Traffic Safety Facts
Research Note

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Belt Use Regression Model - 2003 Update

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This research note describes modifications to NHTSA's BELT USE regression model. BELT USE is a second-degree polynomial model that was created in 1994 (Blincoe, 1994). In this note, that model is referred to as the 1994 version. Basically, this model uses the national observed belt use rate to predict lives-saved by safety belts. The 19-City Surveys and the Fatality Analysis Reporting Systems (FARS) from 1983 to 1991 were fitted to generate the model. NHTSA has used the 1994 version to estimate the lives that would be saved due to increased safety belt use in the general public.

In 2001, NHTSA updated the BELT USE model (Wang & Blincoe, 2001) from its 1994 version. In the 2001 update (2001 version), 8 more years of historical data from 1992 to 1999 were added to refine the modeling process. For continuity of belt use trends and to include more data points, the 2001 version used the State Observational Surveys, instead of the National Occupant Protection Use Survey (NOPUS), as the basis for national belt use rates. The 2001 version still has the format of a second-degree polynomial, but there were three major changes in the process:

(1) The 2001 version modeled the relationship between the observed belt use rates and the belt use rates among fatalities in potential fatal crashes (UPFCs) as opposed to modeling the relationship between the observed belt use rates and lives-saved rate.

(2) The 2001 version used the weighted average belt effectiveness among passenger cars (45 percent) and light trucks (60 percent) to calculate UPFCs as opposed to a single safety belt effectiveness rate of 45 percent.

(3) The 2001 version abandoned the constraint that, in the 1994 version, forced UPFC to be 100 percent when observed use was 100 percent.

Recently, NHTSA's National Center for Statistics and Analysis (NCSA) has re-examined all the methodologies and mathematical formula that are used to estimate lives saved by safety belts and other restraint systems. NCSA has decided to improve the methodologies by incorporating the impact of air bags and using the updated effectiveness rates. For consistency, this update (2003 version) adapts these improvements. The 2003 version also changes the baseline population that is used to calculate belt usage and related statistics. The "Modifications" section details these changes and improvements. Following it is the "Model Results" section, which describes the initially derived model and factors such as time of day and seating position that might influence the outcome of the prediction. One question remaining is whether the model properly predicts UPFC at much higher observed belt rates given that the historical belt use data were all lower than 75 percent. The "Alternatives" section examines 5 alternative approaches to this issue. Finally, the "Discussion" section recommends the model that NHTSA will use to estimate the impact of safety belts in the future. That section also discusses factors such as time of day and seating position and their impacts on the accuracy of the prediction.

Modifications

This section describes the modifications that are made in the 2003 version. The changes include: (1) directly modeling the relationship between UPFCs of all passenger vehicle occupants age 5 and older and observed belt use, (2) adding 2 more years (2000 and 2001) of FARS data and state observed belt use to fit the model, (3) using updated safety belt effectiveness rates, and (4) taking into account the air bag impact.

All Passenger Vehicle Occupants 5 and Older

The 2001 model describes the relationship between the UPFCs in front-outboard passenger vehicle occupants 5 and older and the observed use rates. The rationale was that the observed belt use survey was conducted for front-outboard occupants only. By limiting to frontal-outboard occupants, the model would eliminate the seating bias. However, the regression model is used to estimate overall lives saved by safety belts regardless of the seating positions. Thus, the 2002 version includes all passenger vehicle occupants 5 and older. This way, the model reflects the true relationship between UPFCs for all occupants and the observed belt use rates. Hence, the model would better predict the overall lives that would be saved at a specified observed safety belt use rate.

Table 1
Belt Use Trends From 1983 to 2001

Years	% Use in FARS	% UPFC	% Observed Belt Use
1983	3	6	14
1984	5	8	14
1985	9	16	21
1986	15	24	37
1987	18	29	42
1988	20	32	45
1989	22	34	47
1990	23	36	49
1991	24	37	59
1992	26	40	62
1993	29	43	66
1994	34	49	67
1995	34	50	68
1996	36	52	66
1997	37	53	67
1998	38	54	69
1999	38	54	70
2000	39	56	73
2001	40	57	75

Two Additional Years of Data

The process includes two more years of data: 2000 and 2001 FARS and state observed belt use surveys. The observed belt use rates were 73 and 75 percent for 2000 and 2001, respectively. In total, 19-pairs (from 1983 to 2001) of data points were used to fit the regression model. These two new data points gave the model a slightly better fit at the higher belt use rates. Table 1 lists all the data used to fit the model. Note that data under the column titles "% UPFC" and "% Observed Belt Use" in Table 1 were used in the modeling process. The data under the column "% Use in FARS" were used to derive UPFCs.

Updated Belt Effectiveness Rates

The 2001 model used the weighted effectiveness of 45 percent for passenger car occupants and 60 percent for light trucks/vans. These effectiveness rates represented the seating positions and vehicles that were included in the state observational surveys. The weights were the number of potential fatal injuries in passenger cars and light trucks/vans. Several NHTSA studies (Kahane, 1996 & 2000, Morgan 1999) examine the effectiveness of the restraint systems. These studies show that the effectiveness of safety belts varies depending on many factors such as type of restraint systems (2-point, 3-point, lap/shoulder, and etc), seating position (front, mid, and rear), and vehicle types (passenger cars and light trucks/vans). The 2003 version uses these updated effectiveness rates.

