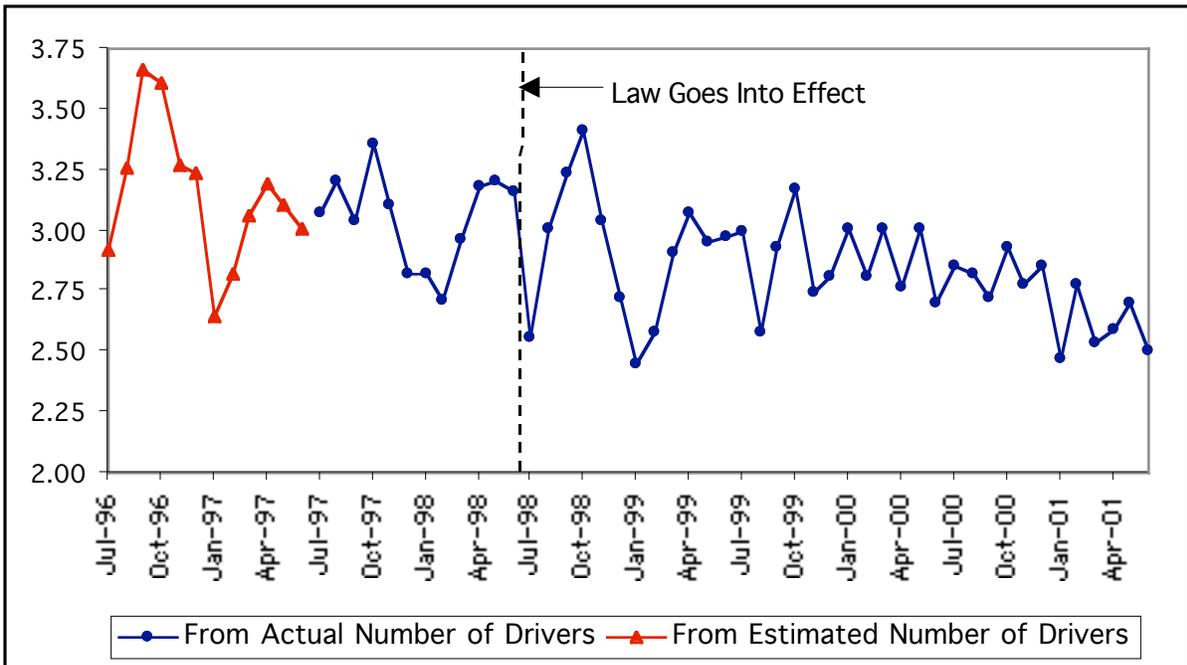
As shown below the percentage of total new licenses made up by each age group is quite consistent over time. Additionally, in a regression, almost all of the months are statistically significant which means that there is a systematic variation between specific months. Therefore, twelve monthly averages were computed and these averages applied to the DMV monthly provisional license report to come up with estimated July 1996 through June 1997 totals for 16 and 17 year-olds.

Figure 8: Percentage of New Provisional Licenses held by 16 and 17 Year-Olds



Using the estimated and actual number of licensed 16 year-old drivers and the number of 16 year-old at fault crashes from the SWITRS database, the number of crashes per 1,000 licensed 16 year-olds was calculated and plotted as shown in Figure 9.

Figure 9: Number Of Crashes per 1,000 Sixteen Year-Old Licensed Drivers



3.3.1 Per Licensed Driver Methodology

The analysis was carried out using a new econometric technique developed by Bai and Perron (2002) that provides a means of distinguishing different regimes of behavior. The key difficulty in undertaking the analysis is to be able to distinguish equilibrium and disequilibrium periods in the data and the Bai-Perron technique allows us to do this. Failure to distinguish the period of adjustment from the trend will lead to errors in the calculation of the impact of the new law. There are three general periods to be considered, the period prior to the change in the law, the period of adjustment after the law is announced and comes into effect, and the period of the new equilibrium when all adjustments to the new law have been internalized.

In our case the regimes are: the law is announced to go into effect at a future date, people rush to get license before law goes into effect, after law goes into effect there are fewer than normal applicants because people moved their decision ahead, over time we move back into equilibrium again. There are three to four regimes in this explanation.

As with the passenger analysis, the coefficients obtained were used to estimate the number of crashes prevented by the new law. These were then used to estimate the number of lives saved and injuries prevented.

3.3.2 Per Licensed Driver Results

The time series technique developed by Bai and Perron (2002) lets the data determine the number of structural breaks or regimes in the model. It is a relatively complex method but a valuable one. The straight lines shown in Figure 10, Figure 11 and Figure 12 represent the different levels within the data that illustrate the different regimes. By distinguishing these differences we are in a position to measure the long run or permanent impact of the new law on crash rates among 16-year old drivers.

