

THE SAFETY EFFECTIVENESS OF LIGHT-DUTY MOTOR VEHICLE OCCUPANT RESTRAINTS : NUMBERS OF OCCUPANT LIVES SAVED AND INJURIES PREVENTED BY SEAT BELTS IN ROAD TRAFFIC COLLISIONS IN CANADA, 1989 - 1995

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ABSTRACT

The first Canadian 'National Symposium on Road Safety' was held in Montreal in 1988. The main purpose was to assess the prevailing levels of safety for the various road users of Canada's roads and highways and identify issues and related goals to pursue for realizing a safer national road transportation system. One of the main recommendations was a commitment to work towards increasing the usage rates of occupant protection restraint systems (e.g., seat belts, child restraints). The reaction to this major goal identified was swift and decisive. A proposal -- The National Occupant Restraint Program (NORP), was prepared by the Canadian Council of Motor Transport Administrators (CCMTA) and presented to the federal and provincial ministers responsible for road safety in September of 1989. The Council of Ministers endorsed the program's target objective of attaining a "95 percent restraint usage rate by occupants of light-duty motor vehicles* by 1995".

Retrospective trend analyses of changes in seat belt usage rates during the six years of NORP demonstrate that the goal was quite realistic. Through National Seat Belt Use Surveys conducted annually by Transport Canada (1996) it was possible to monitor and assess improvements in occupant restraint usage. Two of the most significant and encouraging results revealed that national seat belt usage rates for drivers of passenger vehicles increased from 73.9 % in 1989 to 91.6 % in 1994 -- a percentage increase of about 24 % and very close to the 6-year target objective established by NORP, and the usage rate for occupants of light-duty vehicles increased from 68 % to 87 % during the same period resulting in a 28 % percentage increase.

The major issue that required addressing, however, was to evaluate any safety impacts that can be attributed to the NORP program. In particular, there is a need to know whether the observed increases in seat belt usage rates over the program period yielded significant benefits

(i.e., reductions in fatalities and injuries for collision-involved motor vehicle occupants), and if so, to measure the extent and value of these benefits towards the ultimate goal -- improving road safety. These general objectives formed the basis for the research study reported on in this paper.

INTRODUCTION

Before the extent and value of any road safety benefits attributable to increases in seat belt usage rates can be measured there a number of preliminary tasks to be carried out. To this end five main objectives were identified as the primary focal points for the successful conduction and completion of this research project including: developing a 'reliable' estimate of the safety effectiveness of seat belt restraint systems in preventing death and injury to all occupants of light-duty vehicles involved in road traffic collisions; designing and developing appropriate statistical analysis methodologies for estimating reductions in occupant fatalities and injuries that can be attributed to the increases in seat belt usage rates observed in light-duty vehicles during the NORP program time-frame; implementing these methods to estimate the number of light-duty vehicle occupant lives saved and injuries prevented due to the prevailing seat belt usage rates observed in each of the years between 1989 and 1995; estimating the incremental number of occupant lives saved and injuries prevented (if any) in light-duty vehicle collisions that can be attributed to the observed increases in seat belt usage rates over the NORP period 1989-1995; and developing estimates of the value/magnitude of any measurable benefits that can be accrued to the increased usage of available restraint protection systems by occupants of light-duty vehicles over the 1989-1995 study period. Lastly, from the findings of this research evaluation study, conclusions and recommendations discussing the impacts that can be attributed to the NORP program in improving road travel safety for occupants of light-duty motor vehicles involved in collisions are provided.

* light-duty motor vehicles includes light-trucks, vans and passenger cars

ANALYTICAL METHODS AND PROCEDURES

In order to develop methodology for estimating any reductions in fatalities and injuries that can be attributed to increases in seat belt usage by occupants of light-duty vehicles it is first necessary that estimates of the 'effectiveness' of seat belts in saving lives and preventing injuries are available. That is, a reliable (accurate) estimate of the expected number of unbelted occupant deaths and injuries that occurred and that could have been prevented if they had been wearing a seat belt must be 'known'.

Development Of 'Reliable' Estimates Of Seat Belt Effectiveness In Preventing Death And Injury To Occupants Of Light-Duty Vehicles

Three options for deriving sufficiently accurate estimates of seat belt effectiveness in preventing death and injury to occupants of collision-involved light-duty motor vehicles were identified:

- ① Utilize Canadian police-reported collision information and develop methods and techniques to correct for known limitations and biases inherent to these data bases, or
- ② Identify other available Canadian collision data bases that contain the relevant information required and that do not have the limitations and biases inherent to the police-reported collision data bases in ① above, or
- ③ Search outside of Canada for research conducted and completed on seat belt effectiveness evaluation(s) that meets the requirements of our study.

Option ① was dismissed due to the inability to account for the serious limitations and significant biases contained in the Canadian police-reported data. The pursuit of Option ② revealed the existence of some estimates of seat belt effectiveness developed from detailed national accident investigation data bases -- known as 'Level II accident investigation case studies'. Level II accident investigations are conducted by specially trained accident investigators/reconstructionists and the breadth, detail and accuracy of the information collected on the factors and characteristics present in the collision are significantly greater than that collected in police investigated and reported (Level I) data bases. Specifically, the Level II Accident Investigation Passenger Car Study (PCS), 1984 - 1992 [Stewart, 1996] is an in-depth investigation of motor vehicle collisions in which at least one passenger car is involved and at least one occupant of the vehicles involved was either killed (fatal collision investigations) or injured (injury-producing collision investigations). These data bases were analyzed by Stewart (1992) for the years 1984 to 1989 inclusive using Bayesian statistical probability methods in order to develop estimates of seat

belt effectiveness. Unfortunately it was only possible to develop reliable estimates of effectiveness for front seat occupants of passenger vehicles because of the limited number of case studies investigated coupled with that fact that the target population for the study was restricted -- only accidents in which at least one passenger vehicle was involved were eligible for selection and investigation. Since a major objective of this present study required the development of seat belt effectiveness estimates that are reflective of all occupant seating positions and all light-duty vehicles, i.e., the entire fleet of light trucks and vans in addition to passenger cars, it was decided to pursue Option 3 -- search outside Canada for more accurate estimates. This led to attention being turned to the estimates of seat belt effectiveness developed by the Office of Regulatory Analysis, Plans and Policy, U.S. Department of Transport, National Highway Traffic Safety Administration (NHTSA) (1994) and Leonard Evans (1987) for the following reasons.

Large collision data bases are required for deriving an 'optimum' estimate for the effectiveness of seat belts in preventing fatalities and injuries -- these types of data bases do not exist in Canada but are available in the United States. This is simply due to the large differential existing in the population bases, amounts of 'exposure (to risk)' and therefore consequences of exposure (to risk), i.e., collisions, between the two countries. There are approximately ten times more motor vehicle collisions in the United States than in Canada. These large U.S. data bases provide the capacity to select the collision configurations based on cross-classifications of occupant characteristics required, e.g., numbers of occupants, seating positions, ages of occupants, vehicle type and whether the seat belt was used or not by a particular vehicle occupant at the time of the collision. Subsequently, appropriate groupings, matching and comparisons of these collision case data characteristics (where at least one person is either killed or injured -- the injury severity level analyzed depends upon the effectiveness estimate being derived) provides the capacity to: control for extraneous factors; avoid the problems, limitations and biases inherent to Canadian collision data bases; and design and implement an optimum effectiveness estimation methodology that depends upon the availability of large collision data bases. Therefore, the estimates of seat belt effectiveness developed by NHTSA and Evans were utilized due to the benefits (discussed above) afforded by U.S. collision data bases.

