ON THE RELATIONSHIP OF CRASH RISK AND DRIVER HOURS OF SERVICE

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Summary/Abstract: Changes in the U.S. hours of service policy in January 2004 argue for an assessment of the safety implications of the new policy. Time-dependent logistic regression and case-control sampling are applied to derive a sample of 231 crashes and 462 non-crashes during 2004 for three national-scale trucking companies. The analysis focuses on changes in crash risk associated with driving up to 11 hours in one duty period and multi-day driving schedules over 7 days. Separate analyses of sleeper and non-sleeper crash risk are conducted as the risk factors associated with these operations were found to be different.

Considering all the data together, except for an increase in the second hour, crash risk is statistically similar for the first 6 hours of driving and then increases non-linearly after the 6^{th} hour. The 11^{th} hour has a crash risk more than 3 times the first hour. Multi-day driving schedules are also associated with statistically significant crash risk increases of comparable magnitude to driving time. Non-sleeper operation crash risk is strongly associated with multi-day driving, somewhat more so than with driving time. Sleeper operation crash risk has strong association with driving time, with particularly increased risk in hours 8 through 11.

INTRODUCTION

The safety implications of hours of service policies have long been an interest of safety researchers. There is a persistent literature which has sought to assess these safety implications by analyzing crash data provided by carriers (e.g. Harris et. al. (1971); Jovanis and Chang, (1989); Kaneko and Jovanis, (1992); Lin, Jovanis, and Yang, (1993 and 1994). A major study of crash risk and driver performance was completed in the U.S. in the 1990's by conducting a field experiment with instrumented vehicles and a set of drivers operating particular multi-day schedules (Wylie et. al. (1996)). These are two examples of many U.S. studies that have sought this elusive relationship.

Changes in the U.S. hours of service policy in January 2004 argue for an assessment of the safety implications of the new policy. This paper presents an analysis of data collected from carriers during their operations in 2004. Each carrier was subject to the new hours of service policies implemented in January of that year. The analysis of the data sought to identify how specific hours of service policies were associated with crash risk. As such, particular attention is paid to driving time, as that measure was extended from 10 hours to a maximum of 11 hours in the new policy. Additionally an attempt is made to quantify the effects of multi-day driving, which includes an assessment of the regularity of the driving schedule (i.e. was the driving initiating driving at approximately the same time of day each day for several days) and time of day of driving if regular.

DATA SET

Data were collected from 3 national-scale carriers reflecting their crash and operating experience in 2004. One company conducts less-than-truckload (LTL) operations throughout the U.S. Another conducts LTL-type services, but includes long-haul sleeper berth operations for movement of some shipments. The third carrier is a traditional truckload carrier with primarily sleeper operations. Crash data for the first 2 companies reflect their "at fault" crashes for the year. For the national truckload carrier, crash data reflect the same crash type but for the third quarter of 2004. Consistent with previous research, driver logs for the crash day and the prior 7 days were obtained for these drivers in order to capture the effect of multi-day driving schedule. In addition, 2 control drivers from the same terminal are selected for each crash-involved driver in order to assess driving hours relative risk (Park et. al. (2005). Table 1 summarizes the data set including the sample size for sleeper and non-sleeper operations.

Table 1. Study sample size.

Type of Operation	# of Observations		
	Crash	Non-Crash	Total
Non-Sleeper	115	213	328
Sleeper	116	249	365
	231	462	693

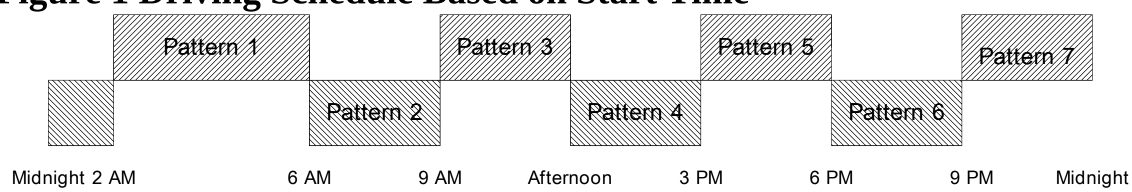
Table 2 summarizes the data broken down by driving time. The first and fourth columns indicate the categories used for driving time; note specifically that the last category represents driving in excess of 10 hours. This category is used to reflect any change in risk associated with driving the 11^{th} hour; added in the January 2004 HOS regulations.