Figure 10: Number of 16 Year-Old Licensed Drivers

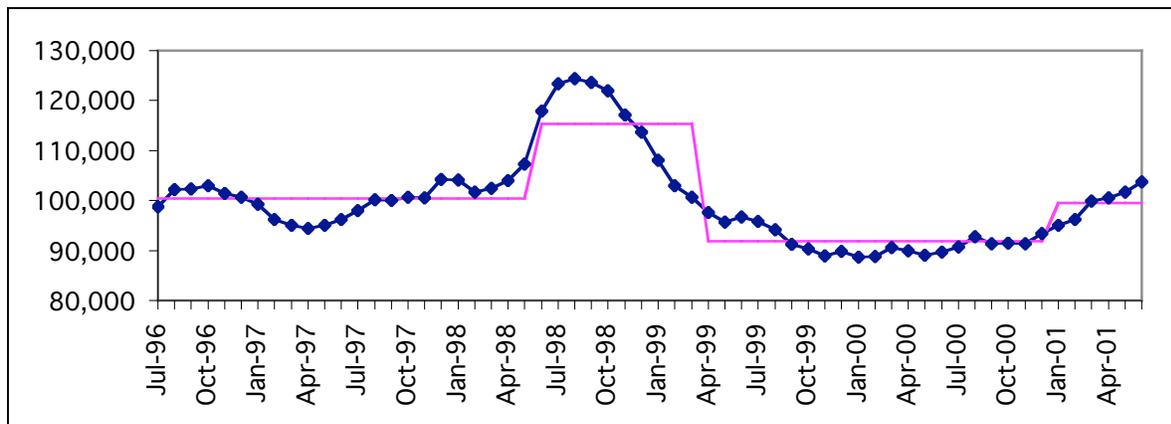


Figure 11: Number Of Crashes By 16-Year-Old At-Fault Drivers

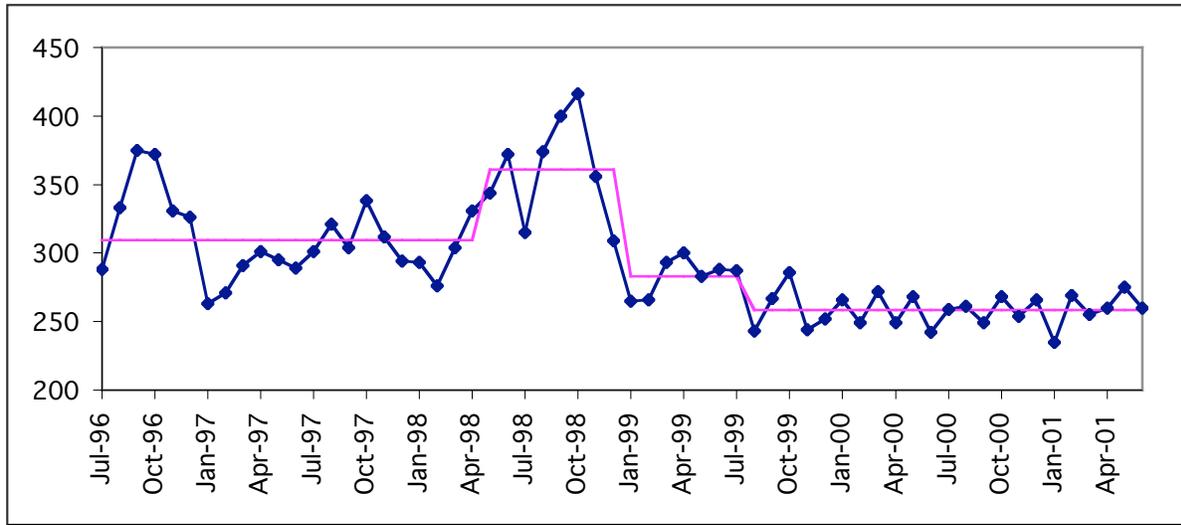
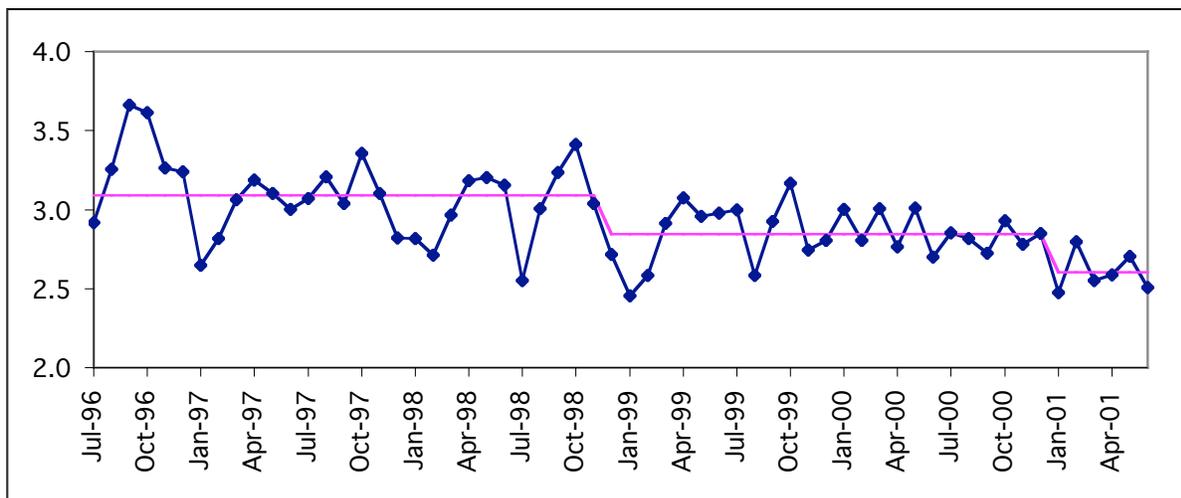


