A Study of Truck Collisions with Focus on California SR-60

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We analyze the national truck collision data on fatal, injury, and property-damage-only accidents. Our focus is placed on California state route 60 (SR-60) because of its importance in freight transportation from San Pedro Bay ports to the High Desert. Inferential statistics and forecasting techniques are employed in the analysis of collision data. Our findings show over-involvement of trucks in fatal, injury, and property-damage-only collisions. We also discuss the economic costs and comprehensive costs of collisions, and estimate these costs for truck collisions in SR-60. These estimates could be used in the benefit-cost analysis of exclusive truck roads in Southern California.

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I. INTRODUCTION

An estimated 2.2 million persons suffered transportation-related injuries in 2007 and about 87% of these injuries resulted from highway collisions (Bureau of Transportation Statistics, 2008). The differential in size between trucks and passenger cars creates a psychological-physical barrier between the two. In addition, trucks have slower braking and acceleration rates and lower maneuverability compared to passenger cars. Due to the size and weight factors, truck collisions generally result in more severe damages than collisions between other vehicles. Collisions involving trucks often remain in the public's memory and receive greater publicity.

In an attempt to reduce the frequency and severity of truck collisions, a verity of strategies for truck lanes/roads have been developed and implemented. Among the more aggressive strategies are: (i) restricted truck lanes (RTLs) where trucks are restricted to specified lanes, (ii) dedicated truck lanes (DTLs) where specified lanes are dedicated only to trucks, and (iii) exclusive truck roads (ETRs) where trucks use a road usually separated by barriers or median.

Separating large trucks from passenger cars in ETR implementations could lead to increased highway safety by reducing the number of truck-related collisions. There are short-segment instances of ETRs and DTLs either in-planning or in-operation phase. While ETRs were proposed and rejected for I-81 in Virginia, they are under study for I-70 from Kansas to Ohio, are being contemplated in Chicago, and there is a potential implementation in Tampa, FL. The New Jersey Turnpike, in its four roadway configuration, bars trucks from using the two center roadways but the outer roadways allow mixed flow of trucks and cars. Perhaps the short segments northbound and southbound I-5 in Los Angeles County at the SR-14 split and southbound I-5 in Kern County at the SR-99 junction are the most prominent examples of in-operation ETRs or DTLs on the U.S. freight transportation network. However, even on these segments, passenger cars are not prohibited from using truck-only lanes. Due to the rare implementation of ETRs and DTLs, most of the truck safety studies are based on either simulation models or investigations of RTLs and mixed flow of trucks and other vehicles.

In our study, we will analyze the national truck collision data and compare it with data collected on passenger car and all vehicle collisions. Three types of collisions will be considered: fatal, injury, and property damage only (PDO). After this general analysis, we will focus our attention on truck collisions in a particular segment of California state route 60 (SR-60) as a case study. We chose SR-60 because of its importance in freight transportation from the ports of Los Angeles and Long Beach to High Desert. We will demonstrate how inferential statistics in form of tests of hypothesis and forecasting techniques can be employed in the analysis of collision data. Finally, we will discuss the concepts of economic and comprehensive costs of fatal, injury, and PDO collisions, and will estimate these costs due to truck collisions in SR-60 corridor. These estimates could ultimately be used in the benefit-cost analysis for construction of exclusive truck roads in SR-60 and elsewhere in the country.

II. TRUCK TRAFFIC IN THE NATION

The analyses in this section use the national data provided in the references listed under large truck and bus crash facts (2008), traffic safety facts (2008), and national transportation statistics (2007). We will present an overview of the truck related accidents in the nation over a period of 10 years (1999-2008).

2.1. Fatal Collisions

Table 1 shows the fatality collisions over a 10-year period in the U.S., partitioned into collisions on public traffic ways involving (i) trucks, (ii) passenger cars (including vans, SUVs, and pickup trucks), and (iii) all motor vehicles (including trucks, passenger cars, as well as buses, motorcycles, etc.). The source of the data is the Fatality Analysis Reporting System –FARS (2008), which is maintained by the National Highway Traffic Safety Administration (NHTSA). FARS is recognized as the most reliable national collision database, although it contains information only on fatal collisions. In our report, the terms truck, large truck, and heavy duty trucks are used interchangeably, unless stated otherwise. According to FARS, a large truck is a truck with a gross vehicle weight rating (GVWR) of more than 10,000 pounds.

It should be noted that the top section of Table 1 titled "Trucks" reports fatal collisions involving truck-truck, truck-car, truck-other vehicles, as well as single trucks. The middle section titled "Passenger Cars" reports fatal collisions involving car-car, car-truck, car-other vehicles, as well as single cars. This implies that truck-car collisions have been counted in both sections of the table. The "All Vehicles" section covers trucks, passenger cars, and all other vehicles collisions.