The overall effectiveness of seat belts in saving lives among all occupants of passenger cars involved in collisions has been estimated by NHTSA to be 45 %. The term 'effectiveness' is defined as the fraction of fatally injured occupants who were not using a seat belt in motor

vehicle collisions and who would not have been killed had they been wearing a seat belt, given all other factors being equal. The effectiveness of seat belts in preventing death and reducing injury severity levels, however, is variable depending upon the vehicle type and seating position of the occupant. Estimates of seat belt effectiveness by vehicle type, occupant seating position and injury severity level (Table 1.) were developed by NHTSA (1994).

Combining occupant injury distributions cross-classified by vehicle seating positions (obtained from Transport Canada's Traffic Accident Information Database -- TRAID [Evaluation and Data Systems Division, Road Safety Programs Directorate, Transport Canada, 1993]) with injury severity level distributions (obtained from Transport Canada's Level II Accident Investigation Passenger Car Study -- PCS, 1984-1992) and the respective seat belt effectiveness estimates in Table 1., an average seat belt effectiveness estimate for each of the three occupant injury severity levels can be derived. After carrying out these computations an average seat belt effectiveness estimate in saving the lives of light-duty vehicle occupants involved in collisions is 47 percent, in preventing moderate to critical injuries (MAIS 2-5) is 52.3 %, and in preventing minor injuries (MAIS 1) is 9.5 %. This overall average fatality reduction estimate of 47 % is quite plausible -- our Canadian estimate for front out-board occupants from the limited national sample of a restricted vehicle collision target group (only collisions in which at least one passenger car was involved) was 39 % [Stewart, 1992].

Finally, analysis of Transport Canada's PCS database for the years 1984 to 1987 inclusive yielded the proportional distributions of MAIS 1 and MAIS 2-5 occupant injury severity levels given by 0.8066 and 0.1934 respectively. Further analyses applying these proportional fractions as weights to the MAIS 2-5 and MAIS 1 injury reduction effectiveness estimates above permits a combined weighted average estimate of seat belt effectiveness in preventing injuries (over all MAIS 1-5 injury severity levels) to occupants of light-duty vehicles involved in collisions to be derived -- resulting in a value of 17.8 percent.

Data Sources For Estimating Occupant Seat Belt Usage Rates In Canada

Two basic sources of data exist for estimating safety belt usage rates among light-duty vehicle occupants. The first source involves the Transport Canada annual observational surveys of the driver or occupant population traveling in light-duty vehicles on the roads and highways. These surveys are considered to be quite accurate since they are based on direct observation of the

Table 1.
Estimates of Seat Belt Effectiveness (%) by Vehicle Type, Occupant Seating Position and Injury Severity Level

OCCUPANT INJURY SEVERITY LEVEL			
	MAIS 2-5 *		MAIS 1 *
	Fatalities	Injuries	Injuries
SEAT BELT EFFECTIVENESS ESTIMATE (%)			
PASSENGER CARS			
Front Seat	45.0	50.0	10.0
Rear Seat	41.0	50.0	5.5
LIGHT TRUCKS AND VANS			
Front Seat	60.0	65.0	10.0
Rear Seat	41.0	50.0	5.5
* MAIS : Economic cost data is stratified according to the level of occupant injury severity. Severity is classified using the Abbreviated Injury Scale (AIS). Under this scale all non-fatal injury severity is defined as follows: AIS 1 = minor injury AIS 2 = moderate injury AIS 3 = serious injury AIS 4 = severe injury AIS 5 = critical injury Frequently, injured occupants sustain more than one injury. Therefore, each injured survivor is classified according to his or her highest (most severe) injury level. This is known as their maximum injury severity level and is abbreviated as MAIS.			

traffic. They are limited, however, in that they are only conducted during day-time hours of 7 a.m. to 5 p.m. and therefore not necessarily representative of the seat belt usage rates for all light-duty vehicle collisions.

The other source of motor vehicle occupant restraint information comes from police-reported collision data records collected in all ten provinces and the two territories of Canada. These data are stored and maintained in Transport Canada's national TRAIID database system and, when available, provide indicators of seat belt usage by all occupants of motor vehicles involved in collisions. The major criteria for establishing whether a restraint system was used or not relies upon the documentation of 'hard' evidence such as seat belt bruise marks on the occupants body or direct observation by the police investigating the accident. Quite frequently, unfortunately, the restraint status of a particular occupant is not determinable by the above direct methods and the only available evidence is statements made to the police by witnesses or persons involved in the collision. Due to their very nature these 'indirect' methods for establishing restraint status are considered to be biased and tend to yield inflated restraint usage rates. This is quite easily demonstrated by the fact that the recorded seat belt use rates for occupants involved in collisions during the years 1992 and 1993 were 92.3 % and 92.9% respectively, compared to 81.4 % and 83.4 % found in the observational day-time surveys conducted during the same two years. Inflated estimates are more of a problem for property damage and minor to moderate injury (MAIS 1-2) cases than for occupants who were killed in collisions. This is explained by the fact that a large proportion of occupants involved in high severity level collisions are killed on impact, and the attending police can make a direct observation of seat belt use status. Even in these cases it is surprising that the seat belt use status of a fatally injured motor vehicle occupant is still 'unknown' for approximately 10 percent of the cases.

Therefore, due to the high reporting bias inherent to the TRAIID database, reliable estimates of seat belt usage are not generally available from police-reported collision investigations. With respect to the fatally injured occupant population, however, TRAIID usage rates (although not precise) do provide the necessary data inputs to develop evaluation methodology for estimating the number of occupant lives saved in light-duty vehicle collisions. Overall, however, the observational surveys of the traffic on the roads and highways, although not directed at the collision-involved population, are believed to be the best available indicators of seat belt usage rates to use in the development of the evaluation methodology.

Three different evaluation methods, therefore, were developed to derive estimators of the number of light-duty vehicle occupant lives saved by seat belts. Method 1

utilizes seat belt usage information contained in Transport Canada's TRAIID database, specifically national seat belt usage rates obtained from police collision reports for all occupants of light-duty vehicles involved in accidents. The other two methods (Methods 2a and 2b) utilize the occupant seat belt usage data obtained from 'direct' observational surveys of the traffic -- Transport Canada's annual national occupant restraint surveys. The difference, as will be seen, between Methods 2a and 2b involves a phenomenon referred to as 'selective recruitment' (of seat belt users) [Evans, 1987]-- a process which is not accounted for in Method 2a but is taken into account in Method 2b.

Method 1. An Estimator Of The Additional Number Of Occupant Lives Saved In Light-Duty Motor Vehicles Involved In Collisions In Each Of The Years 1990 - 1995 That Are Attributable To Increases In Seat Belt Usage Rates Over The 1989 'Base Year' Level Of 68 % : A Method Based On Seat Belt Usage Rates Among The Collision-Involved Light-Duty Vehicle Occupant Population

Occupant restraint system devices will not save the life of every motor vehicle occupant who is involved in a potentially fatal collision. This is because the effectiveness, e , of seat belts in preventing death in motor vehicle collisions is not 100 % -- it is 47 % in light-duty motor vehicle collisions (as established earlier). This means that for every 100 unbelted occupants who died in a given year, 47 of them would have been saved if all 100 had been belted, and 53 would have died anyway because seat belts are not capable of preventing death to all occupants of motor vehicles involved in collisions. In reality, some motor vehicle collisions are non-survivable by all occupants even if they are wearing a seat belt.