Figure 12: Crashes Per 1,000 Licensed 16 Year-Old Drivers



The first regime encompasses the period July, 1996 to approximately March, 1998. In this period, the mean number of crashes equals 309.5, and the mean number of drivers equals 100,347, yielding a crash rate of approximately 3.09. This regime can be viewed as the normal or equilibrium, prior to any effects of the announcement of the change in legislation.

The second regime begins in approximately May, 1998, and lasts until the end of 1998 or early in 1999. In this regime, the mean number of drivers *increases* from 100,347 to 115,376. This is before the law has come into affect, and therefore, it must be a response of individuals wishing to avoid the ramifications of the new law. Also in this regime, the number of at-fault crashes *increases* in response to the increased number of drivers. However, there is no break in the crash rate in response to these two changes, as the mean crash rate in the second regime equals approximately 3.12, which is not significantly different from the first regime. Clearly the *crash rate* has not changed

The third regime begins in early 1999. In this regime, the mean number of drivers decreases to 91,812. This decrease can be viewed as an adjustment response in the following manner. In regime 2, approximately 5,000 16 year olds shifted their decisions to become drivers early, in anticipation of the change in legislation. Therefore, the number of 16 year-old drivers in regime 2 was above the equilibrium of regime 1, and the adjustment to equilibrium requires that the number of drivers decrease in regime 3. Also in regime 3, the mean number of at fault crashes decreases to approximately 283. This decrease is partially in response to the decrease in the number of drivers, and partially a response to the change in legislation. To see this, notice that, in spite of the fact that both the number of crashes and the number of drivers decreases in this regime, the mean crash rate still falls to approximately 2.84.

The final regime begins in late 1999/early 2000. In this regime, the mean number of drivers increases to 99,528, which is the last stage of the adjustment process of drivers, leaving the mean number of drivers very close to the equilibrium or normal mean number of drivers in the first regime. Also in this regime, the raw number of crashes decreases to 258,65, and the mean crash rate decreases to equal approximately 2.60.

From the analysis it is evident that the introduction of the law appears to have had a temporary effect on the number of drivers, both a temporary and a permanent effect on the number of at fault crashes, and a permanent effect on the crash rate. The temporary increase in drivers and crashes occurs in regime 2. The permanent decrease in the number of at fault crashes and the crash rate is seen in the decreases in regimes 3 and 4.

We are now in a position to determine how many lives the law has saved and how many severe and minor injuries have been prevented. We do this by simulating the number of crashes that would have occurred had the law not been put in place and compare it to the actual result. The difference in crashes is then linked to the average number of people in crash involved cars to determine the number of lives saved and injuries prevented.

The simulation involved three steps. First, we had to simulate what the distribution of drivers over time would have been had no change in the law occurred (i.e., with no rush to obtain a license and no change in driving habits). Once we have the 'normal' number of drivers and their distribution over time we can simulate the number of crashes and the crash rate that would have occurred in the absence of the law.

Figure 13 contains a comparison of the crash rate for 16-year-old drivers without the law, the upper line, and the actual crash rate, the lower line. The change in the law had no impact on the long run number of drivers but it did have a permanent impact on the accident rate of these young drivers.