As the table shows, over the 10-year period the average miles traveled per truck is 26.2 thousand miles compared to 12.1 thousand miles for passenger cars. (It is important to note that approximately 22% of large trucks are combination trucks carrying 20, 40, or 56 feet containers; for these trucks the average VMT is more than 60,000 miles per year.) If fatal collision occurs, the average fatality per truck collision is 1.16, while that of passenger car collisions is 1.12. However, it should be noted that the average occupant fatality for passenger cars (0.91) is significantly higher than the occupant fatality for trucks (0.17). This could be expected due to the size and sturdiness of trucks compared to cars. We should note that in Table 1, in vehicle/crash column for “Truck” section, only the number of trucks in collision were reported, whereas for passenger cars and all vehicles, the total number of vehicles involved per crash were reported.

TABLE 1. TRUCKS, PASSENGER CARS, AND ALL VEHICLES FATALITY COLLISIONS IN THE US: 1999-2008.

Year	Fatal Crashes	Vehicles Involved	Occupant Fatalities	Total Fatalities	Million VMT (MVMT)	Million Vehicles Registered	1000 Miles / Vehicle	Vehicle / Crash	Occupant Fatalities / Crash	Total Fatalities / Crash	Fatal Crashes / 100 MVMT	Fatalities / 100 MVMT	Fatal Crashes / Million Vehicles
Trucks													
1999	4,560	4,920	759	5,380	202,688	7.8	26.0	1.08	0.17	1.18	2.25	2.65	585.37
2000	4,573	4,995	754	5,282	205,520	8.0	25.6	1.09	0.16	1.16	2.23	2.57	570.20
2001	4,451	4,823	708	5,111	209,032	7.9	26.6	1.08	0.16	1.15	2.13	2.45	566.28
2002	4,224	4,587	689	4,939	214,603	7.9	27.1	1.09	0.16	1.17	1.97	2.30	532.66
2003	4,335	4,721	726	5,036	217,917	7.8	28.1	1.09	0.17	1.16	1.99	2.31	558.63
2004	4,478	4,902	766	5,235	220,811	8.2	27.0	1.09	0.17	1.17	2.03	2.37	548.10
2005	4,551	4,951	804	5,240	222,523	8.5	26.2	1.09	0.18	1.15	2.05	2.35	536.67
2006	4,350	4,766	805	5,027	222,513	8.8	25.2	1.10	0.19	1.16	1.95	2.26	493.20
2007	4,204	4,633	805	4,822	227,060	9.0	25.1	1.10	0.19	1.15	1.85	2.12	465.56
2008	3,733	4,066	677	4,229	227,458	9.0	25.2	1.09	0.18	1.13	1.64	1.86	414.32
Average: Trucks							**26.2**	**1.09**	**0.17**	**1.16**	**2.01**	**2.32**	**527.10**
Passenger Cars													
1999	34,163	47,896	32127	38,571	2,470,122	200.0	12.3	1.40	0.94	1.13	1.38	1.56	170.81
2000	34,379	48,300	32225	38,695	2,523,346	203.9	12.4	1.40	0.94	1.13	1.36	1.53	168.60
2001	34,496	48,417	32043	38,725	2,571,539	207.7	12.4	1.40	0.93	1.12	1.34	1.51	166.07
2002	35,123	49,042	32843	39,514	2,624,508	212.0	12.4	1.40	0.94	1.13	1.34	1.51	165.68
2003	34,879	48,861	32271	39,148	2,656,173	216.7	12.3	1.40	0.93	1.12	1.31	1.47	160.93
2004	34,530	48,168	31866	38,759	2,727,054	228.3	11.9	1.39	0.92	1.12	1.27	1.42	151.26
2005	34,837	48,133	31549	38,933	2,749,472	231.9	11.9	1.38	0.91	1.12	1.27	1.42	150.22
2006	34,204	46,671	30686	38,140	2,773,025	234.5	11.8	1.36	0.90	1.12	1.23	1.38	145.85
2007	32,787	44,666	29072	36,460	2,784,738	237.4	11.7	1.36	0.89	1.11	1.18	1.31	138.11
2008	29,415	39,448	25351	32,479	2,724,453	238.3	11.4	1.34	0.86	1.10	1.08	1.19	123.43
Average: Passenger Cars							**12.1**	**1.39**	**0.91**	**1.12**	**1.28**	**1.43**	**154.10**
All Vehicles													
1999	37,140	56,820	35875	41,717	2,691,056	212.7	12.7	1.53	0.97	1.12	1.38	1.55	174.62
2000	37,526	57,594	36348	41,945	2,746,925	217.0	12.7	1.53	0.97	1.12	1.37	1.53	172.91
2001	37,862	57,918	36440	42,196	2,797,287	221.2	12.6	1.53	0.96	1.11	1.35	1.51	171.14
2002	38,491	58,426	37375	43,005	2,855,508	225.7	12.7	1.52	0.97	1.12	1.35	1.51	170.56
2003	38,477	58,877	37341	42,884	2,890,450	230.6	12.5	1.53	0.97	1.11	1.33	1.48	166.83
2004	38,444	58,729	37304	42,836	2,964,788	243.0	12.2	1.53	0.97	1.11	1.30	1.44	158.20
2005	39,252	59,751	37727	43,510	2,989,430	247.4	12.1	1.52	0.96	1.11	1.31	1.46	158.65
2006	38,648	58,302	37001	42,708	3,014,371	250.8	12.0	1.51	0.96	1.11	1.28	1.42	154.07
2007	37,435	56,430	35751	41,259	3,032,399	254.4	11.9	1.51	0.96	1.10	1.23	1.36	147.15
2008	34,017	50,598	32031	37,261	2,973,509	255.9	11.6	1.49	0.94	1.10	1.14	1.25	132.92
Average: All Vehicles							**12.3**	**1.52**	**0.96**	**1.11**	**1.30**	**1.45**	**160.70**
Ratio: Truck/Passenger Car										**1.03**	**1.57**	**1.63**	**3.42**