In order to estimate the number of lives that were saved by seat belts in year i at year i seat belt usage rates, $S(R)_i$, we need to know the total number of restrained occupant deaths that occurred in year i , $D(R)_i$. This information permits us to conclude that $(1 - e)$ % of all fatally injured occupants that were not saved by seat belts in year i is equal to $D(R)_i$. With this relationship established it is then possible to estimate the (unknown) number of lives that were saved by seat belts in year i at year i seat belt usage rates, $S(R)_i$. The mathematical formula for computing $S(R)_i$ is given as follows:

$$S(R)_i = D(R)_i * [e / (1 - e)] \quad (1.)$$

Now: assuming that the ratio of belted to total occupants killed in light-duty vehicle collisions in the 1989 'base year', given by $R(R | T)_{1989} = 0.456$, remained constant over the years 1990 - 1995 inclusive; and given

that the total number of light-duty vehicle occupant fatalities for a given year i , D_i , is known; and lastly that the effectiveness of seat belt systems, e , in preventing death to occupants of light-duty motor vehicles involved in potentially fatal collisions is known; it is then possible to estimate the expected number of occupant lives that would have been saved by seat belts in light-duty vehicle collisions in the years 1990 - 1995 at 1989 'base year' seat belt usage rates, $S(R,1989)_i$, by the following equation,

$$S(R,1989)_i = D_i * R(R | T)_{1989} * [e / (1 - e)] \quad (2.)$$

and the 'expected belted fatal cases (at 1989 seat belt use rate)' is computed using equation (3.).

$$D(R,1989)_i = D_i * R(R | T)_{1989} \quad (3.)$$

Subtraction of equation (2.) from equation (1.), i.e., $[S(R)_i - S(R,1989)_i]$, yields an estimator of the extra number of occupant lives saved (if any) by seat belts in year i that can be attributed to the increased seat belt usage rate in year i relative to the 1989 'base year' seat belt usage rate -- denoted as $ES(R)_i : 1989$. The results of all computations of the equations involved for the implementation of Method 1 (as described above) are provided in Table 2.. The last column of the table gives the desired estimators -- the estimated number of additional lives saved by light-duty vehicle occupant seat belts in year i that would not have been saved had the seat belt usage rate remained at the 1989 'base year' level of 68 percent.

Table 2.

Estimates Of The Number Of Extra Occupant Lives Saved In Light-Duty Vehicle Collisions In Each Of The Years 1990 - 1995 (Attributable To Increases In Safety Belt Usage Rates) That Would Have Died If Seat Belt Usage Rates Had Remained At The 1989 'Base Year' Level Of 68 %

YEAR	S-B USE RATE ¹	TOTAL FATAL CASES ²	BELTED FATAL CASES ³	RATIO (BELTED TO TOTAL FATAL CASES) ⁴	OCCUP. LIVES SAVED BY S-B (DUE TO YEAR S-B USE RATE) ⁵	EXPECTED BELTED FATAL CASES (AT 1989 S-B USE RATE) ⁶	EXPECTED OCCUP. LIVES SAVED BY S-B (AT 1989 S-B USE RATE) ⁷	EXTRA OCCUP. LIVES SAVED BY S-B (DUE TO YEAR S-B USE RATE) ⁸
Y_i	UR_i (%)	D_i	$D(R)_i$	$R(R T)_i$	$S(R)_i$	$D(R,1989)_i$	$S(R,1989)_i$	$ES(R)_i : 1989$
1989	68.0	3,129	1,428	0.456	1,266			
1990	76.0	2,804	1,439	0.513	1,276	1,279	1,134	<u>142</u>
1991	80.0	2,632	1,416	0.538	1,255	1,200	1,064	<u>191</u>
1992	81.4	2,583	1,453	0.562	1,289	1,178	1,045	<u>244</u>
1993	83.4	2,620	1,506	0.575	1,336	1,195	1,060	<u>276</u>
1994	86.8	2,360	1,399	0.593	1,241	1,076	954	<u>287</u>
1995	86.8	2,476	1,494	0.604	1,325	1,129	1,001	<u>324</u>

1 National seat belt usage rate for occupants of light-duty vehicles in road traffic.

2 Total occupants killed in light-duty vehicle collisions.

3 Total restrained occupants killed in light-duty vehicle collisions.

4 Ratio of restrained to total occupants killed in light-duty vehicle collisions.

5 Total number of occupant lives saved in light-duty vehicle collisions attributable to seat belt usage rate, UR_i .

6 Expected number of restrained occupants that would have been killed in light-duty vehicle collisions if seat belt usage rate had been at the 1989 level of 68 %.

7 Expected number of occupant lives that would have been saved by restraint systems if seat belt usage rate had been at the 1989 level of 68 %.

8 Extra number of occupant lives that were saved by restraint systems due to the increase in seat belt usage rate in year i over the 1989 'base year' level of 68 %.

^ Indicates the value has been estimated.

Interpretation Of Method 1 Results – The national seat belt survey usage rates for occupants of light-duty motor vehicles for each of the years 1989 to 1995 are given in column 2 of Table 2. -- denoted as UR_i . Comparing these usage rates with the 'extra occupant lives saved by seat belts (due to increased seat belt usage rates in year i over 'base year' 1989)' -- last column of the table denoted by $ES(R)_{i,1989}$ -- reveals the additional number of occupant lives being saved in light-duty motor vehicle collisions in each of the years 1990 to 1995 that are attributable to the increases in seat belt usage rates over the 1989 'base year' usage rate of 68 %. Graphical representations of all major results are provided in Figures 1 and 2.

Examination of the results provided in Table 2. and Figures 1. and 2. reveals the following noteworthy findings. There were 7,722 light-duty vehicle occupant lives saved by seat belts in collisions during the six year NORP program period 1990 - 1995. An increase of 8 % in occupant seat belt usage by the light-duty vehicle motorists (i.e., 76 % in 1990 compared to 68 % in 1989) resulted in an 'additional' 142 lives being saved by seat belts in 1990 that would have been lost had the seat belt usage rate in 1990 remained at the 1989 seat belt usage rate level of 68 %. Further analyses of these results shows that each percentage point increase in seat belt usage in 1990 over the 1989 usage rate translates into an 'additional' 18 occupant lives being saved in collision-involved light-duty vehicles in 1990 who would have been killed had the seat belt usage rate in 1990 remained at the 1989 level of 68 %. These same types of analyses and interpretations comparing the years 1991 to 1995 with the 1989 'base year' reveal that: 191, 244, 276, 287 and 324 'additional' occupant lives were saved by seat belts in light-duty motor vehicles involved in collisions in the corresponding years 1991, 1992, 1993, 1994 and 1995 due to increases in seat belt usage rates (over the 1989 'base year' level of 68 %) of 12.0 %, 13.4 %, 15.4 %, 18.8 % and 18.8 % respectively. These results translate into approximately 16, 18, 18, 15 and 17 'additional' occupant lives being saved in collision-involved light-duty vehicles for each percentage point increase in seat belt usage over the 1989 'base year' level of 68 % in the years 1991, 1992, 1993, 1994 and 1995 respectively. An analysis of the collective benefits over the six year NORP program period (1990 - 1995) reveals that 1,464 'additional' light-duty motor vehicle occupant lives have been saved in collisions that are directly due to the increases in seat belt usage rates that have occurred since the comparison 'base year' 1989. In other words, 1,464 more occupant fatalities would have occurred during the NORP program period (1990 - 1995) if the seat belt usage rates among the occupants of light-duty motor vehicles

had remained at the 1989 level of 68 %.