Table 2. Summary of data concerning driving time.

Driving Hour (hr)	Accident	Non-Accident	Driving Hour (hr)	Accident	Non-Accident
D.H. ≤ 1	28	1	6 < D.H. ≤ 7	24	62
1 < D.H. ≤ 2	31	6	7 < D.H. ≤ 8	24	73
2 < D.H. ≤ 3	29	9	8 < D.H. ≤ 9	16	106
3 < D.H. < 4	19	7	9 < D.H. ≤10	12	105
4 < D.H. ≤ 5	22	29	10 < D.H. ≤11	4	30
5 < D.H. ≤ 6	22	34	Total	231	462

Figure 1 contains definitions of the driving schedules used in this modeling; they were developed based upon a review of the safety and driving schedule literature. In order to capture the effect of driving during different times of day, a scheme was developed to allocate each driver to a unique time of day based upon the time when they started to drive (i.e. first driving after at least the mandatory 10 hours off duty). In all, 11 schedules were used, 7 regular and 4 irregular. Given sample size constraints, this approach allows the model to be sensitive to multi-day driving, while not in as detailed as way as in a recent TRB paper by the authors (Park, et. al., 2005).

Figure 1 Driving Schedule Based on Start Time



Regular driving schedule:
Pattern 1: DP1: drivers started driving during early morning (i.e. 2 AM to 6 AM)
Pattern 2: DP2: drivers started driving during morning (6 AM to 9 AM)
Pattern 3: DP3: drivers started driving during late morning (9 AM to 12 PM)
Pattern 4: DP4: drivers started driving during afternoon (12 PM to 3 PM)
Pattern 5: DP5: drivers started driving during late afternoon (3 PM to 6 PM)
Pattern 6: DP6: drivers started driving during early night (6 PM to 9 PM)
Pattern 7: DP7: drivers started driving during late night (9 PM to 2 AM)
Irregular driving schedule:
Pattern 8: DP8: Advancing driving schedule (i.e. a schedule with periodicity less than *24 hours;* the driver starts driving progressively earlier each day)
Pattern 9: DP9: Delaying driving schedule (i.e. a schedule with periodicity greater than 24 hours; the driver starts driving later each day)
Pattern 10: DP10: Alternating driving schedule (i.e. a schedule which alternates between 2 start times every other day)
Pattern 11: DP11: Highly irregular schedule (i.e. a schedule with no apparent pattern).

MODELING APPROACH

The model used in this research is the time-dependent logistic regression model, specifically:

$$P_{it} = P(Y_{ti} = 1 | Y_{t'i} = 0 \text{ for } t' < t, X_i) = \frac{\exp[g(X_i, t, \beta)]}{1 + \exp[g(X_i, t, \beta)]} \quad \text{(Eq. 1)}$$

The model is interpreted as the probability that driver *i* has an accident (outcome Y = 1) at time *t*, given survival until that time (i.e. an outcome Y = 0, for all time periods *t´* prior to time period *t*) is given by the familiar logistic function with time *t*, predictor variables, *X*, and estimated parameters, *β*. A linear additive function is assumed for *g(X, t, β)*. In our case, X_i is the category for driving time, multi-day driving schedule (as in Figure 1) and sleeper berth operation (1 if sleeper and 0 if not). A data replication scheme is need to capture the important effect of "survival": a driver who has a crash in the 9th hour of driving survives the first 8 (Lin, et. al., (1993); Park, et. al., (2005)). There is evidence in the statistical literature to support the use of this type of model (e.g. Hosmer and Lemeshow, 1989).