Table 2 lists all the updated safety belt effectiveness rates used to generate the 2003 version. For each seating position, the effectiveness of the unknown restraint type is set

Table 2
Effectiveness of Safety Belts Against Occupant Fatalities by Vehicle Type, Restraint Type, and Seating Position

Passenger Cars	Driver	Front - Right	Front - Middle	Rear-Outboard	Rear - Middle	Other
2-point	32	32	na	na	na	na
3-point	48	37	na	na	na	na
Lap/Shoulder	48	37	na	44	na	na
Lapbelt	32	32	19	32	32	32
Unknown Type	32	32	19	32	32	32
Light Trucks/ Vans						
2-point	na	na	na	na	na	na
3-point	61	58	na	na	na	na
Lap/Shoulder	na	na	na	73	na	na
Lapbelt	na	na	32	63	63	63
Unknown Type	61	58	32	63	63	63

na – not applicable

to be equal to the smallest number among those of the known types. As shown in Table 2, safety belts have a greater effectiveness against light truck/van occupant fatalities. With increasing numbers of light trucks/vans on the roadway, the use of new and refined effectiveness rates should improve the model's predictability of belt benefits.

Air Bag Impact

The methodology and theory for the 1994 version of BELTUSE model (Blincoe, 1994) was developed when air bags were not prevalent. Thus, the model did not take into account the safety impact of air bags, nor was this addressed in the 2001 version. Wang & Blincoe addressed the air bag effect on lives saved estimates by belt use in their 1999 research note (Wang & Blincoe, 1999). When air bag vehicles comprised a very small portion of the operational fleet, its impact on safety belt benefits would have been minimal. However, the number of vehicles equipped with air bags has steadily increased since 1990. The portion of air bag equipped vehicles in fatal crashes has increased to 43 percent in 2001 from only 1 percent in 1990. Since all new light vehicles now have air bags, the on-road fleet is gradually moving towards 100 percent air bag penetration. The impact of air bags can no longer be ignored.

The impact of air bags on safety belt benefit estimates is due to the interaction of air bags and safety belts in saving lives. This interaction modifies our estimates of the belted potential fatalities (PF) and thus impacts UPFCs. Its impact only applies to belted frontal-outboard occupants in air bag equipped vehicles. Air bags are 11 percent effective against belted driver fatalities and 14 percent against unbelted driver fatalities regardless of vehicle types (The Fifth/Sixth Report to Congress, 2001). These air bag effectiveness rates also apply to the front-right passenger fatalities. Table 3 lists the combined effectiveness of safety belts and air bags. The combined effectiveness (e) was derived based on the formula:

Table 3

The Combined Effectiveness of Safety Belts and Air Bags* Against Occupant Fatalities

Passenger Cars	Driver	Front - Right	Front - Middle**	Rear- Outboard**	Rear - Middle**	Other**
2-point	39	39	na	na	na	na
3-point	54	44	na	na	na	na
Lap/Shoulder	54	44	na	44	na	na
Lapbelt	39	39	19	32	32	32
Unknown Type	39	39	19	32	32	32
Light Trucks Van						
2-point	na	na	na	na	na	na
3-point	65	63	na	na	na	na
Lap/Shoulder	na	na	na	73	na	na
Lapbelt	na	na	32	63	63	63
Unknown Type	65	63	32	63	63	63

* Air bag effectiveness is 11 percent against belted occupant fatalities regardless of vehicle type.
** Same as belt only effectiveness

$$e = e_b + e_a - e_b * e_a$$

where e_b = belt effectiveness and e_a = air bag effectiveness.

Only drivers and front-right occupants have air bags, therefore, the combined effectiveness rates impact the front-outboard occupants only. The effectiveness rates for other occupant positions are the same as the safety belt effectiveness that are shown in Table 2.

To consider the air bag effect, the combined effectiveness rates of safety belts and air bags were used to derive (PF). PF is a function of fatalities and effectiveness rates and has the general format $\frac{f}{1-e}$, where f is the fatalities and e is the effectiveness rate. A higher effectiveness results in a larger PF and higher benefits. In practice, fatalities were first partitioned into small subsets based on their restraint types, seating positions, and vehicle types, i.e., fatalities were partitioned into "driver fatalities with lap/shoulder belt in passenger cars", "front-outboard passengers with lap/shoulder belt in passenger cars," etc. These partitions were generated to correspond to the proper effectiveness rates of the restraint system.

Total PF was the sum of all these subsets. The formula is:

$$PF = \sum_i \frac{f_i}{1-e_i}$$ where f_i is the fatalities in the i^{th} partition, e_i is the effectiveness rate.

The 1994 and 2001 model versions used the belt only effectiveness for

e_i (with the 1994 version based on passenger car effectiveness and the 2001 version based on weighted effectiveness for both passenger cars and light trucks/vans). For example, for the subset "drivers with lap/shoulder belts in air bag equipped passenger cars", safety belts are 48 percent effective and air bags are 11 percent effective against belted fatalities. The 2001 version used 48 percent for e_i to calculate the historical PF (belt only consideration) and subsequent UPFCs for data fitting. The 2002 model, by contrast, uses the combined effectiveness of 54 (=0.48 + 0.11 - 0.48 * 0.11) percent. The older versions would underestimate PF about 13 percent for the belted driver fatalities in air bag equipped passenger cars.