Method 2a. An Estimator Of The Additional Number Of Occupant Lives Saved In Light-Duty Motor Vehicles Involved In Collisions In Each Of The Years 1990 - 1995 That Are Attributable To Increases In Seat Belt Usage Rates Over The 1989 'Base Year' Level of 68 % : A Method Based On Observed Occupant Seat Belt Usage Rates In Light-Duty Vehicles Traveling On The Roads And Highways -- 'Without Selective Recruitment'

This second method for deriving estimators of any 'additional' light-duty vehicle occupant lives that have been saved in collisions that are attributable to increases in seat belt usage is based on seat belt usage rate results obtained from observational surveys of the general traffic on the roads and highways. These day-time surveys have been conducted by Transport Canada annually between 1979 and 1990 and biannually after 1990. They are designed using a complex multistage stratified probability sampling plan resulting in a national sample of 240 roadside observational sites selected by province, road type and community size. The surveys are conducted during a one-week time period (either in the fall -- October, or in the spring -- June) between the hours of 7 a.m. and 5 p.m.. Seat belt use information was only collected for vehicle drivers in the 1989 - 1991 surveys while the surveys after 1991 have collected the belt use information for all occupants of the vehicles observed. The results of the 1989 to 1996 Transport Canada surveys providing seat belt usage rates for drivers of passenger vehicles, drivers of light-duty vehicles and all occupants of light-duty vehicles by year and month are given in Table 3..

Using these seat belt usage rates (Table 3.) estimators of any decreases in the numbers of casualties (fatalities or injuries) to collision-involved light-duty vehicle occupants that are attributable to increases in seat belt usage rates between two periods of time can be derived. Specifically, the reductions in light-duty vehicle occupant casualties (fatalities or injuries) realized in year i compared to an earlier time period say 'base year' b , denoted as $CR^{2a}(O, LV)_{i,b}$, can be estimated when four quantities are known -- the seat belt effectiveness estimate, the current year i seat belt usage rate, the comparison or 'base year' b seat belt usage rate, and the number of casualties (fatalities or injuries) that occurred in the comparison or 'base year' b . Inputting these quantities into the following mathematical formula (4.) and performing the computations yields the desired estimators of casualty (fatality or injury) reductions between the two evaluation time periods i and b :

**ESTIMATES OF THE TOTAL NUMBER OF LIVES SAVED BY SEAT BELTS AMONG
OCCUPANTS OF LIGHT-DUTY VEHICLES INVOLVED IN COLLISIONS AT THE
PREVAILING YEAR'S AND THE 1989 USAGE RATE LEVEL, AND CUMULATIVE TOTALS :
1990 - 1995**

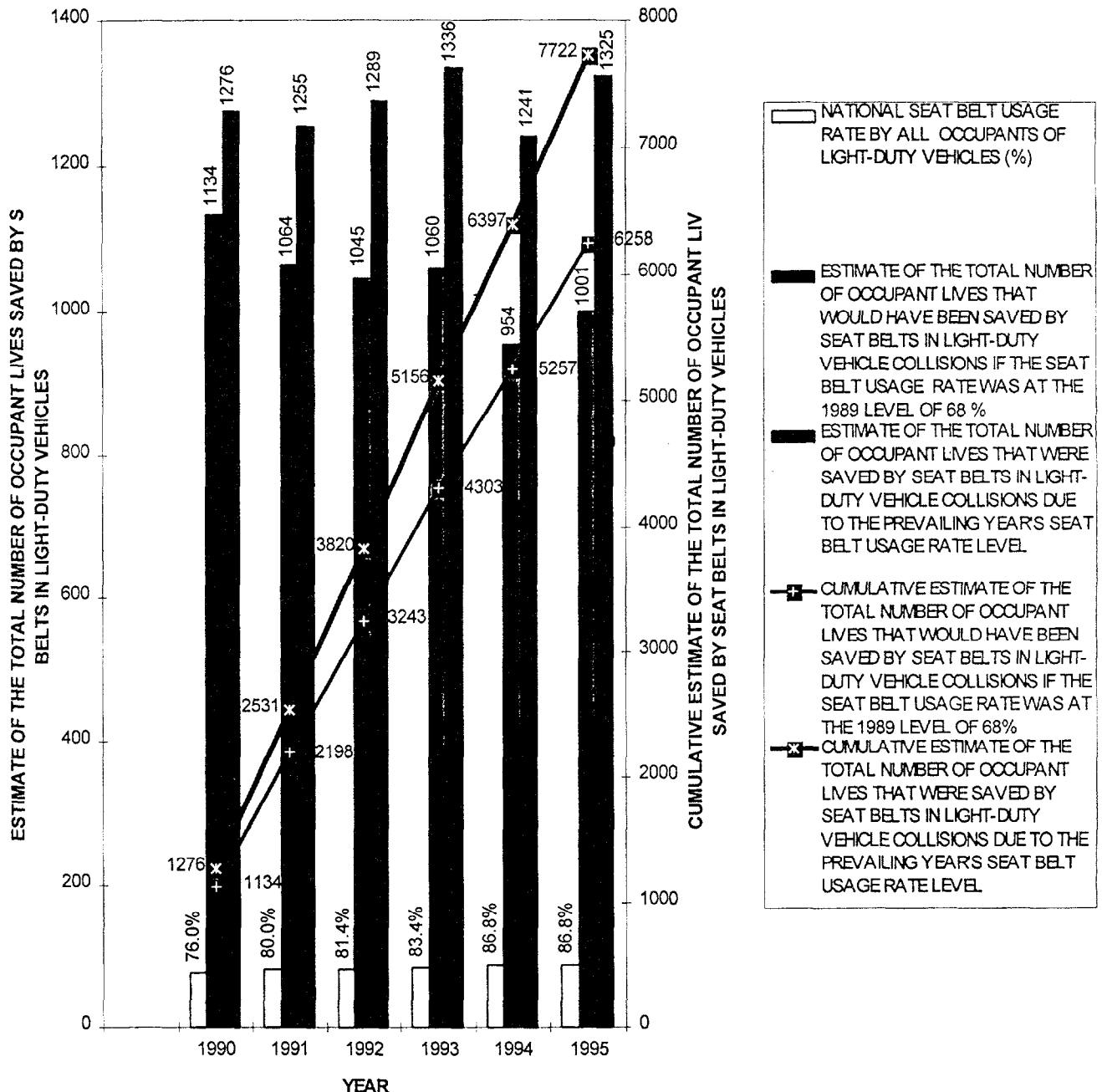


Figure 1. Estimators of : the total number of occupant lives that would have been saved by seat belts in collision-involved light-duty vehicles in each of the years 1990 to 1995 and cumulative totals over the years if the seat belt usage rate had remained at the 1989 'base year' level of 68 %, and the total number of occupant lives that were saved by seat belts in collision-involved light-duty vehicles in each of the years 1990 to 1995 and cumulative totals over the years that are attributable to the prevailing year's seatbelt usage rate level.