Figure 13: Accident Rate With And Without Change In Law

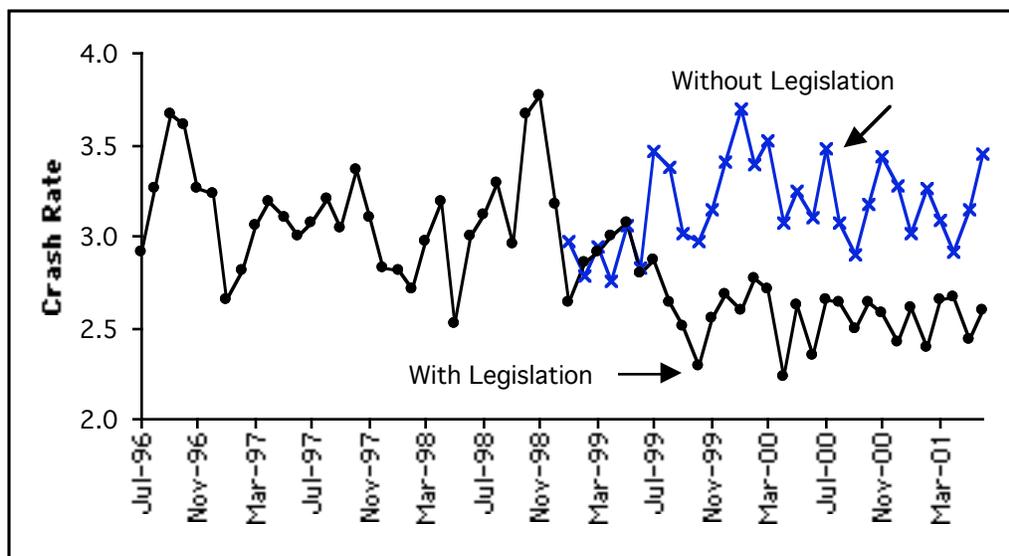


Figure 13 clearly shows the effects of the legislation. Not only has the mean number of crashes decreased from 309 to 258, but the variability of accidents has also decreased. Between January 1999, and June 2001, in the absence of the legislation, there would have been a total of 9,580 at-fault crashes. Over this same period, with the legislation in effect, this number of crashes is reduced to 7,952. Therefore, the legislation is estimated to have prevented 1,628 crashes, a 17% reduction.

Using these figures, the monthly average number of passengers in 16 year-old at-fault crashes, as well as the average percentage injury distribution, the reduction in crashes from January 1999 through June 2001 resulted in 17 lives saved and 1,225 injuries prevented.

3.4 Passengers

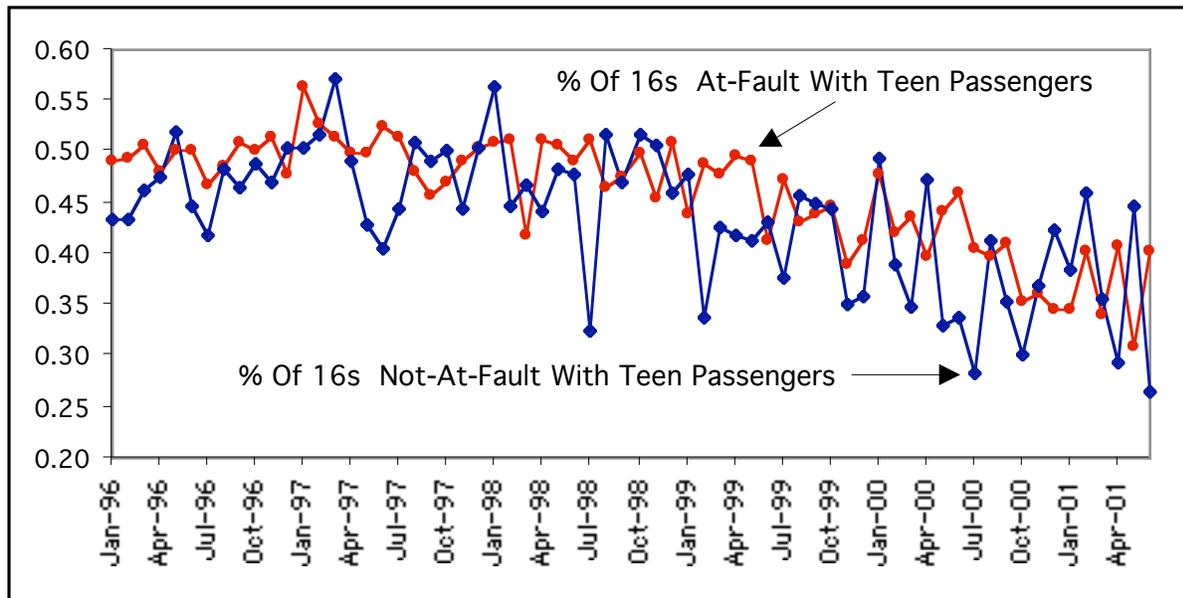
During the first six months of a provisional license, it is illegal to carry passengers under 20 years of age unless "accompanied and supervised by a parent, guardian, licensed driver 25 years of age or older, or a licensed or certified driving instructor"(California Vehicle Code).

This restriction has two potential effects on fatal and injury crashes by 16 year-old drivers. First, there is evidence to suggest that the presence of teenage passengers increases the risk of a crash (Chen et al 2000, IIHS Status report 1999, Preusser et al 1998, Doherty et al 1998). Second, given that a crash occurs, the presence of passengers increases the number of potential victims. Both of these issues will be addressed here. First we show that carrying teen passengers does increase the risk of causing a crash and then we will show how the new law has reduced the number of teen passengers thus saving lives and preventing injuries.