Model Results

Based on the graphic presentation of the relationship of UPFC and observed use rate, the regression process first uses the second polynomial format $u = a_1 * u_o + a_2 * u_o^2$ to fit the data. In this format, u represents UPFC, a_1 and a_2 are the parameters, and u_o is the observed use rate. Note that, the format does not have a constant term because the regression process was extended to include an extra data point (0,0). This inclusion was to force the model to predict 0 percent UPFC at the 0 observed belt use rate (0 restriction rule). The regression model is:

$$u = 0.56782 * u_o + 0.25642 * u_o^2$$
(Model 1)

The model has an adjusted R^2 = 0.9950 and sum of error square (SSQ) = 0.0145. The R^2 represents the squared correlation of predicted UPFCs and the actual UPFCs. The SAS procedure PROC REG (SAS, 1994) was used as the modeling tool to derive the model parameters a_1 and a_2. This model predicts 82 percent UPFC at the 100 percent observed belt use rate. Ideally, UPFC would be 100 percent when the observed belt use rate reached 100 percent. However, as previously noted, observational belt use surveys are conducted for front-outboard occupants during daytime hours. These use patterns do not reflect belt use at nighttime and among rear-seated occupants. Thus, a model that forces the 100 percent observed rate to correspond to the 100 percent UPFC might overestimate the UPFCs and benefits of safety belts.

Table 4
UPFC and Belt Use
Day vs Night

Year	UPFC				Belt Use Among Fatalities			
	Daytime	Nighttime	% Points Difference	Night /Day Ratio	Daytime	Nighttime	% Points Difference	Night /Day Ratio
1983	7	4	3	.57	4	2	2	.50
1984	10	6	4	.60	6	3	3	.50
1985	21	12	9	.57	12	7	5	.58
1986	30	18	12	.60	19	11	8	.58
1987	36	22	14	.61	23	13	10	.57
1988	41	23	18	.56	27	14	13	.52
1989	42	25	17	.60	28	15	13	.54
1990	44	27	17	.61	30	17	13	.57
1991	45	28	17	.62	30	17	13	.57
1992	48	31	17	.65	32	19	13	.59
1993	51	34	17	.67	36	21	15	.58
1994	57	38	19	.67	41	25	16	.61
1995	58	39	19	.67	42	25	17	.60
1996	59	42	17	71	43	27	16	63
1997	61	42	19	.69	44	28	16	.64
1998	62	43	19	.69	46	28	18	.61
1999	62	43	19	.69	45	28	17	.62
2000	64	46	18	.72	47	30	17	.64
2001	65	46	19	.71	48	30	18	.63

Source: 1983-2001 FARS

Daytime vs Nighttime

Table 4 shows the UPFC trend from 1983 to 2001 for all passenger vehicle occupant fatalities age 5 and older. UPFC in daytime is consistently higher than in night-time – about 17-19 percentage points higher in recent years. UPFC is a function of both belt use rates among fatalities and effectiveness rates. Both belt use and effective-ness affect the magnitude of UPFCs and thus could contribute to the discrepancy between day and night UPFC rates. Specific studies are not available to assess night-time effectiveness rates, but a sense of the relative importance of the difference in usage compared to effectiveness can be gathered by examining use rates among fatalities.

As shown in Table 4, the difference between daytime and nighttime belt use among fatalities follows the same pattern as UPFCs. In general, belt use in the daytime was higher than in the nighttime – about 17 percent points higher in recent years. The 17 percentage points difference is close to that of UPFCs. This indicates that effectiveness of the restraint systems has a smaller variation between daytime and nighttime, and thus affects UPFCs less. Most of the impact on day vs night is due to lower nighttime usage rates.

To further verify that the UPFC difference between daytime and nighttime was not greatly inflated by different average effectiveness rates, an alternative methodology was used to assess the effectiveness rates. This analysis uses a double-pair comparison analysis and fatality reduction process as stated in Kahane's report (Kahane, 2000) to estimate the difference of effectiveness between daytime and nighttime. Only the 1996 to 2001 FARS were used for this purpose. Data are limited to cars with both a driver and a right-front (RF) occupant. At least one of them was killed and both were at least 14 years old. There were a total of 33,951 fatalities that occurred in the daytime and 28,194 occurred in the nighttime. Table 5 tabulates the results and lists the driver-RF and RF-driver risk ratios. These risk ratios were used to derive effectiveness rates (or reduction rates) of safety belts.