ESTIMATES AND CUMULATIVE TOTALS OF 'ADDITIONAL' LIVES SAVED AMONG LIGHT-DUTY VEHICLE OCCUPANTS INVOLVED IN COLLISIONS FOR THE YEARS 1990 TO 1995 DUE TO INCREASES IN SEAT BELT USAGE RATES SINCE 1989 'BASE YEAR'

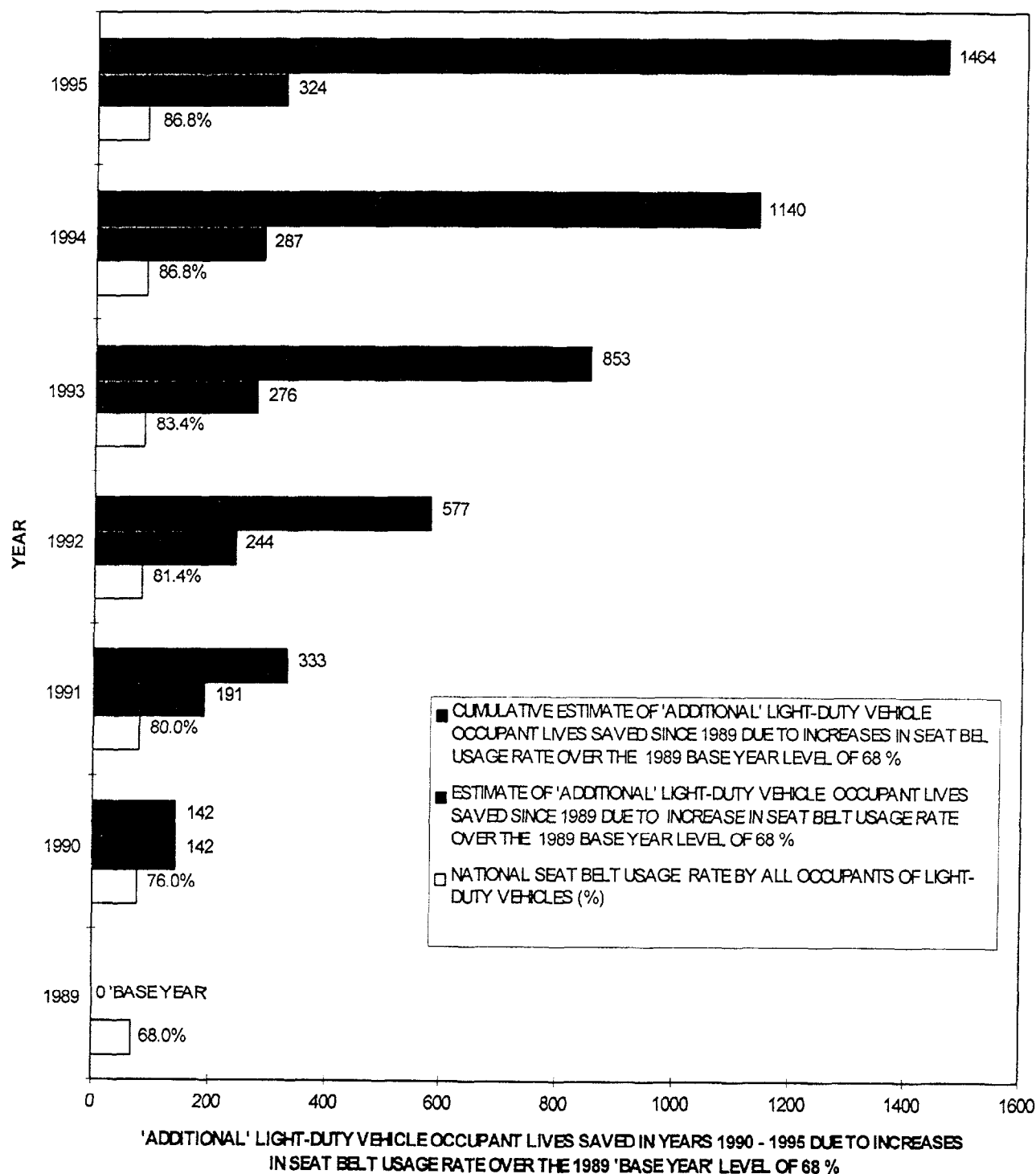


Figure 2. Estimators of : the 'additional' number of occupant lives that were saved by seat belts in light-duty vehicles involved in collisions in each of the years 1990 to 1995 that are attributable to increases in the seat belt usage rate level that took place in the prevailing year (i.e., 1990,...,1995) over the 1989 'base year' level of 68 %.

Table 3.

Estimators Of Seat Belt Usage Rates For Drivers Of Passenger Vehicles, Drivers Of Light-Duty Vehicles, And All Occupants of Light-Duty Vehicles : 1989-1996

Survey Year and Month	Seat Belt Use Rate: Drivers, Passenger Vehicles (%)	Seat Belt Use Rate: Drivers, Lt.-Duty Vehicles (%)	Seat Belt Use Rate: Occupants, Lt.-Duty Vehicles (%)
$Y_{i,m}$	UR(D,PV)	UR(D,LV)	UR(O,LV)
1989, Oct.	73.9	70.6	68.0*
1990, Oct.	81.9	80.0	76.0*
1991, June	85.1	83.0	80.0*
1991, Oct.	86.0	83.8	
1992, June	85.9	84.4	81.4
1992, Oct.	87.1	85.7	
1993, June	87.8	86.2	83.4
1993, Oct.	87.8	87.0	
1994, June	90.1	88.7	86.8
1994, Oct.	91.6	90.6	
1995			86.8**
1996, June	91.9		88.7

* These seat belt usage rates are estimated from the observed seat belt usage rates for drivers of light-duty vehicles for the respective year (column 3)

** A national seat belt survey was not conducted in 1995, therefore the previous year's estimate is used

$$CR^{2a}(O,LV)_{i;b} = \frac{[UR(O,LV)_i - UR(O,LV)_b] * e_c * C_b}{1 - [e_c * UR(O,LV)_b]} \quad (4.)$$

where,

$CR^{2a}(O,LV)_{i;b}$ is the estimated reductions in casualties (injuries or fatalities -- depending upon injury severity level being evaluated) to occupants of light-duty motor vehicles involved in collisions in estimation year i compared to comparison 'base year' b,

e_c is the overall effectiveness estimate of seat belt systems in preventing casualties (death or injury) to occupants of light-duty motor vehicles involved in collisions (e_c has two different values as established earlier -- one for death reduction and another for injury reduction), $UR(O,LV)_i$ is the seat belt usage rate for occupants of light-duty motor vehicles traveling on the roads and highways in estimation year i,

$UR(O,LV)_b$ is the seat belt usage rate for occupants of light-duty motor vehicles traveling on the roads and highways in comparison 'base year' b,

C_b is the number of casualties (fatalities or injuries, depending upon the injury severity level reduction being estimated) that took place in comparison 'base year' b.

METHOD 2b. AN ESTIMATOR OF THE ADDITIONAL NUMBER OF OCCUPANT LIVES SAVED IN LIGHT-DUTY MOTOR VEHICLES INVOLVED IN COLLISIONS IN EACH OF THE YEARS 1990 - 1995 THAT ARE ATTRIBUTABLE TO INCREASES IN SEAT BELT USAGE RATES OVER THE 1989 'BASE YEAR' LEVEL OF 68 % :
A METHOD BASED ON OBSERVED OCCUPANT SEAT BELT USAGE RATES IN LIGHT-DUTY VEHICLES TRAVELING ON THE ROADS AND HIGHWAYS -- 'WITH SELECTIVE RECRUITMENT'

This method, unlike Method 2a, takes into account a phenomenon known as 'selective recruitment' -- a process in which the group of drivers who change from being non seat belt users to seat belt users have lower accident involvement rates than the remaining group of non users. Analytical methods to account for this have been developed by Evans (1987) and are therefore implemented in this study for the purposes of assessing the estimates developed by Methods 1 and 2a. The mathematical formula for implementing Method 2b to compute estimates of 'additional' light-duty vehicle occupant lives saved and injuries prevented in collisions that are attributable to increases in seat belt usage rates between two time periods i and b is given by:

$$CR^{2b}(O,LV)_{i;b} = \left[\frac{e_c \{ \Delta u + 0.47 [UR(O,LV)_i^3 - UR(O,LV)_b^3] \}}{1 + 0.47 - e_c \{ UR(O,LV)_b + 0.47 [UR(O,LV)_b] \}} \right] * C_b \quad (5.)$$

where,

$CR^{2b}(O,LV)_{i;b}$ is the estimated fractional reduction in casualties (injuries or fatalities, depending upon the level of severity being evaluated) to occupants of light-duty motor vehicles involved in collisions in estimation year i compared to comparison 'base year' b,

e_c , $UR(O,LV)_i$, and C_b are as defined in the previous section under Method 2a,

Δu is the fractional difference between $UR(O,LV)_i$ and $UR(O,LV)_b$.