3.4.1 Effect of Carrying Passengers

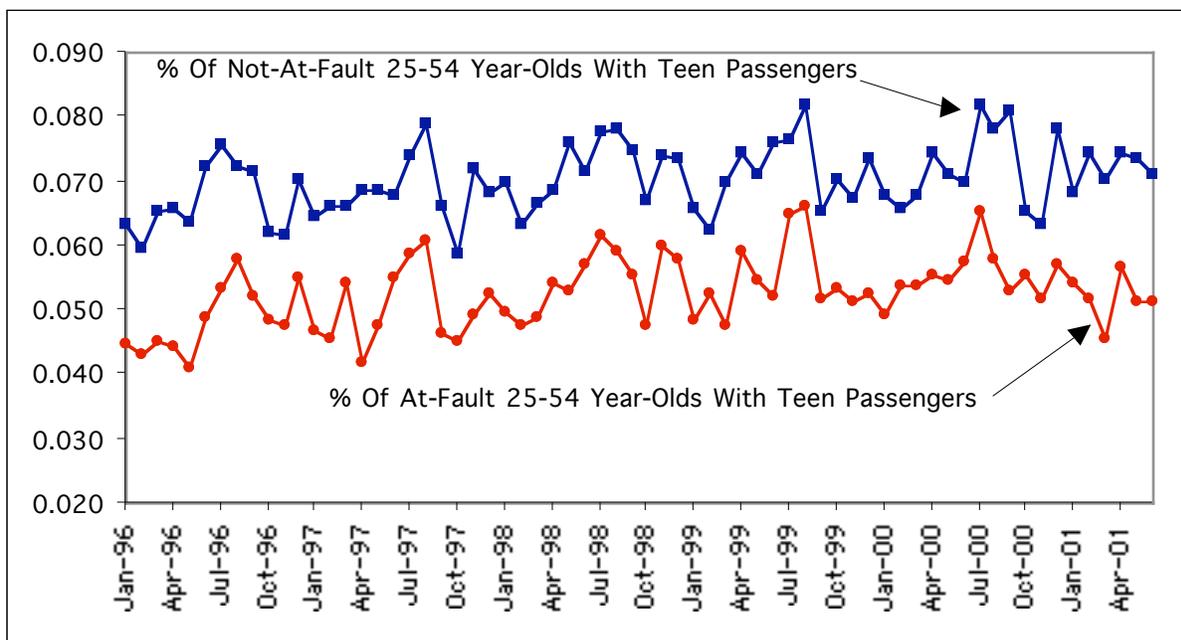
If carrying passenger has no effect on the accident rate for 16 year-old drivers, we would expect to see 16 year-olds who cause crashes to be carrying passengers at the same rate as those who do not cause crashes. To see if this is the case, the percentage of 16 year-olds who were at-fault in a crash and were carrying at least one passenger was compared to the percentage of 16 year-olds who were not-at-fault in a crash and were carrying at least one passenger. The results are shown in Figure 14. A two-sample t-test assuming unequal variances was performed and the difference was highly significant ($p = .0125$)

Figure 14: Percentage Of 16 Year-Old Drivers In Crashes With Teen Passengers



The same test was carried out with three other age groups: 17-19, 20-24, and 25-54 years-old. For the 17-19 year-olds, teenage passengers continue to be a problem with their presence significantly higher in at-fault cars ($p = 0.0256$). For the 20-24 and 25-54 year-old age groups the difference between at-fault and not-at-fault drivers was again highly significant except in this case it was in the opposite direction ($p = 0.037$ and $p = 0$, respectively). That is, while teenage passengers are a contributing factor in crashes involving teen drivers, they appear to lead to safer driving in older adults. The graphical comparison of the percentage of at-fault and not-at-fault 25 to 54 year-old drivers carrying teenage passengers is shown in Figure 15.