Table 5
Front-Outboard Occupant Risk Ratios

Daytime Fatalities	Driver Died	RF Died	Total Died	Driver/RF Risk Ratio (Driver/RF)	RF/Driver Risk Ratio (RF/Driver)
1. Driver Not Belted, RF Not Belted	5,972	6,207	12,179	0.962	1.039
2. Driver Belted, RF Not Belted	863	2,633	3,496	0.328	3.051
3. Driver Not Belted, RF Belted	1,748	642	2,390	2.723	0.367
4. Driver Belted, RF Belted	7,195	8,691	15,886	0.828	1.208
Total	**15,778**	**18,173**	**33,951**	**0.868**	**1.152**
Nighttime Fatalities					
1. Driver Not Belted, RF Not Belted	7,573	7,409	14,982	1.022	0.978
2. Driver Belted, RF Not Belted	739	2,098	2,837	0.352	2.839
3. Driver Not Belted, RF Belted	1,945	714	2,659	2.724	0.367
4. Driver Belted, RF Belted	3,736	3,980	7,716	0.939	1.065
Total	**13,993**	**14,201**	**28,194**	**0.985**	**1.015**

Source: 1996 to 2001 FARS

Two double-pair comparisons – one using belted RF as the control group and the other using the unbelted RF – are used to derive the belt effectiveness against driver fatalities. Similarly, two double-pair comparisons using belted and unbelted drivers as control groups determine the belt effectiveness against RF fatalities. Readers can consult Kahane's (2000) report for details of that process. Based on the two double-pair comparisons, the fatality reduction rates for driver in daytime are 66 and 70 percent. The corresponding rates at nighttime are 66 and 66 percent – identical. The fatality reduction rates for RF are 60 and 65 percent for daytime and 63 and 63 for nighttime. After applying weights (driver 77%, RF 23%) and the Universal Exaggeration Factor (UEF)[1] (Kahane, 2000) of 1.369, the fatality reduction rate for daytime is 55 percent and 52 percent for nighttime. The belt effectiveness at daytime is similar to that at nighttime. Thus, the effect of belt effectiveness rates on the discrepancy between daytime and nighttime UPFCs is minimal.

Given that belt use is the dominate factor influencing the difference in day vs night UPFCs, and that belt use in daytime was consistently 17 percentage points higher than that in the nighttime, state observational belt use surveys conducted during

[1] UEF is an adjustment factor to measure the overly reported belt use by survivors in FARS in response to belt use laws. UEF = (1 – e1)/(1 – e2), where e1 is the unbiased 3-point belt effectiveness (i.e., before the laws) and e2 is the biased 3-point belt effectiveness.

the daytime overestimate the overall belt use rates.

Front-Seat vs Rear-Seat

Belt use rates also are different by seating position. Table 6 lists the belt use trend from 1983 to 2001 for front-outboard and rear-outboard passenger vehicle occupant fatalities age 5 and older. The first half of the table is for daytime and the other is for nighttime trends. As shown in the table, belt use rates are higher among front-outboard occupant fatalities than among rear-outboard occupants. From 1997 to 2001, on average, belt use among front-outboard occupant fatalities during the daytime was about 19 percentage points higher than rear-outboard occupants. The difference during the nighttime was about 12 percentage points. This also indicates that state observational surveys of front-outboard occupants might not be appropriate for rear-seating occupants.

Alternatives

As described in the “Model Result” section, the naturally fitted model $0.56782 * u_o + 0.25642 * u_o^2$ only predicts 82 percent UPFC at 100 percent observed belt use rate. This study examines two approaches to modify the original model to better address the 100 percent issue. The first approach is to segment the potential fatalities into four portions by their seating position (front, rear) and time of crash (daytime, nighttime). Their corresponding UPFCs are: $UPFC_{front, day}$, $UPFC_{front, night}$, $UPFC_{rear, day}$, and $UPFC_{rear, night}$. Then, the approach hypothesizes that at the 100 percent observed belt use rate, the UPFC among front seating occupants at daytime would reach 100 percent, i.e., $UPFC_{front, day}$ =

Table 6

Day vs Night Belt Use and UPFC

Front-Outboard vs Rear-Outboard Occupant Fatalities

Daytime

Year	Fatalities		Belt Use Among Fatalities			Potential Fatalities		UPFC		
	Front	Rear	Front	Rear	Points Diff-erence	Front	Rear	Front	Rear	Points Diff-erence
1983	11235	593	4%	4%	0%	11661	605	8%	6%	2%
1984	12202	577	6%	7%	-1%	12853	597	11%	10%	1%
1985	12550	656	13%	13%	0%	13953	701	21%	18%	3%
1986	13325	759	20%	14%	6%	15689	821	32%	21%	11%
1987	14013	781	24%	19%	5%	17056	869	38%	27%	11%
1988	14560	848	28%	22%	6%	18206	963	42%	32%	10%
1989	14618	901	30%	20%	10%	18541	1013	45%	29%	16%
1990	14141	839	31%	20%	11%	18145	950	46%	30%	16%
1991	13421	852	32%	24%	8%	17262	1002	47%	35%	12%
1992	13136	862	35%	20%	15%	17247	1015	50%	32%	18%
1993	13771	924	38%	23%	15%	18501	1131	53%	37%	16%
1994	14788	1032	44%	27%	17%	20820	1312	60%	43%	17%
1995	15177	920	44%	29%	15%	21692	1188	60%	45%	15%
1996	15542	999	45%	27%	18%	22635	1265	62%	42%	20%
1997	15729	1116	47%	29%	18%	23328	1490	63%	47%	16%
1998	15664	1069	48%	30%	18%	23797	1443	65%	48%	17%
1999	15875	1105	48%	28%	20%	24229	1509	65%	47%	18%
2000	15573	1057	50%	32%	18%	24493	1504	66%	52%	14%
2001	15508	1051	51%	31%	20%	24909	1488	67%	51%	16%