On the average, there were 1.09 trucks involved in each truck fatal collision. To find the total number of vehicles involved in truck related collisions, we checked several other sources such as NHTSA, but did not succeed in establishing a universally referenced and accepted number. However, to provide an estimate, we have used the data available at the Motor Carrier Management Information System (MCMIS) Crash File maintained by Federal Motor Carrier Safety Administration (FMCSA). For instance, using the file’s 2008 data, at least one in-transport-vehicle was involved in 75% for fatal, 80% for injury, and 70% for PDO collisions, respectively. Therefore, the minimal number of vehicles involved in truck related fatal collisions was 1.75 compared to 1.34 for passenger cars and 1.49 for all vehicles. Over the ten year period, the average number of vehicles involved in passenger car collisions, including those involving trucks with passenger cars, was 1.39.

The average number of fatal collisions per 10^8 vehicle miles traveled (VMT) is 2.01 for trucks, while for passenger cars it is 1.28, indicating an over-involvement rate of about 57% for trucks. The average fatality per 10^8 miles traveled is 2.32 for trucks, while for passenger cars it is 1.43, indicating an over-involvement rate of about 63% for trucks. The average fatal collision per million trucks is 527, while for passenger cars it is 154. It appears that a truck carries about 3.42 times risk of being involved in a fatal accident than a car.

2.2. Injury and Property Damage Only Collisions

Table 2 and Table 3 show injury and PDO collisions, respectively, using the same format as Table 1. The source for injury and PDO collisions is General Estimates System (GES), which is also maintained by NHTSA. GES provides national estimates based on nationally representative samples of all police-reported fatal, injury, and PDO collisions. GES definition of large trucks is the same as that of FARS. As Table 2 shows, while injury collisions per vehicle registered is 21% higher for trucks than passenger cars, the other ratios provide no indication of over-involvement of trucks in injury collisions. Indeed the number of injury collisions as well as the number of injuries per mile traveled is significantly less for trucks. Comparing these results with Table 1 findings, one can conclude that truck collisions leads to more fatalities than injuries.

TABLE 2. TRUCKS, PASSENGER CARS, AND ALL VEHICLES INJURY COLLISIONS IN THE US: 1999-2008.