Figure 15: Percentage Of 25-54 Year-Old Drivers In Crashes With Teen Passengers



3.4.2 Effect of The New Law on Teenage Passengers

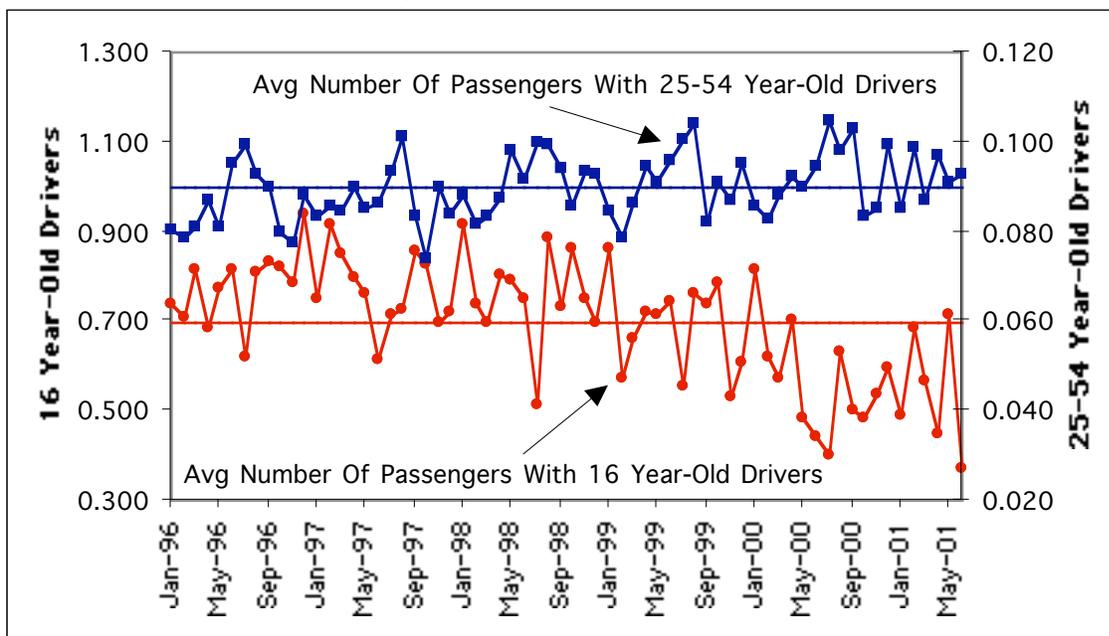
One of the features apparent in the figure showing the percentage of 16 year-old drivers in crashes with teen passengers (Figure 10) is the change in slope of both the at-fault and not-at-fault lines, indicating a decrease in the number of cars with teen passengers, after the law went into effect in July 1998. In order to test the significance and size of that change as well as to determine the factors involved, a regression analysis was performed with the average number of passengers in all not-at-fault vehicles driven by 16 year-olds as the dependent variable and Time, Law (a dummy variable equal to zero through June 1998 and equal to 1 thereafter), TimeLaw (an interaction term to see if the slope of the line changes after the law went into effect), and the months of the year as independent or explanatory variables (Table 5). The variables for each month are designed to remove influences that are associated with the month and not with the change in the law. Not-at-fault crashes were chosen because, as discussed in the earlier section "Selection Of Data", we feel they represent a random sample of the drivers of that age group on the road. Concerns regarding the factors affecting the accuracy of this technique, while important, should not affect the conclusions drawn from this study because we will be looking at each group's crash involvement as a time series. Since whatever biases may exist should remain relatively constant over the period of study within a specific age group, they will not affect the validity of the results.

Table 5: Regression Results For Average Number Of Teen Passengers Per Crash

Dependent Variable: AVGPAXPERCRASH			
Method: Least Squares			
Included observations: 65 after adjusting endpoints			
Variable	Coefficient	t-Statistic	Probability
C	0.8043	16.4286	0.0000
TIME	-0.0005	-0.3098	0.7581
LAW	0.0083	0.2268	0.8215
TIMELAW	-0.0074	-3.7803	0.0004
JAN	0.0595	0.9541	0.3447
FEB	-0.0178	-0.3370	0.7376
MAR	-0.0218	-0.4007	0.6904
APR	-0.0188	-0.3477	0.7295
MAY	-0.0007	-0.0132	0.9895
JUN	-0.0793	-1.4661	0.1490
JUL	-0.1732	-3.0643	0.0035
AUG	0.0295	0.5238	0.6028
SEP	0.0054	0.0949	0.9248
OCT	0.0320	0.5829	0.5627
NOV	-0.0579	-0.9274	0.3582
AR(1)	-0.2269	-1.6465	0.1061
R-squared	0.6842		
Adjusted R-squared	0.5875		
S.E. of regression	0.0868		
Sum squared resid	0.3688		
Log likelihood	75.8520		
Durbin-Watson stat	2.0621		

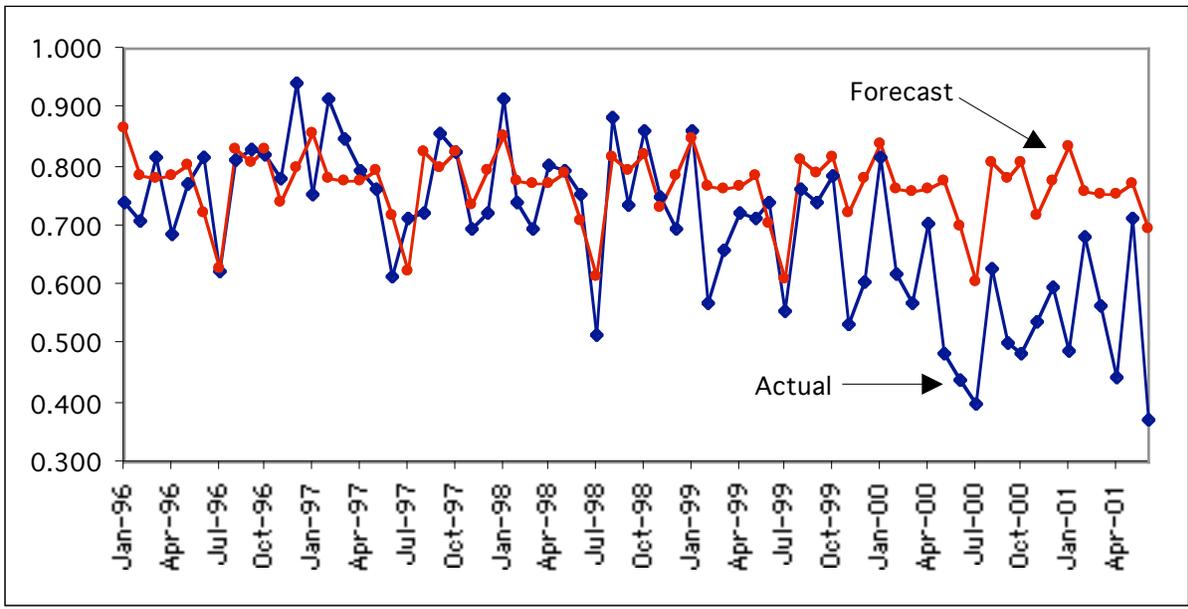
The variable TimeLaw is highly significant and has a negative sign indicating that the average number of teen passengers decreases after the law goes into effect. The only other significant variable is the month variable for July which shows a decrease in passengers during that month. By way of comparison, a similar regression of the number of teenage passengers in crashes with drivers aged 25-54, yielded no statistically significant results. The difference in change over time between the two age groups is illustrated in Figure 16.