Nighttime

Year	Fatalities		Belt Use Among Fatalities			Potential Fatalities		UPFC		
	Front	Rear	Front Diff-erence	Rear	Points	Front	Rear Diff-erence	Front	Rear	Points
1983	13926	706	3%	2%	1%	14227	711	5%	2%	3%
1984	14037	745	4%	4%	0%	14489	766	7%	7%	0%
1985	13626	750	7%	5%	2%	14499	770	13%	7%	6%
1986	14900	911	11%	10%	1%	16415	958	20%	14%	6%
1987	15079	959	14%	11%	3%	16949	1021	23%	17%	6%
1988	15486	892	15%	11%	4%	17548	945	25%	16%	9%
1989	14905	882	16%	12%	4%	17053	946	26%	18%	8%
1990	14585	936	18%	11%	7%	16930	1012	29%	18%	11%
1991	13510	879	19%	12%	7%	15781	961	30%	19%	11%
1992	12666	830	20%	11%	9%	15020	902	33%	18%	15%
1993	12568	842	23%	14%	9%	15199	944	36%	23%	13%
1994	12168	851	26%	15%	11%	15216	961	41%	24%	17%
1995	12841	887	27%	18%	9%	16297	1030	42%	29%	13%
1996	12814	984	29%	15%	14%	16771	1137	45%	27%	18%
1997	12559	949	30%	18%	12%	16548	1129	45%	31%	14%
1998	12296	911	30%	21%	9%	16447	1114	45%	35%	10%
1999	12387	886	30%	16%	14%	16804	1057	46%	30%	16%
2000	12697	960	32%	20%	12%	17657	1162	48%	34%	14%
2001	12510	989	32%	21%	11%	17561	1253	48%	38%	10%

Table 7

UPFC Adjustment Process Using 1997-2001 Average Data

Category	Potential Fatalities: Number	Potential Fatalities: Percent (Used as Weights)	Method 1: Point Difference	Method 1: At 100 Percent Observed Belt Use	Method 2: Percent Ratio	Method 2: At 100 Percent Observed Belt Use
Front, Daytime	24151	55.2%	0	100%	100.0%	100%
Front, Nighttime	17003	38.8%	19%	81%	71%	71%
Rear, Daytime	1487	3.4%	16%	84%	75%	75%
Rear, Nighttime	1143	2.6%	31%	69%	52%	52%
Total	**43784**	**100.0%**				
Weighted UPFC				**91%**		**87%**

Note: Figures in Table 6 were used to derive the 1997-2001 averages.

Table 8

Summary of Regression Models and Related Statistics

Models With a Square Term (Model Number)		Associated Statistics: R2 Value	SSQ	Predicted UPFC at 100% Observed Belt Use
$0.56782 * u_o + 0.25642 * u_o^2$	(1)	0.9950	0.01450	82%
$0.43751 * u_o + 0.47249 * u_o^2$	(2)	0.9941	0.01819	91%
$0.49829 * u_o + 0.37171 * u_o^2$	(3)	0.9950	0.01555	87%
Models With Degree Greater Than 2				
$0.63018 * u_o + 0.24192 * u_o^3$	(4)	0.9951	0.01422	87%
$0.64326 * u_o + 0.25829 * u_o^{3.5}$	(5)	0.9952	0.01410	90%
$0.65223 * u_o + 0.28341 * u_o^4$	(6)	0.9952	0.01399	94%

Table 9

Predicted UPFCs for Observed Belt Use Rates 75* Percent and Higher

Observed Belt Use Rate (%)	Model 1 (82%)	Model 2 (91%)	Model 3 (87%)	Model 4 (87%)	Model 5 (90%)	Model 6 (94%)
75	57	59	58	57	58	58
80	62	65	64	63	63	64
85	67	71	69	68	69	70
90	72	78	75	74	76	77
95	77	84	81	81	83	84
100	82	91	87	87	90	94

*2001 national level

100 percent. Other UPFCs would be adjusted proportionally to $UPFC_{front, day}$. The second approach is to investigate other model formats such as higher degree polynomials.

First Approach

This approach assumes that the observed belt use rate is truly a reflection of the belt use among potential front-outboard occupant fatalities that occurred during daytime. In order words, $UPFC_{front, day}$ = 100 percent when the observed belt use rate reached 100 percent. Two methods are used to estimate other UPFCs at the 100 percent observed belt use level. The first method assumes that the absolute difference between $UPFC_{front, day}$ and other UPFCs is constant, i.e., for example, $UPFC_{front, day} – UPFC_{front, night}$ = constant. To better predict the future trend, the latest five years (1997-2001) averages were used.

These averages are:

($UPFC_{front, day} – UPFC_{front, night}$) = 19 percent points

($UPFC_{front, day} – UPFC_{rear, day}$) = 16 percent points, and

($UPFC_{front, day} – UPFC_{rear, night}$) = 31 percent points.