MODEL RESULTS

Pooled Model

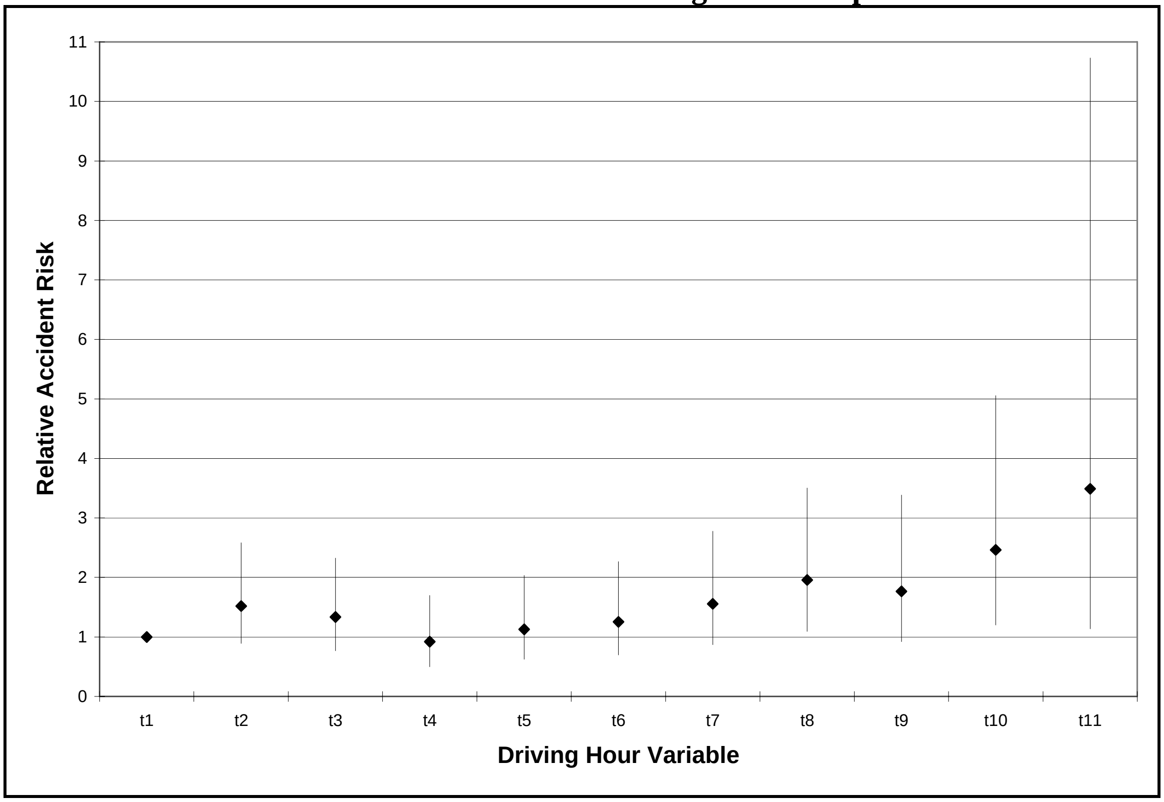
Table 3 contains the results of the initial model with all data included (a pooled model). This model includes all the driving schedules shown in Figure 1 as predictors, along with driving time, as defined in Table 2. Notice that the last driving time is the 11th hour of driving, the "new" hour added in the new HOS rules implemented in January 2004. All variables are categorical. The B column is the parameter value from the model estimation; S.E. is the standard error of the parameter; Sig. is the significance probability and Exp (B) is the odds ratio compared to the baseline category. The model is significant at the .05 level of significance and shows reasonable improvement in model fit compared to a constant term alone.