Interpretation Of Results For Methods 2a And 2b --
 The estimators of the 'additional' light-duty vehicle

occupant lives saved in collisions for the years 1990 to 1995 that are due to increases in seat belt usage rates that have occurred since the inception of the NORP program in 1990 are depicted in Figure 3. The results for the 'additional' light-duty vehicle occupant injuries prevented in collisions over the same time period (1990 - 1995) that are also attributable to the increases in seat belt usage rates since the NORP program implementation can be seen in Figure 4.

Examining the 'additional' light-duty vehicle occupant lives saved (Figure 3.) reveals that the increase in seat belt usage by the light-duty vehicle motorists from 68 % in 1989 to 76 % in 1990 (an 8 % increase) resulted in anywhere between 173 (Method 2a) and 188 (Method 2b) 'additional' light-duty vehicle occupant lives being saved by seat belts in 1990 -- that would not have been saved if the 1990 seat belt usage rate level had remained at the 1989 level of 68 %. This translates into about 23 'additional' light-duty vehicle occupant lives being saved in collisions for each percentage point increase in seat belt usage that occurred in 1990 over that of the 1989 'base year' level of 68 %. Comparison of the other years (1991 to 1995) to the 1989 'base year' reveal the following results: between 259 and 290, between 290 and 326, between 333 and 379, between 406 and 473, and between 406 and 473 'additional' light-duty vehicle occupant lives were saved by seat belts in collisions in the years corresponding to 1991, 1992, 1993, 1994 and 1995 that are directly attributable to increases in seat belt usage rates (over the 1989 'base year' level of 68 %) of 12.0 %, 13.4 %, 15.4 %, 18.8 % and 18.8 % respectively. Overall, this means that approximately 23 'additional' occupant lives were saved in collision-involved light-duty vehicles for each percentage point increase in restraint usage over the 1989 'base year' level of 68 % in each of the years 1991 through 1995. Further analyses of Figure 3 reveals that between 1,867 (according to Method 2a) and 2,129 (according to Method 2b) 'additional' light-duty motor vehicle occupant lives were saved in collisions over the entire NORP program period 1990 - 1995 due to increases in seat belt usage rates that have taken place since the 1989 'base year'. This implies that about 2,000 (the average of Methods 2a and 2b results) 'additional' light-duty vehicle occupant fatalities would have occurred in collisions during the six year NORP program period (1990 - 1995) if the seat belt usage rate levels among those occupants had remained at the 1989 'base year' level of 68 %.

Figure 4 illustrates the comparable results for the 'additional' light-duty vehicle occupant injuries that have been prevented in collisions for the six year NORP program period that are directly attributable to increases in seat belt usage rates that have occurred since the program's inception in 1990. It can be readily inferred

that the increase of 8 % in seat belt usage by the light-duty vehicle motorists (from 68 % in 1989 to 76 % in 1995) translates into a minimum of 3,740 (according to Method 2a) and as many as 4,303 (according to Method 2b) 'additional' light-duty vehicle occupant injuries that were prevented by seat belts in 1990 over that of the 1989 'base year'. This is interpreted as: "between 3,740 and 4,303 light-duty vehicle occupant injuries were prevented in collisions in 1990 that would not have prevented if the 1990 seat belt usage rate level (of 76 %) had remained at the 1989 level of 68 %. Further interpretations of the results in Figure 4. reveal that each percentage point increase in seat belt usage in 1990 over that of the 1989 usage rate level of 68 % among light-duty vehicle motorists resulted in between 468 (according to Method 2a) and 538 (according to Method 2b) injuries prevented in 1990 that would not have been prevented had the seat belt usage rate in 1990 remained at the 1989 'base year' usage rate level of 68 %. Similar analyses and interpretations were carried out comparing the years 1991 through 1995 to the 1989 'base year' revealing the following: between 5,609 and 6,611, between 6,264 and 7,445, between 7,199 and 8,661, between 8,788 and 10,795, and between 8,788 and 10,795 'additional' light-duty vehicle occupant injuries were prevented by seat belts in collisions in the years corresponding to 1991, 1992, 1993, 1994 and 1995 that are directly attributable to increases in seat belt usage rates (over the 1989 'base year' level of 68 %) of 12.0 %, 13.4 %, 15.4 %, 18.8 % and 18.8% respectively. Taking an average of the estimates produced by Methods 2a and 2b for each of the five years translates into about 509, 512, 515, 521 and 521 'additional' occupant injuries being prevented in collision-involved light-duty vehicles for every percentage point increase in seat belt usage over the 1989 'base year' level of 68 %. Collectively, over the entire six year NORP program period (1990 - 1995) there were between 40,388 (according to Method 2a) and 48,610 (according to Method 2b) 'additional' light-duty motor vehicle occupant injuries prevented in collisions due to the increases in seat belt usage rates that have occurred since the 1989 'base year'. In total, therefore, approximately 44,500 (the average of the results obtained from Methods 2a and 2b) 'additional' injuries would have occurred during the NORP program period if the seat belt usage rates among occupants of light-duty motor vehicle travel had remained at the 1989 'base year' level of 68 %.

CONCLUSIONS

Road Safety Benefits

All three methods developed and implemented in this study for estimating the lives that have been saved and

**ESTIMATES OF 'ADDITIONAL' LIVES SAVED AMONG LIGHT-DUTY VEHICLE
OCCUPANTS INVOLVED IN COLLISIONS FOR THE YEARS 1990 TO 1995 DUE TO
INCREASES IN SEAT BELT USAGE RATES SINCE 1989 'BASE YEAR'**