Figure 16: Average Number Of Teenage Passengers In Not-At-Fault Cars Driven By 16 And 25-54 Year-Old Drivers



Using the regression coefficients, the average number of teenage passengers was computed without the law related variables to forecast what the average number of teenage passengers would have been had the law not been passed. The forecast line as well as the line representing the actual average number of teen passengers per crash car in not-at-fault crashes are plotted in Figure 17. The area between the two lines represents those teens kept out of cars driven by 16 year-olds who were not-at-fault in crashes.

Figure 17: Average Number of Teen Passengers In Crashes With 16 Year-Old Drivers



The same procedure was repeated for passengers with 16 year-old at-fault drivers. Using the number of passengers who, without the law, would have been in the crash vehicles and the average number of passengers who fall into each injury category when accompanying 16 year-old drivers, the number of deaths and injuries prevented were estimated as shown in Table 6. One of the features to note is the increase over time, as more drivers are subject to the law and knowledge of the law increases. We feel that this is a conservative estimate in that it was calculated assuming no change in the overall number of crashes. As demonstrated earlier, a decrease in the number of teenage passengers should lower the number of crashes which would result in even greater savings in terms of lives and injuries.

Table 6: Passenger Deaths and Injuries Prevented

Year	Passengers "Saved"	Degree Of Injury				
		None	Killed	Severe	Visible	Pain
1998-1999	109	57	1	2	19	30
1999-2000	496	259	3	11	87	136
2000-2001	845	442	4	19	148	232

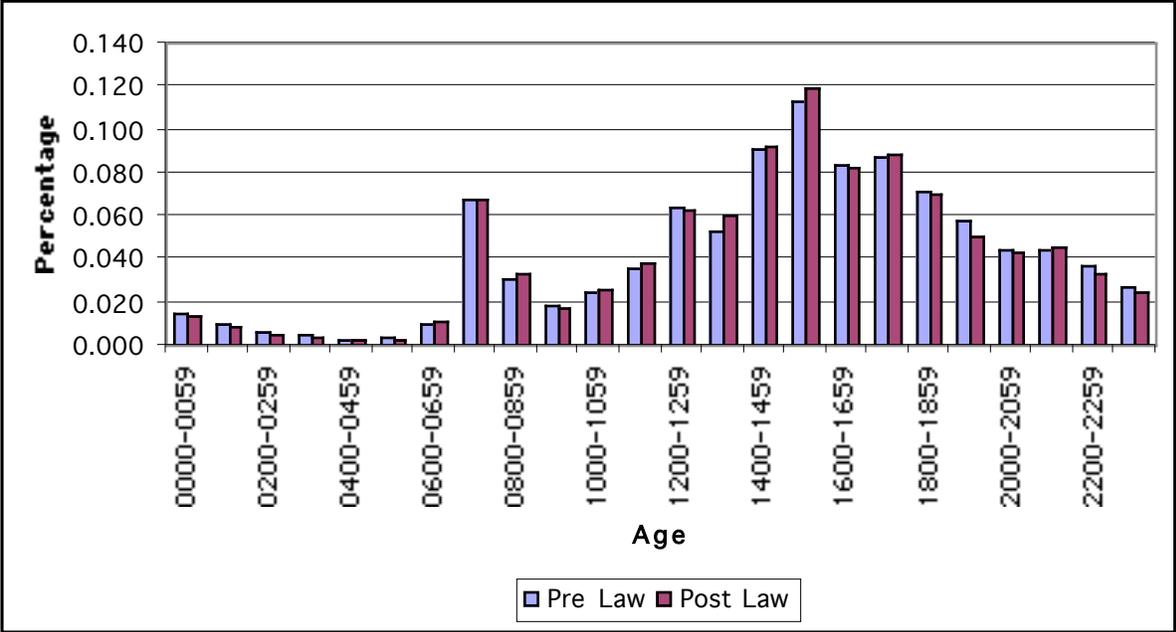
3.5 Crashes By Time Of Day

There is convincing evidence in the literature that the accident involvement rates of young drivers vary by time of day. While nighttime driving is riskier than daytime for everyone, it is especially so for teens (Doherty et al 1998, Williams and Wells 1995, Massie et al. 1995). For this reason, one of the key provisions of the graduated licensing law is the imposition of a curfew