At 100 percent observed belt use, $UPFC_{front, day}$ is assumed to be 100 percent. Thus,

$UPFC_{front, night}$ = 81 (=100-19) percent,

$UPFC_{rear, day}$ = 84 (=100-16) percent, and

$UPFC_{rear, night}$ = 69 (=100-31) percent.

Using their potential fatalities as weights, the overall weighted UPFC would be 91 (= 0.552*100 + 0.388*81 + 0.034*84 + 0.026* 69) percent. Table 7 illustrates this process.

Table 10

Summary of Regression Models and Corresponding Predicted UPFC Results

Year	UPFC	Models with Square Term					
		Model 1 (100% ~ 82%) $0.56782*u_o + 0.25642*u_o^2$		Model 2 (100% ~ 91%) $0.43751*u_o + 0.47249*u_o^2$		Model 3 (100% ~ 87%) $0.49829*u_o + 0.37171*u_o^2$	
		Predicted UPFC	Error*	Predicted UPFC	Error	Predicted UPFC	Error
1983	6	8	2	7	1	8	2
1984	8	8	0	7	-1	8	0
1985	16	13	-3	11	-5	12	-4
1986	24	25	1	23	-1	24	0
1987	29	28	-1	27	-2	27	-2
1988	32	31	-1	29	-3	30	-2
1989	34	32	-2	31	-3	32	-2
1990	36	34	-2	33	-3	33	-3
1991	37	42	5	42	5	42	5
1992	40	45	5	45	5	45	5
1993	43	49	6	49	6	49	6
1994	49	50	1	51	2	50	1
1995	0	50	0	52	2	51	1
1996	52	49	-3	49	-3	49	-3
1997	53	50	-3	51	-2	50	-3
1998	54	51	-3	53	-1	52	-2
1999	54	52	-2	54	0	53	-1
2000	56	55	-1	57	1	56	0
2001	57	57	0	59	2	58	1

Year	UPFC	Models with Degree Greater Than 2					
		Model 4 (100% ~ 87%) $0.63018*u_o + 0.24192*u_o^3$		Model 5 (100% ~ 90%) $0.64326*u_o + 0.25829*u_o^{3.5}$		Model 6 (100% ~ 94%) $0.65223*u_o + 0.28341*u_o^4$	
		Predicted UPFC	Error*	Predicted UPFC	Error	Predicted UPFC	Error
1983	6	9	3	9	3	9	3
1984	8	9	1	9	1	9	1
1985	16	13	-3	14	-2	14	-2
1986	24	25	1	25	1	25	1
1987	29	28	-1	28	-1	28	-1
1988	32	31	-1	31	-1	31	-1
1989	34	32	-2	32	-2	32	-2
1990	36	34	-2	34	-2	34	-2
1991	37	42	5	42	5	42	5
1992	40	45	5	45	5	45	5
1993	43	49	6	48	5	48	5
1994	49	49	0	49	0	49	0
1995	50	50	0	50	0	50	0
1996	52	49	-3	48	-4	48	-4
1997	53	49	-4	49	-4	49	-4
1998	54	51	-3	51	-3	51	-3
1999	54	52	-2	52	-2	52	-2
2000	56	55	-1	56	0	56	0
2001	57	57	0	58	1	58	1

* Difference between UPFC and predicted UPFC

We re-ran the regression process and forced the 100 percent observed belt use rate to predict a 91 percent UPFC, the model (Model 2 - 91% model) became $0.43751 * u_o + 0.47249 * u_o^2$ with $R^2 = 0.9941$ and SSQ = 0.01819.

The second method assumes that the ratios of other UPFCs and $UPFC_{front, day}$ are constants, i.e., for example, $UPFC_{front, night} / UPFC_{front, day}$ = constant. As shown in Table 7, $UPFC_{front, night} / UPFC_{front, day}$ = 71 percent, $UPFC_{rear, day} / UPFC_{front, day}$ = 75 percent, $UPFC_{rear, night} / UPFC_{front, day}$ = 52 percent. At the 100 percent observed belt use rate, the overall weighted UPFC is 87 (= 0.552*100 + 0.388*71 + 0.034*75 + 0.026* 52) percent.

We re-ran the regression process and forced the 100 percent observed belt use rate to predict a 87 percent UPFC, the model (Model 3 - 87% model) became $0.49829 * u_o + 0.37171 * u_o^2$ with $R^2 = 0.9950$ and SSQ = 0.01555.

Second Approach

The quadratic format might be too conservative to predict the future UPFCs. The research note examines three different models with a higher degree of polynomials: (1) $a_1 * u_o + a_2 * u_o^3$, (2) $a_1 * u_o + a_2 * u_o^{3.5}$, and (3) $a_1 * u_o + a_2 * u_o^4$. With the 0 restriction rule, the three models are:

(1) $0.63018 * u_o + 0.24192 * u_o^3$, with $R^2 = 0.9951$ and SSQ = 0.01422 (Model 4),

(2) $0.64326 * u_o + 0.25829 * u_o^{3.5}$ with $R^2 = 0.9952$ and SSQ = 0.01410 (Model 5), and

(3) $0.65223 * u_o + 0.28341 * u_o^4$ with $R^2 = 0.9952$ and SSQ = 0.01399 (Model 6).