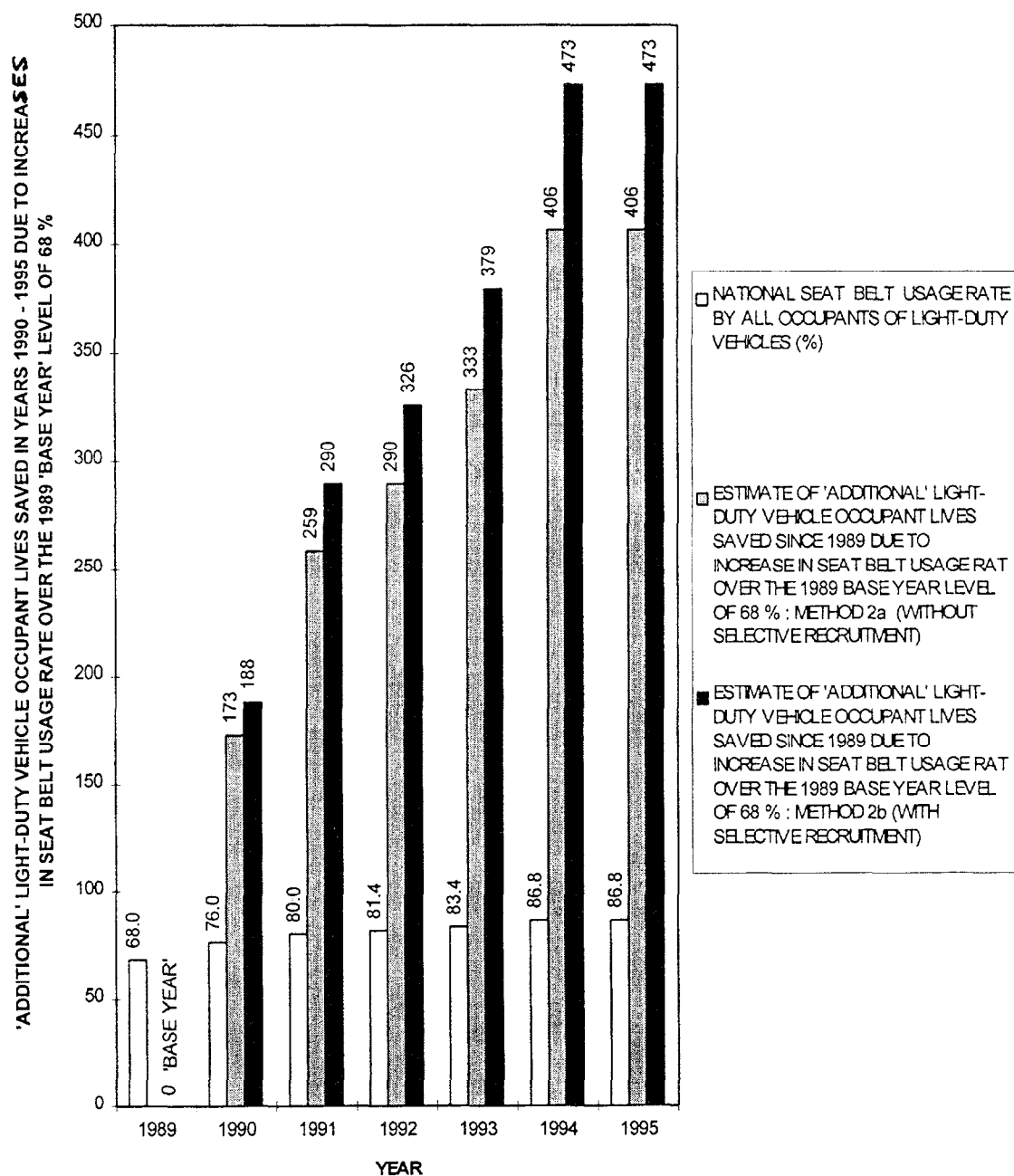


Figure 3. Estimators of the 'additional' number of lives that were saved by seat belts among light-duty vehicle occupants involved in collisions in each of the years 1990 to 1995 that are attributable to increases in the seat belt usage rate level that took place in the prevailing year (i.e., 1990,...,1995) over the 1989 'base year' level of 68 % for Methods 2a and 2b.

**ESTIMATES OF 'ADDITIONAL' INJURIES PREVENTED AMONG LIGHT-DUTY
VEHICLE OCCUPANTS INVOLVED IN COLLISIONS FOR THE YEARS 1990 TO 1995
DUE TO INCREASES IN SEAT BELT USAGE RATES SINCE 1989 'BASE YEAR'**

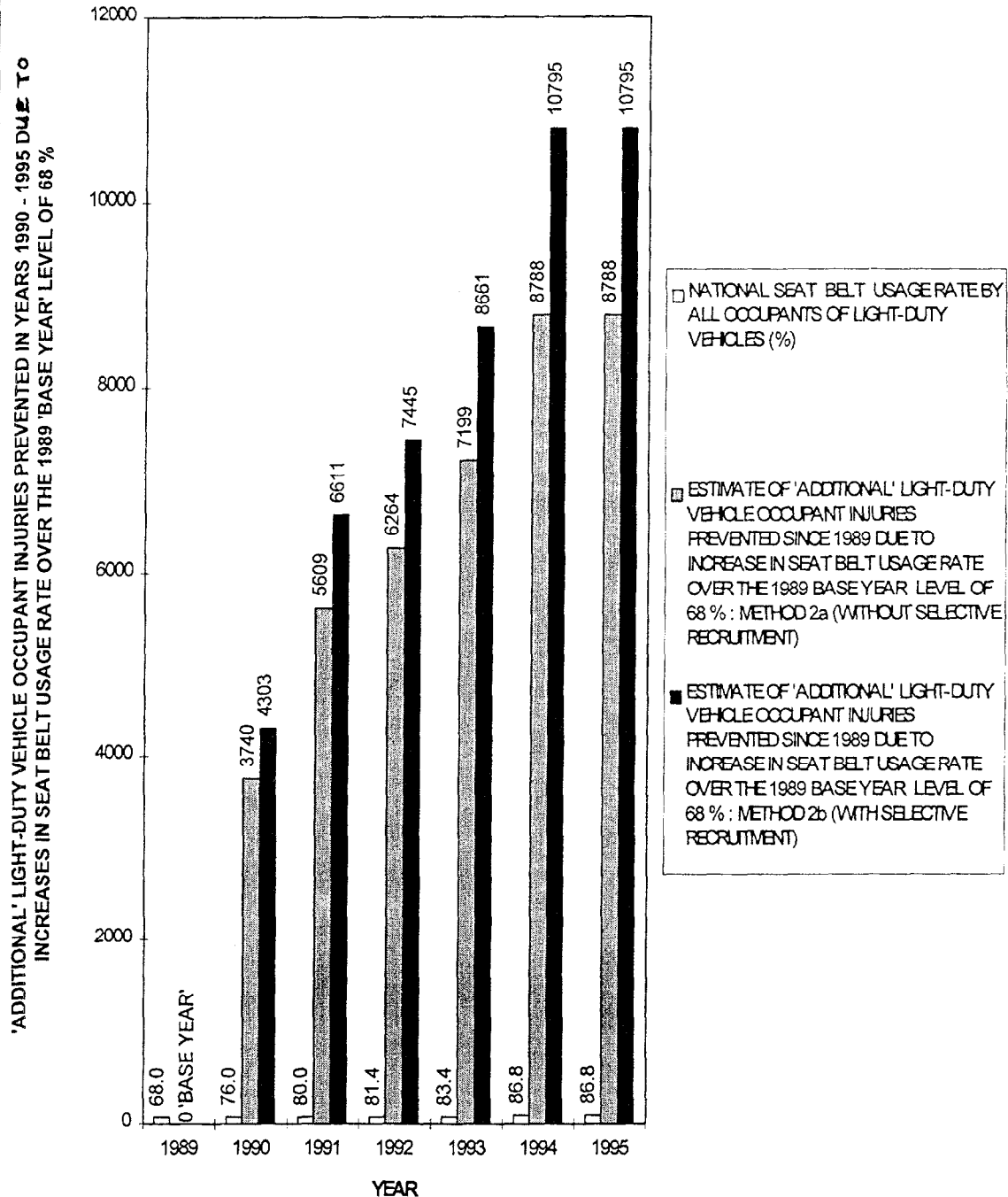


Figure 4. Estimators of the 'additional' number of injuries that were prevented by seat belts among light-duty vehicle occupants involved in collisions in each of the years 1990 to 1995 that are attributable to increases in the seat belt usage rate level that took place in the prevailing year (i.e., 1990,...,1995) over the 1989 'base year' level of 68 % for Methods 2a and 2b.

injuries that have been prevented among light-duty vehicle occupants that are directly attributable to increases in seat belt usage rates over the years are valid. The differentials in their strengths and weaknesses are owing to the accuracy of the input data required for each method as well as their respective capacities to develop estimates of 'total' and 'incremental' savings in lives and injuries due to the increased seat belt usage rates.