Year	Injury Crashes	Vehicles Involved	Persons Injured	Million VMT (MVMT)	Million Vehicles Registered	Vehicle / Crash	Injured / Crash	Injury Crashes / 100 MVMT	Injuries / 100 MVMT	Injury Crashes / 1000 Vehicles
Trucks										
1999	95,000	101,000	142,000	202,688	7.8	1.06	1.49	46.87	70.06	12.20
2000	96,000	101,000	140,000	205,520	8.0	1.05	1.46	46.71	68.12	11.97
2001	86,000	90,000	131,000	209,032	7.9	1.05	1.52	41.14	62.67	10.94
2002	90,000	94,000	130,000	214,603	7.9	1.04	1.44	41.94	60.58	11.35
2003	85,000	89,000	122,000	217,917	7.8	1.05	1.44	39.01	55.98	10.95
2004	83,000	87,000	116,000	220,811	8.2	1.05	1.40	37.59	52.53	10.16
2005	78,000	82,000	114,000	222,523	8.5	1.05	1.46	35.05	51.23	9.20
2006	77,000	80,000	106,000	222,513	8.8	1.04	1.38	34.60	47.64	8.73
2007	72,000	76,000	101,000	227,060	9.0	1.06	1.40	31.71	44.48	7.97
2008	64,000	66,000	90,000	227,458	9.0	1.03	1.41	28.14	39.57	7.10
Average for Trucks						**1.05**	**1.44**	**38.3**	**55.3**	**10.1**
Passenger Cars										
1999	2,005,000	3,603,000	3,175,000	2,470,122	200.0	1.80	1.58	81.17	128.54	10.02
2000	2,017,000	3,605,000	3,123,000	2,523,346	203.9	1.79	1.55	79.93	123.76	9.89
2001	1,954,000	3,496,000	2,974,000	2,571,539	207.7	1.79	1.52	75.99	115.65	9.41
2002	1,877,000	3,346,000	2,863,000	2,624,508	212.0	1.78	1.53	71.52	109.09	8.85
2003	1,873,000	3,362,000	2,828,000	2,656,173	216.7	1.79	1.51	70.51	106.47	8.64
2004	1,802,000	3,236,000	2,718,000	2,727,054	228.3	1.80	1.51	66.08	99.67	7.89
2005	1,754,000	3,102,000	2,625,000	2,749,472	231.9	1.77	1.50	63.79	95.47	7.56
2006	1,681,000	2,995,000	2,500,000	2,773,025	234.5	1.78	1.49	60.62	90.15	7.17
2007	1,642,000	2,871,000	2,412,000	2,784,738	237.4	1.75	1.47	58.96	86.61	6.92
2008	1,561,000	2,719,000	2,266,000	2,724,453	238.3	1.74	1.45	57.30	83.17	6.55
Average for Trucks						**1.78**	**1.51**	**68.6**	**103.9**	**8.3**
All Vehicles										
1999	2,054,000	3,773,000	3,236,000	2,691,056	212.7	1.84	1.58	76.33	120.25	9.66
2000	2,070,000	3,783,000	3,189,000	2,746,925	217.0	1.83	1.54	75.36	116.09	9.54
2001	2,003,000	3,663,000	3,033,000	2,797,287	221.2	1.83	1.51	71.61	108.43	9.05
2002	1,929,000	3,520,000	2,926,000	2,855,508	225.7	1.82	1.52	67.55	102.47	8.55
2003	1,925,000	3,536,000	2,889,000	2,890,450	230.6	1.84	1.50	66.60	99.95	8.35
2004	1,862,000	3,415,000	2,788,000	2,964,788	243.0	1.83	1.50	62.80	94.04	7.66
2005	1,816,000	3,287,000	2,699,000	2,989,430	247.4	1.81	1.49	60.75	90.28	7.34
2006	1,746,000	3,181,000	2,575,000	3,014,371	250.8	1.82	1.47	57.92	85.42	6.96
2007	1,711,000	3,064,000	2,491,000	3,032,399	254.4	1.79	1.46	56.42	82.15	6.73
2008	1,630,000	2,894,000	2,346,000	2,973,509	255.9	1.78	1.44	54.82	78.90	6.37
Average for Trucks						**1.82**	**1.50**	**65.0**	**97.8**	**8.0**
Ratio: Truck/Passenger Car							**0.95**	**0.56**	**0.53**	**1.21**

Table 3 shows the PDO collision data. While the PDO collisions per vehicle is 108% higher for trucks than passenger cars, PDO collisions per mile is 4% more for passenger cars. This result was expected since the average truck miles traveled per year was 26.2 thousand compared to 12.1 thousand for passenger cars.

TABLE 3. TRUCKS, PASSENGER CARS, AND ALL VEHICLES PDO COLLISIONS IN THE US: 1999-2008.