between the hours of midnight and 5:00 AM for the first year that a provisional license is held.

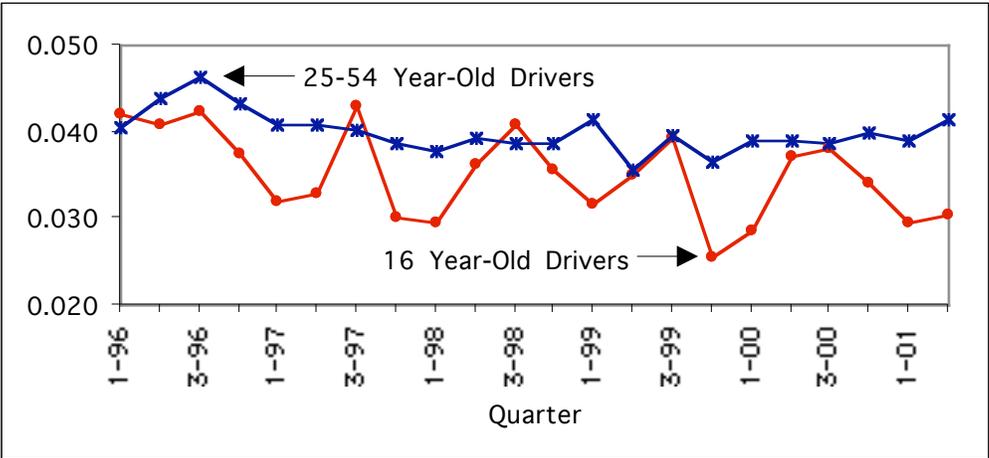
Figure 18 shows the distribution of fatal and injury crashes by 16 year-old involved drivers for the two years prior to the new law (January 1996 to December 1997) and the last two years for which we have crash data (July 1999 to June 2001).

Figure 18: Distribution Of 16 Year-Old Involved Crashes By Time Of Day



If the curfew has had an effect on the driving habits of 16 year-olds, we would expect to see a change in the percentage of their crashes occurring during that time. Figure 18 does show a decrease in the percentage of 16 involved crashes during all five hours of curfew. To test the significance of the changes, regression analysis was performed on the quarterly percentage of curfew crashes for both 16 and 25-54 year-olds. Quarterly data was used due to the relatively small number of curfew crashes for 16 year-olds. Graphical representation of the curfew percentages for both groups is shown in Figure 19.

Figure 19: Percentage of Crashes Occurring During Curfew



For both age groups there is a long term down trend which is highly significant for 25-54 year-olds ($p = 0.01$) and nearly significant for 16 year-olds ($p = 0.12$). For the older group there is also a highly significant reversal in direction just after the change in the licensing law, with the percentage of crashes occurring during curfew starting to rise at that point. For 16 year-olds there was a small, non-significant lessening of the long-term downward trend at the time of the implementation of the new law. The new law does not appear to have had a material effect on the percentage of driving done by 16 year-olds during curfew hours. This percentage was in a downtrend prior to the law and continued after the law took effect.

4. DISCUSSION

The July 1998 changes to California's graduated driver licensing laws (GDL) for new drivers under the age of 18 has had a significant effect on 16 year-old drivers. In the three years following implementation of the new law, crashes caused by 16 year-old drivers decreased by 17% and the average number of teen-age passengers carried by 16 year-olds decreased by approximately 25%. The combination of these two decreases resulted in the saving of 25 lives and the prevention of 1,910 injuries.

Restrictions on driving between midnight and 5 AM do not appear to have had a material effect on the percentage of driving done by 16 year-olds during those hours. This percentage was in a downtrend prior to the law and continued after the law took effect.

Median licensing age for 16 & 17 has increased from 16 years six months to 16 years eight months.

One important factor working against the efficacy of the new law is that it is very difficult to enforce since there is no way to tell if a specific car has a driver who is violating the law. It is only after a car has been stopped for some other violation that the conditions of the graduated licensing law can be checked. Additionally, there appears to be a great deal of reluctance on the part of law enforcement personnel to cite drivers even when they are found in violation. As an example, during the years 1999 and 2000, in the entire state, the CHP wrote only 252 and 832 citations, respectively, for violations of the graduated licensing law.

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