The appealing strength of Method 1 resides in its ability to estimate both the 'total lives saved' as well as the 'additional lives saved' that are directly attributable to the various levels of seat belt usage rate increases that took place over the specified evaluation time period -- in this case over the six year NORP program period. This is possible through the Method 1 estimation procedure because estimates of the expected number of total occupant lives saved by light-duty motor vehicle seat belt systems are derivable for any seat belt usage rate, and the difference between any two estimates computed for different seat belt usage rate levels provides the 'additional' or 'incremental' lives that were saved (if any) that are directly attributable to the differential in seat belt usage between the two evaluation time periods. One of the main weaknesses of Method 1 is that the estimators could, however, be 'under-estimates' due to the 'unknown' restraint use status for a significant proportion (10 % in this study) of the occupants who were fatally injured. The other weakness, or limitation, comes from the fact that the methodology does not permit the capability of estimating the 'numbers of injuries prevented' that are due to seat belt usage rate increases because sufficiently accurate data on the seat belt use status of injured occupants is not available.

The big advantage of Methods 2a and 2b come from their capacity to estimate both the 'additional' or 'incremental' lives saved as well as the injuries prevented that are directly attributable to increases in seat belt usage rates between two specified evaluation time periods. The major limitation, however, to both of these methods is their inability to estimate the 'total lives saved' or 'total injuries prevented' due to increases in seat belt usage rates. This is owing to the fact that the mathematical formulae only provide the capacity to derive estimates of the expected 'fractional reductions in casualties' for a specified period of time relative to a previous period in time that can be attributed to the differential in seat belt usage rate that existed between the two periods. Another limitation affecting these two methods is that they depend upon seat belt usage rates that are only representative of day-time travel (between 7 a.m. and 5 p.m. -- the time period during which the national seat belt surveys are conducted) which could result in 'over-estimates'.

Notwithstanding the above limitations, it is our opinion that the 'total lives saved' estimated by Method 1

and the average of the estimated 'fractional reductions in casualties (fatalities or injuries, depending upon the injury severity level estimated)' in Methods 2a and 2b are considered to be quite reasonable (accurate) for quantifying the 'additional' lives saved and injuries prevented that can be attributed to increases in seat belt usage that took place between the 1989 'base year' and the end of the six year NORP program in 1995. Therefore the total number of lives that have been saved by seat belts among occupants of collision-involved light-duty vehicles during the period 1990 - 1995 is estimated to be in excess of 7,700. Two thousand of these 7,700 lives would have been lost if the light-duty vehicle seat belt usage rates had not increased from the 1989 'base year' level of 68 % to the higher levels observed over the six year period 1990 - 1995. In other words, increases in seat belt usage rates of 8.0 %, 12.0 %, 13.4 %, 15.4 %, 18.8 % and 18.8 % over the 1989 'base year' level of 68 % in each of the years 1990, 1991, 1992, 1993, 1994 and 1995 respectively has resulted in an 'additional' 2,000 light-duty vehicle occupant lives saved. With respect to injuries, it is estimated that approximately 44,500 have been prevented among light-duty vehicle occupants that are directly attributable to the seat belt increases that took place during the 1990- 1995 period.

Economic Benefits

From an economic perspective, it is estimated that the value of a 'lost life' and an 'injured life' (i.e., societal costs) are (on average) equivalent to a financial loss of \$1.5 million and \$ 11,800 respectively. The benefits, therefore, that can be accrued to the increased usage of available seat belt systems by occupants of light-duty motor vehicles over the six year NORP program period (1990 - 1995) are in excess of \$ 3.5 billion.

SUMMARY AND RECOMMENDATIONS

The six year NORP program (1990 - 1995) had a significant impact on improving road travel safety. The increases in seat belt usage by light-duty vehicle occupants yielded large safety benefits with respect to lives saved and injuries prevented in motor vehicle collisions, which translated into sizable economic benefits (i.e., societal cost savings) of approximately three and one half billion dollars. The results of this research provide some incite and guidance on the expected 'potential' gains to be realized from the present (second) NORP program (1996 - 2001) that has been designed and implemented to affect further increases in the seat belt usage rates among the light-duty vehicle motorists.

Conservatively, the estimators derived from Method 1 indicate that about 17 'additional' occupant lives were

saved in collisions in each of the years 1990 to 1995 for each percentage point increase in seat belt usage over the 1989 'base year' level of 68 %, and the equivalent figure, averaged from Methods 2a and 2b, was 23 'additional' occupant lives saved. On the injury side, it was estimated that approximately 516 light-duty vehicle occupant injuries were prevented in collisions for each percentage point increase in the seat belt usage rate. Now, according to the 1995 national seat belt survey, the seat belt usage rate among light-duty vehicle occupants was 86.8 %. If this usage rate could be raised to 95 % by the year of 2001 through efforts under the present NORP program this would translate into an 8.2 % increase. Combining this seat belt increase with the above estimators of the expected number of lives that would be saved and injuries prevented yields the final road safety benefits and associated economic benefits that can be attributed to the NORP 1996 - 2001. After carrying out the computations, it turns out that: between 139 and 189 light-duty vehicle occupants lives would be saved, and about 4,230 light-duty vehicle occupant injuries would be prevented in the year 2001. From an economic perspective, this translates into a minimum savings of about \$ 258 million and the savings could be as high as \$ 333 million -- and these benefits are all realized in the year of 2001. Similar road safety and economic benefits will also be realized in each of the years 1996, 1997, 1998, 1999 and 2000 -- with their relative amounts being directly proportional to the magnitude of the seat belt usage rate increase (over that of the 1995 'base year' level of 86.8 %) in each of the years. Although the total benefits to be realized from NORP 1996 - 2001 cannot be determined until the program is completed, it is possible to estimate the 'expected' benefits if the seat belt usage rate is increased to 95 % by the end of the year 2001 and if the overall 8.2 % seat belt usage increase (from 86.8 in 1995 to 95 % in 2001) increases uniformly (i.e., about 1.2 % per year) over the six year period 1996 - 2001. Under this plausible scenario the total number of 'additional' light-duty vehicle occupant lives expected to be saved in collisions that are directly attributable to the increases in seat belt usage rates would be at least 496 and could be as many as 672, and the corresponding figure for the number of injuries prevented would amount to 15,067. These road safety benefits translate into significant economic benefits -- with the total societal cost savings amounting to a minimum of \$ 922 million dollars and possibly as much as \$ 1.2 billion over the NORP 1996 - 2001 program period.

In light of the substantial savings that can be realized due to the 1996 - 2001 NORP, from both a human (lives saved and injuries prevented) and economic (societal cost savings) perspective, it is recommended that programs aimed at increasing and maintaining seat belt usage rates

among the light-duty vehicle motorists be given a 'high' priority. Large investments in the order of 'tens of millions of dollars' in both human and financial resources are far out-weighed by the benefits that can be realized from mounting intensive and effective programs, e.g., public education, enforcement, etc., for realizing a 95 % seat belt usage rate level among light-duty vehicle occupants traveling on Canada's roads and highways.

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