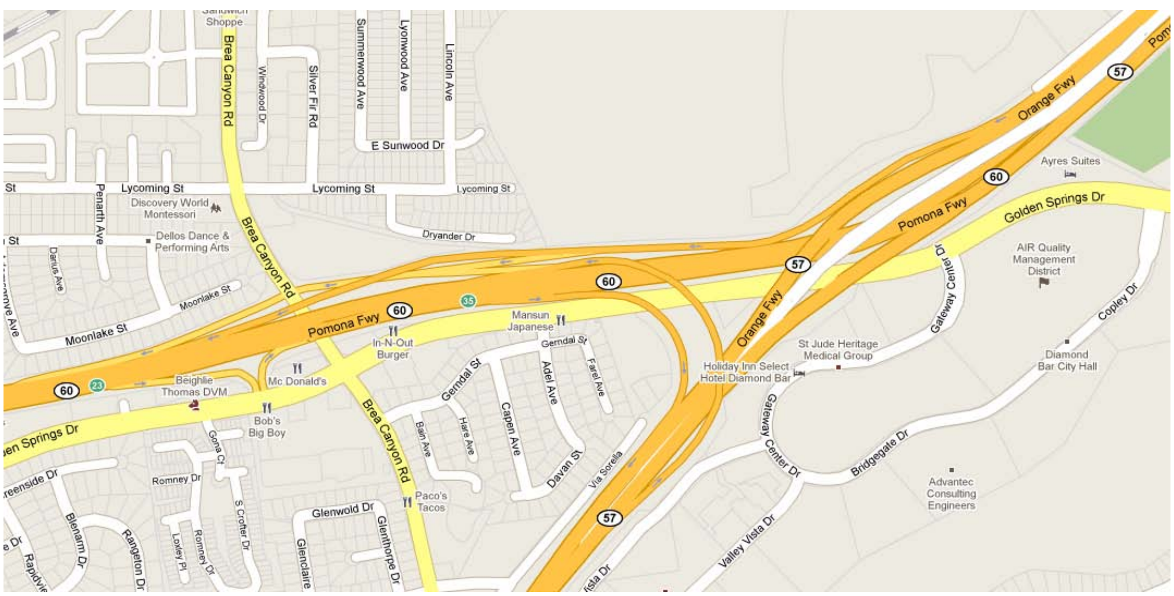
Year	PDO Crashes	Vehicles Involved	Million VMT (MVMT)	Million Vehicles Registered	Vehicle / Crash	PDO Crashes / 100 MVMT	PDO Crashes / 1000 Vehicles
Trucks							
1999	353,000	369,000	202,688	7.8	1.05	174.16	45.31
2000	337,000	351,000	205,520	8.0	1.04	163.97	42.02
2001	319,000	335,000	209,032	7.9	1.05	152.61	40.59
2002	322,000	336,000	214,603	7.9	1.04	150.04	40.61
2003	347,000	363,000	217,917	7.8	1.05	159.23	44.72
2004	312,000	324,000	220,811	8.2	1.04	141.30	38.19
2005	341,000	354,000	222,523	8.5	1.04	153.24	40.21
2006	287,000	300,000	222,513	8.8	1.05	128.98	32.54
2007	317,000	333,000	227,060	9.0	1.05	139.61	35.11
2008	297,000	309,000	227,458	9.0	1.04	130.57	32.96
Average for Trucks					**1.04**	**149.4**	**39.2**
Passenger Cars							
1999	4,058,000	6,961,000	2,470,122	200.0	1.72	164.28	20.29
2000	4,151,000	7,088,000	2,523,346	203.9	1.71	164.50	20.36
2001	4,168,000	7,079,000	2,571,539	207.7	1.70	162.08	20.07
2002	4,228,000	7,199,000	2,624,508	212.0	1.70	161.10	19.94
2003	4,230,000	7,160,000	2,656,173	216.7	1.69	159.25	19.52
2004	4,170,000	7,102,000	2,727,054	228.3	1.70	152.91	18.27
2005	4,174,000	7,088,000	2,749,472	231.9	1.70	151.81	18.00
2006	4,084,000	6,979,000	2,773,025	234.5	1.71	147.28	17.41
2007	4,141,000	7,022,000	2,784,738	237.4	1.70	148.70	17.44
2008	4,027,000	6,779,000	2,724,453	238.3	1.68	147.81	16.90
Average for Trucks					**1.70**	**156.0**	**18.8**
All Vehicles							
1999	4,188,000	7,402,000	2,691,056	212.7	1.77	155.63	19.69
2000	4,286,000	7,510,000	2,746,925	217.0	1.75	156.03	19.75
2001	4,282,000	7,480,000	2,797,287	221.2	1.75	153.08	19.36
2002	4,348,000	7,608,000	2,855,508	225.7	1.75	152.27	19.27
2003	4,365,000	7,594,000	2,890,450	230.6	1.74	151.01	18.93
2004	4,281,000	7,489,000	2,964,788	243.0	1.75	144.39	17.62
2005	4,304,000	7,511,000	2,989,430	247.4	1.75	143.97	17.40
2006	4,189,000	7,345,000	3,014,371	250.8	1.75	138.97	16.70
2007	4,275,000	7,431,000	3,032,399	254.4	1.74	140.98	16.80
2008	4,146,000	7,166,000	2,973,509	255.9	1.73	139.43	16.20
Average for Trucks					**1.75**	**147.6**	**18.2**
Ratio: Truck/Passenger Car					**0.61**	**0.96**	**2.08**

III. ANALYSIS OF TRUCK TRAFFIC IN CALIFORNIA STATE ROUTE 60

In this section, we will focus on truck collision over a 37 mile segment along California SR-60 between Interstate freeways I710 and I15. State Route 60 truck traffic is of particular importance since it connects ports of Los Angeles and Long Beach to the High Desert. We will concentrate on the detailed collision and victim data for the 37-mile segment of the corridor over a period of ten years from 1999 to 2008. We will show how inferential statistics and forecasting techniques can be employed to analyze truck collision data.

The most crucial safety issue along the SR-60 corridor is the SR-57 merge due to the short weaving distances. Weaving areas are segments of freeway formed by a divergent area that closely follows a merge area. Operationally, weaving areas are of concern because the "crossing" of vehicles creates turbulence in the traffic streams. When trucks form a large portion of the traffic volume and are restricted to the rightmost lanes, a physical barrier composed of trucks can form next to the weaving areas. Trucks limit the visibility and maneuverability of smaller vehicles attempting to enter and exit the freeway system. An indication of the barrier effect is an over-involvement of trucks in weaving area collisions, rear-end collisions, and side collisions. Forcing trucks to merge in inadequate distances increases the potential for collisions due to their size and operational characteristics. The combination of speed limits that are ten miles slower for trucks, and restricting trucks to the right lanes increases the potential for car-truck collisions. Moreover, truck lane restriction creates a barrier effect in merging areas. Building an exclusive truck road for SR-60 would potentially improve the corridor's safety. The underlying hypothesis is that physically separating heavy trucks from light vehicles will improve highway safety by reducing the number of truck-related collisions. An ETR could minimize the car-truck interaction, diminish the merging difficulties, and reduce the speed differential on the freeway. Furthermore, the exclusive lanes would be designed to alleviate the weaving conditions in the SR-60/SR-57 merged segment. Figure 1 shows the map of the merge segment of SR-60 and SR-57.

FIGURE 1. MERGE SEGMENT OF SR-60 AND SR-57.