With the exception of the jump in relative risk in hour 2, the driving time has a risk indistinguishable from the baseline through the 6th hour, but then a steady, non-linear increase in risk thereafter. The 11th hour of driving has a risk more than 3 times that in the baseline first hour. This is the now-familiar increase in relative risk with time-on-task. For ease of interpretation, the crash odds reflected by each parameter are plotted with their standard errors in Figure 2. Note that the standard errors increase with driving time, particularly during hours 10 and 11. Another interesting aspect of the model is the scale and significance of the parameters for multi-day driving schedule. All the regular schedules and all but one of the irregular schedules have crash risk greater than the baseline 6-9PM start time. Further, the scale of the parameters is in the same range as the parameter estimates for driving time; in fact, parameter values exceed the estimates of all but that for the 11th driving hour. This is a strong indication of the importance of multi-day driving on crash risk

Table 3. Variables in the equation: pooled model with all data.

Variable	B	S.E.	Sig.	Exp (B)
T2	.418	.271	.124	1.518
T3	.290	.282	.304	1.337
T4	-.083	.313	.791	.920
T5	.121	.301	.689	1.128
T6	.227	.302	.452	1.255
T7	.441	.296	.136	1.555
T8	.672	.297	.024	1.959
T9	.569	.332	.086	1.766
T10	.901	.367	.014	2.463
T11	1.250	.573	.029	3.491
DP1	.790	.428	.065	2.203
DP2	1.045	.364	.004	2.844
DP3	.628	.428	.142	1.874
DP4	.713	.527	.176	2.040
DP5	1.038	.411	.012	2.825
DP7	1.014	.417	.015	2.756
DP8	.510	.369	.167	1.665
DP9	.477	.557	.392	1.611
DP10	.914	.386	.018	2.494
DP11	.991	.346	.004	2.695
Constant	-4.124	.377	.000	.016

FIGURE 2. Crash odds and driving time with pooled model.



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Separate Models of Sleeper and Non-Sleeper Operations

During the analysis of the data, differences in the factors that contribute to crash risk for sleeper berth operations compared to non-sleepers became apparent. In order to test this hypothesis, separate models were developed for the crash and control data for sleepers and non-sleepers.

Non-sleeper berth model. Table 4 indicates that there are several important changes in the pattern of variable significance compared to the pooled model. The driving time risk increases in time periods 2, 3, 5, 7 and 9. While the increases are of marginal statistical significance (*p* values of .117 to .235) the parameter values are quite large. This variation in significance may reflect the reduced data sample available for non-sleeper modeling. The last driving time period contains no crash data, so the parameter value is not meaningful. All the regular driving time patterns have coefficients that are significantly different from the baseline and of a magnitude higher than the driving time in the model. This is the first time there are consistent parameter estimates for multi-day driving schedules which are higher then driving time. Irregular driving also has elevated crash risk, particularly schedules 10 (an alternating driving schedule) and 11 (a highly irregular schedule with no discernable pattern). As with the pooled model, the model as a whole is statistically significant and an improvement compared to a model with a constant term alone.

Table 4. Variables in the equation for non-sleeper berth operations.

	B	S.E.	Sig.	Exp(B)
T2	.596	.389	.125	1.815
T3	.617	.393	.117	1.853
T4	.171	.436	.696	1.186
T5	.491	.414	.235	1.634
T6	-.132	.493	.789	.876
T7	.759	.409	.064	2.135
T8	.331	.476	.487	1.393
T9	.800	.465	.085	2.224
T10	.450	.671	.502	1.569
T11	-17.839	13251.707	.999	.000
DP1	1.258	.540	.020	3.519
DP2	1.205	.511	.018	3.336
DP3	1.047	.552	.058	2.850
DP4	1.315	.730	.072	3.724
DP5	1.127	.518	.030	3.087
DP7	1.494	.500	.003	4.454
DP8	.233	.514	.650	1.263
DP9	-17.374	5204.543	.997	.000
DP10	.996	.492	.043	2.708
DP11	.905	.460	.049	2.471
Constant	-4.233	.508	.000	.015