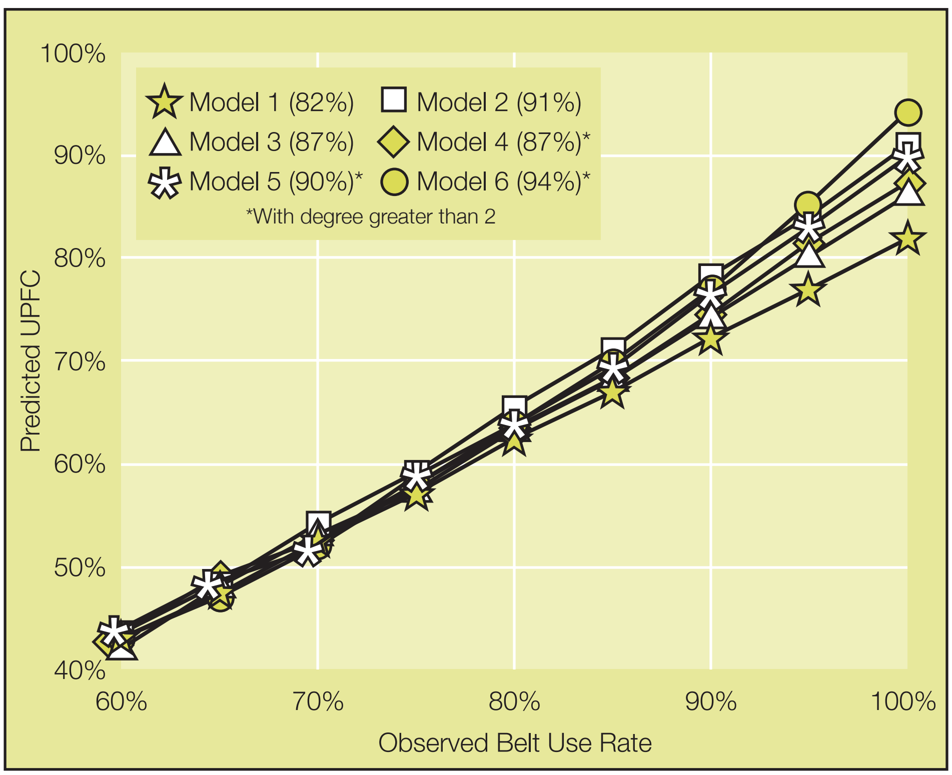
Note that these higher power polynomials were also fitted with a square term, i.e, polynomials with format as $a_1 * u_o + a_2 * u_o^2 + a_3 * u_o^i$, where i = 3, 3.5, and 4. These models have a large SSQ and a much smaller R^2, thus the results were not as good as these models without the square term.

Table 8 summarizes the six models introduced here – the original hyperbolic model and the alternatives. Figure 1 depicts these models. As shown in the Figure 1, the variations of predicted values from these models are very small until the observed belt use rate reaches 85 percent. Table 9 lists the predicted UPFCs for observed belt use rates 75 percent and higher. Table 10 compares the actual UPFCs and predicted UPFCs from these models.

Discussion

All 6 models introduced in this analysis provide a good fit to the historical belt use data. In each case R^2 values exceed .99 and SSQs are less than .02, with differences between models that are trivial. However, selection of a preferred model must be based on judgments regarding their reliability to predict UPFC values at belt use levels that have not yet been achieved. From Figure 1, it is apparent that there is very little difference in predicted UPFCs among these models until observed use reaches about 85 percent – roughly 10 points beyond current use levels. From that point they begin to disperse until there is as much as a 12 percentage point difference between their predictions at 100 percent observed usage.

Figure 1
Predicted UPFCs



There are really 2 basic issues that are of interest in selecting the best model. The first is, how accurate will it be in predicting UPFC over the span of predicted observed usage rates that are likely to occur in the next few years. This distinction is of interest because, over time, additional years data will become available and there will be opportunities to revise the algorithm in light of these added data. Therefore, its most immediate use is of principle interest. In this regard, it can be noted that while the national observed use rate in 2001 is 75 percent, some states were already achieving rates of 85-90 percent. Indeed, there is a large discrepancy between states that have passed primary belt laws and those that haven't, with individual state usage rates ranging from 52 percent to 91 percent. The majority of states fall within the 70-85 percent range, but the states that still haven't passed primary laws, and for which legislative action would be most meaningful, average roughly 10 points below this. Large increases of 10 points or more are possible with the passage of primary belt use laws, but raising belt use becomes more difficult at higher levels because the remaining pool of belt non-users tends to include the least risk-averse parts of the driving population. As such, they are the least likely to respond to campaigns that appeal to their own safety, or to campaigns that threaten them with legal sanctions. This means that the expected increases for states with current high rates will be relatively small, while for states that have low rates, the potential is fairly large. The range of observed use from about 65 to 90 percent is therefore likely to be the focus of most programs over the next few years.

The last 6 years of data appear to be the most relevant to this range of usage rates. During this time, the SSQs for Models 2 and 3 are about half that of the 3 higher order models, and roughly 25-30 percent less than Model 1, with Model 2 being about 20 percent lower than Model 3. Although the differences for all models are small, for the most recent time period, there appears to be an advantage to the predictions of Model 2.