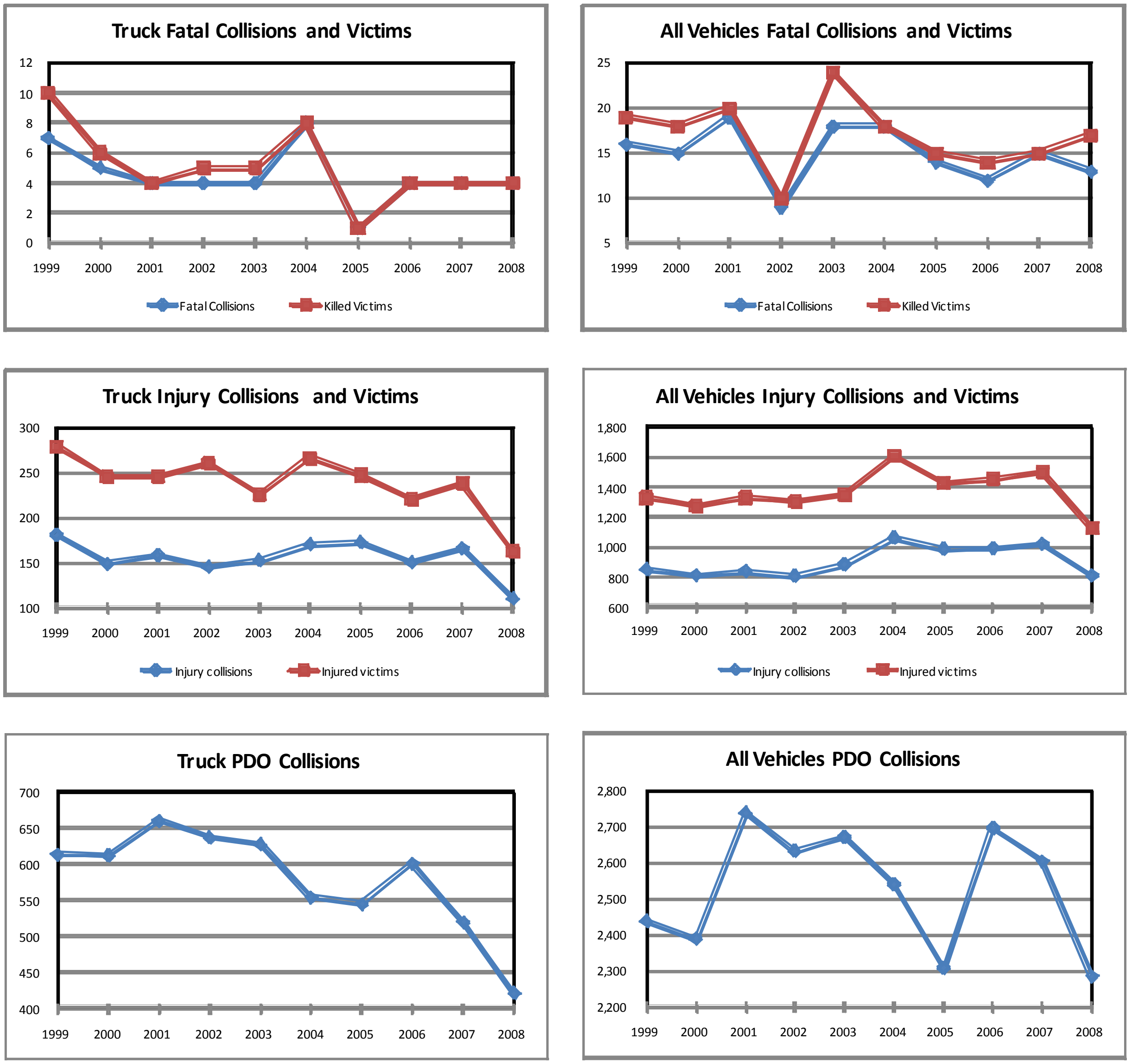
3.1. Truck Collision in SR-60

In support from the staff of Statewide Integrated Traffic Records System (SWITRS) maintained by California Highway Patrol, we extracted fatality, injury, and PDO collision data for the SR-60 corridor. Information obtained from the SWITRS database is kept on a timesequence basis and enables assessment of the percentage of collisions in which heavy-duty trucks have been involved. These data are shown in Table 4 rows (1) for All Vehicles and (2) for All Trucks throughout all segments of the table. However, we later realized that in SWITRS, pickup trucks are also included in trucks category, while according to Federal Highway Administration (FHWA) definition, pickup trucks are considered as passenger cars. Subsequently, in collaboration with CalTrans district 8, we were able to obtain the data for large truck collisions on SR-60. The large truck collision data are shown in rows (3) throughout Table 4. The ratio of all truck to all vehicle collisions is shown as (2)/(1)%, while the ratio for large trucks to all vehicle is shown as (3)/(1) %. Graphical comparison of all trucks and all vehicles collisions are presented in Figure 2.

TABLE 4. FATALITY, INJURY AND PDO DATA FOR ALL VEHICLES AND TRUCKS, SR-60, 1999-2008.