Sleeper berth model. The results in Table 5 indicate that the sleeper berth models fit the data very well overall and several variables are significantly associated with changes in crash risk. Driving time has the more traditional patterns of increased risk with driving time; the risk is particularly high in driving hours 8, 10 and 11. Interestingly, the regular driving schedules appear to have relatively small association with crash risk, except for patterns 2 and 5. Irregular driving has a very significant association with crash risk as all irregular schedules are significantly higher than the baseline. All irregular schedules have coefficients higher than that for the 11th driving hour reflecting a very significant association with increased relative crash risk. Both the magnitude and the pattern of parameter significance for this model are quite different from Model E. This leads us to suspect that crash risk has a different underlying pattern of association between the 2 types of operations. A chi-squared test has been conducted to compare the fit of the data to the pooled model compared to the individual operation-type models; not surprisingly, the separate models are a statistically significant improvement compared to the pooled model.

Table 5. Variables in the equation for sleeper berth model.

	B	S.E.	Wald	df	Sig.	Exp(B)
T2	.244	.382	.407	1	.523	1.276
T3	-.064	.418	.024	1	.878	.938
T4	-.328	.457	.515	1	.473	.720
T5	-.283	.457	.383	1	.536	.754
T6	.488	.389	1.571	1	.210	1.629
T7	.101	.443	.052	1	.820	1.106
T8	.937	.387	5.874	1	.015	2.552
T9	.376	.481	.610	1	.435	1.457
T10	1.170	.455	6.623	1	.010	3.223
T11	1.637	.620	6.966	1	.008	5.141
DP1	1.005	1.128	.793	1	.373	2.731
DP2	1.847	1.029	3.221	1	.073	6.341
DP3	1.023	1.105	.858	1	.354	2.782
DP4	1.186	1.166	1.034	1	.309	3.274
DP5	1.709	1.108	2.379	1	.123	5.521
DP6	.860	1.128	.582	1	.446	2.364
DP8	1.553	1.033	2.260	1	.133	4.725
DP9	1.895	1.109	2.920	1	.088	6.650
DP10	1.638	1.071	2.339	1	.126	5.143
DP11	1.916	1.021	3.521	1	.061	6.796
Constant	-4.909	1.043	22.146	1	.000	.007

Baseline: Pattern 7: drivers started driving during 9 PM to 2 AM (5hrs) – Late Night

CONCLUSIONS

Using crash and operations data from 3 carriers in 2004, the modeling and analysis indicates that crash risk is statistically similar through the first 6 hours of driving (except for an increase in the second hour), then increases non-linearly. The highest crash risk relative to the 1^{st} hour of driving is hour 11 with a risk more than 3 times the first hour. These results are qualitatively similar to those obtained in a recent research paper (Park, et. al., (2005)) using data from the 1980's. These findings, using data 20 years apart, establish a consistent pattern of increased crash risk with hours driving, particularly in the last few hours: the 9^{th}, 10^{th}, and 11^{th} hours. Multi-day driving schedules are also associated with crash risk increases. Consistent with recent research using 1980's data from Park et. al. (2005), the risk associated with the multi-day patterns is statistically significant and of comparable magnitude to driving time.

Models also indicate that crash risk is different for non-sleeper operations than for sleeper schedules. Models of non-sleeper operations associate crash risk with multi-day driving, somewhat stronger than with driving time (i.e. many parameter values for multi-day driving are significant and their magnitude is generally larger then the parameters for driving time). Driving time shows elevated risk in hours 2, 3, and 5 in addition to an increase in risk in hours 7 and 9. Models of sleeper operations indicate strong association of crash risk and driving time, with particularly increased risk in the 8^{th}, 10^{th} and 11^{th} hours. Interestingly, there is much less association of crash risk with regular schedules and substantial risk associated with irregular schedules. One tentative conclusion is that the rigors of sleeper operations appear to result in a greater decline in performance at extended driving hours than for comparable non-sleeper operations. The team would feel more confident in this conclusion if other studies supported this finding as well.

Considered as a whole, these models of two separate operations reveal important differences in crash risk associated with the two different types of trucking operations. Statistical tests confirm that models of crash risk are different for sleeper and non-sleeper operations. This implies that subsequent modeling should treat these operations distinctly, to the extent possible.

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