The second issue of concern is the model's ultimate prediction of UPFC when observed usage is 100 percent. This is of interest because it is a measure that is often cited in discussions of the lifesaving potential of safety belts, but it is also relevant because it can be an indicator of the accuracy of predictions at lower levels. Because use is currently only about 75 percent, the behavior of the curve at higher levels is necessarily somewhat speculative. The relevant issue in addressing expected UPFC at 100% is the behavior of those who are most resistant to belt use. As mentioned above, at higher observed usage levels the remaining pool of belt non-users tends to include the least risk-averse parts of the driving population. As such, they are the least likely to respond to campaigns that appeal to their own safety, or to campaigns that threaten them with legal sanctions. The question becomes, at what point do these most reticent users begin to consistently buckle up, and how many of them will still be unbuckled even after observed use reaches 100 percent. The answer determines the degree of curvilinearity that would be expected, especially at the upper range of the curve.

Model 1 is the least curvilinear of these models – it projects a continuation of current trends without significant change as observed usage approaches 100 percent. It essentially seems to predict that there will be no relative change in the behavior of those who are the least risk averse. Although this is theoretically a possible outcome, it seems unlikely in light of surveys that indicate that most non-use reflects lapses by occasional users rather than hard-core refusal to use belts. In NHTSA's 2000 Motor Vehicle Occupant Safety Survey, only 4 percent of drivers indicated that they either never or rarely wore belts. About 77 percent claimed to wear belts all the time while the remaining 19 percent represent drivers who wore belts either most of the time or some of the time. The most common reasons given for occasionally not wearing belts were that they felt it was unnecessary for short distance trips, or that they forgot. Both of these factors should be well represented in any statistically reliable daytime observation survey, and if we obtain a statistically reliable observed use rate of 100 percent, then the behavior of these occasional users will have to shift to more closely match those who always wear their belts. The behavior of the 4 percent who rarely or never use belts would also have to change, although since they represent a relatively small part of the driving population, there is some chance that they might be missed by the survey. In any case, the implication is that as observed daytime usage approaches 100 percent, UPFC for daytime crashes should approach the observed usage rate. Model 1, which reflects the sampling error at current and previous use rates in all seating positions at all hours, does not predict this condition.

Models 4, 5, and 6 involve the same basic interactions as model 1. However, they were designed to force higher estimates of UPFC as observed use approaches 100 percent and this is reflected in their results. Unfortunately, as noted above their added curvilinearity also causes more variation in UPFC predictions at current use levels.

By contrast, Models 2 and 3 are specifically designed to reflect a daytime UPFC that is equal to daytime observed usage, while maintaining the relative gap in nighttime usage that has existed for over a decade. Model 2 does this by maintaining the percentage point gap between daytime front outboard and other positions, while Model 3 does it by maintaining the ratios between them. From Table 4, the gap between day and night UPFC has been a fairly stable 17-19 points since 1988. During this time (through 2001), daytime UPFC has increased by 24 points and nighttime UPFC has increased by 23 points. However, the Nighttime/Daytime ratio has steadily increased. A number of day and night belt use increase scenarios were analyzed to determine which would be consistent with this experience. These scenarios were based on the ratio of increased belt use at nighttime vs. that experienced in daytime. While 3 different scenarios could produce an increasing Day/Night ratio, only one – which assumes equal percentage point growth for both day and night, was consistent with the patterns found in the historical data in Table 4. This would seem to imply that most new belt wearers during this period either became full time users, or that whatever level of occasional use they brought into the mix was offset by improved belt use habits of others. In either case, the result is a consistent percentage point gap between daytime and nighttime use rates as UPFC increases. For this reason, as well as for the accuracy advantage it gives at current use levels, Model 2 ($u = 0.43751 * u_o + 0.47249 * u_o^2$) is selected as the preferred model.

Note that, based on this model, the observed belt use u_0 can be derived from known UPFC (u) by rearranging the quadratic equation as follows:

$$0.47249 * u_o^2 + 0.43751 * u_o - u = 0.$$

The observed belt use rate (as a function of UPFC) would be the solution of the above quadratic equation. The solution is:

$$u_o = \frac{-0.43751 + \sqrt{(0.43751)^2 - 4 * 0.47249 * (-u)}}{2 * 0.47249}$$

i.e.,

$$u_o = \frac{-0.43751 + \sqrt{0.191415 + 1.88996 * u}}{0.94498}$$

It is unknown whether this daytime/nighttime pattern will continue. An alternative scenario that could occur would be one in which daytime usage increases at a faster rate than nighttime usage. This might occur if the most risk adverse drivers wear belts during daylight hours to avoid penalties for non-use under primary law enforcement, but frequently ride unbelted at night when such enforcement is difficult. Another scenario that might create this result would be if those most reluctant to buckle up also have a higher tendency to both drink and drive at night and don't buckle up when they are inebriated. Both of these scenarios may already be occurring to some extent, but they do not appear to be a dominant factor in the relative increase in day and night belt use. If they were, the absolute difference would be increasing while the night/day ratio would be decreasing. The patterns of observed belt use and UPFC will be monitored as usage increases to determine whether such a shift is occurring, and whether a further revision in the algorithm is appropriate.

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