	Vehicle Type	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Average**
VMT (millions)	(1)All Vehicles	2,962	2,985	3,162	3,262	3,228	3,203	3,178	3,189	3,213	3,119	3,150
	(2) All Trucks	329	321	308	324	336	318	329	303	312	308	319
	(2)/(1) %	11.1%	10.7%	9.7%	9.9%	10.4%	9.9%	10.3%	9.5%	9.7%	9.9%	10.1%
	(3) Large Trucks	229	242	227	245	254	241	227	226	221	208	232
	(3)/(1) %	**8%**	**8%**	**7%**	**8%**	**8%**	**8%**	**7%**	**7%**	**7%**	**7%**	**7%**
Collisions	(1)All Vehicles	3,301	3,220	3,595	3,448	3,575	3,618	3,304	3,702	3,641	3,109	3,451
	(2) All Trucks	803	767	824	787	785	734	719	757	691	536	740
	(2)/(1) %	24.3%	23.8%	22.9%	22.8%	22.0%	20.3%	21.8%	20.4%	19.0%	17.2%	21.5%
	(3) Large Trucks	702	674	713	719	691	660	644	664	624	480	657
	(3)/(1) %	**21%**	**21%**	**20%**	**21%**	**19%**	**18%**	**19%**	**18%**	**17%**	**15%**	**19%**
Fatal Collisions	(1)All Vehicles	16	15	19	9	18	18	14	12	15	13	15
	(2) All Trucks	7	5	4	4	4	8	1	4	4	4	5
	(2)/(1) %	43.8%	33.3%	21.1%	44.4%	22.2%	44.4%	7.1%	33.3%	26.7%	30.8%	30.7%
	(3) Large Trucks	5	5	3	4	3	6	1	4	4	3	4
	(3)/(1) %	**31%**	**33%**	**16%**	**44%**	**17%**	**33%**	**7%**	**33%**	**27%**	**23%**	**26%**
Killed Victims	(1)All Vehicles	19	18	20	10	24	18	15	14	15	17	17
	(2) All Trucks	10	6	4	5	5	8	1	4	4	4	5
	(2)/(1) %	52.6%	33.3%	20.0%	50.0%	20.8%	44.4%	6.7%	28.6%	26.7%	23.5%	30.7%
	(3) Large Trucks	5	6	3	5	4	6	1	4	4	3	4
	(3)/(1) %	**26%**	**33%**	**15%**	**50%**	**17%**	**33%**	**7%**	**29%**	**27%**	**18%**	**24%**
Injury Collisions	(1)All Vehicles	846	815	836	805	883	1,058	981	992	1,019	810	905
	(2) All Trucks	182	150	159	146	153	171	173	151	167	111	156
	(2)/(1) %	21.5%	18.4%	19.0%	18.1%	17.3%	16.2%	17.6%	15.2%	16.4%	13.7%	17.4%
	(3) Large Trucks	164	141	146	134	139	163	164	144	153	101	145
	(3)/(1) %	**19%**	**17%**	**17%**	**17%**	**16%**	**15%**	**17%**	**15%**	**15%**	**12%**	**16%**
Injured	(1)All Vehicles	1,328	1,274	1,327	1,301	1,347	1,607	1,429	1,451	1,498	1,131	1,369
	(2) All Trucks	280	246	246	261	226	267	248	221	239	163	240
	(2)/(1) %	21.1%	19.3%	18.5%	20.1%	16.8%	16.6%	17.4%	15.2%	16.0%	14.4%	17.5%
	(3) Large Trucks	250	232	221	248	207	255	235	214	222	148	223
	(3)/(1) %	**19%**	**18%**	**17%**	**19%**	**15%**	**16%**	**16%**	**15%**	**15%**	**13%**	**16%**
PDO Collisions	(1)All Vehicles	2,439	2,390	2,740	2,634	2,674	2,542	2,309	2,698	2,607	2,286	2,532
	(2) All Trucks	614	612	661	637	628	555	545	602	520	421	580
	(2)/(1) %	25.2%	25.6%	24.1%	24.2%	23.5%	21.8%	23.6%	22.3%	19.9%	18.4%	22.9%
	(3) Large Trucks	533	528	564	581	549	491	479	516	467	376	508
	(3)/(1) %	**22%**	**22%**	**21%**	**22%**	**21%**	**19%**	**21%**	**19%**	**18%**	**16%**	**20%**

FIGURE 2. SCHEMATIC REPRESENTATION OF FATALITY, INJURY AND PDO DATA FOR ALL MOTOR VEHICLES AND TRUCKS, SR-60, 1999-2008.



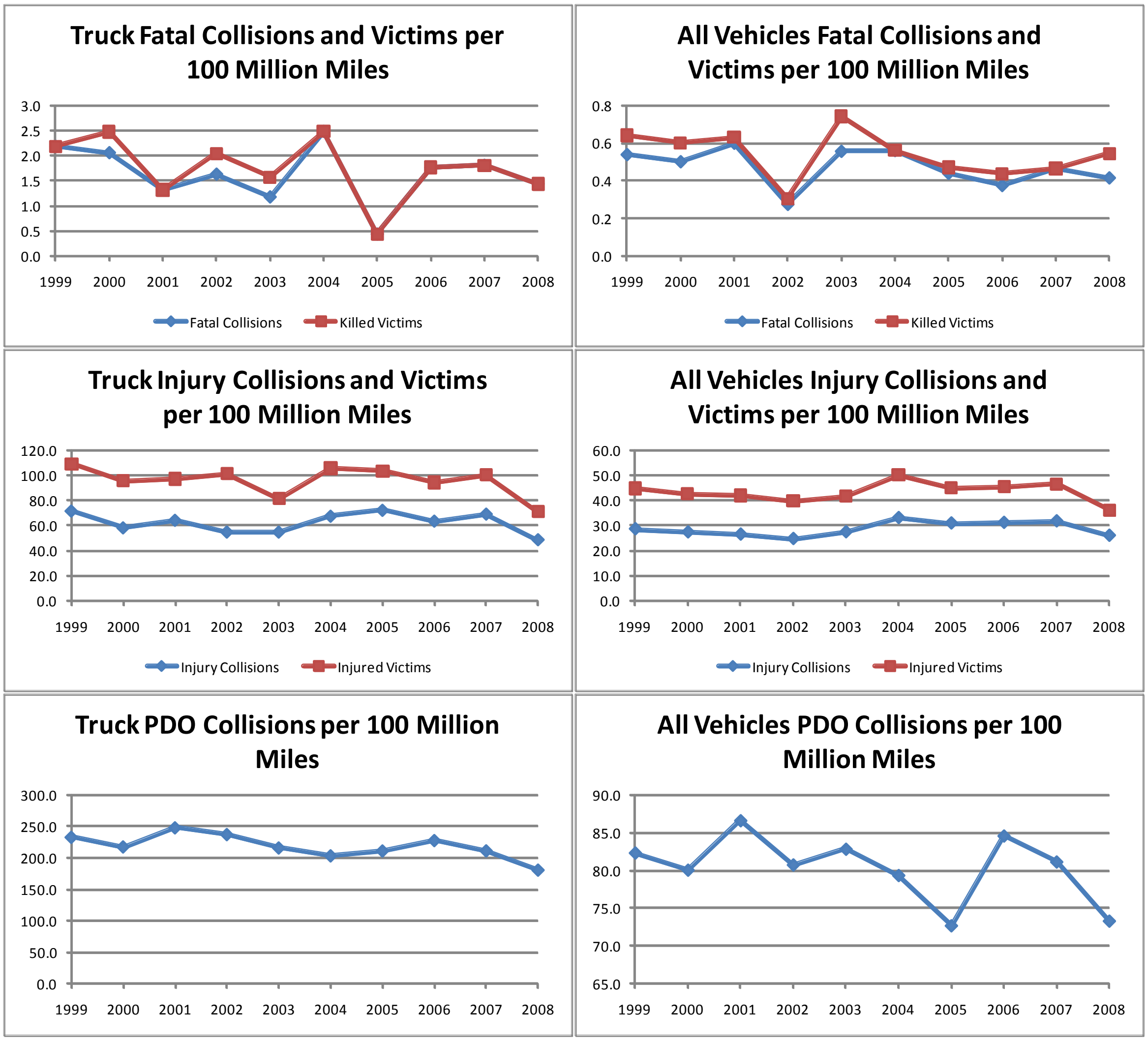
It should be noted that the truck miles traveled data was not available neither for SR-60 nor for Southern California Freeways. Therefore, the research team used the AADT (annual average daily traffic) data for mixed flow and truck flow on each segment of SR-60 available at CalTrans traffic count site. Based on these segment-to-segment AADT and AADTT (annual average daily truck traffic) data as well as the length of each segment, we calculated VMT for all vehicles and large trucks in the corridor for years 1999-2008. The relative collision data per 10^8 miles travelled are shown in Table 5.

TABLE 5. FATALITY, INJURY AND PDO DATA PER 10^8 MILES TRAVELLED FOR ALL VEHICLES AND TRUCKS, SR-60, 1999-2008.

	Vehicle Type	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Average
VMT (millions)	(1)All Vehicles	2,962	2,985	3,162	3,262	3,228	3,203	3,178	3,189	3,213	3,119	3,150
	(2) All Trucks	329	321	308	324	336	318	329	303	312	308	319
	(2)/(1) %	**11.1%**	**10.7%**	**9.7%**	**9.9%**	**10.4%**	**9.9%**	**10.3%**	**9.5%**	**9.7%**	**9.9%**	**10.1%**
	(3) Large Trucks	229	242	227	245	254	241	227	226	221	208	232
	(3)/(1) %	**8%**	**8%**	**7%**	**8%**	**8%**	**8%**	**7%**	**7%**	**7%**	**7%**	**7%**
Collisions	(1)All Vehicles	111.4	107.9	113.7	105.7	110.8	112.9	104.0	116.1	113.3	99.7	109.5
	(2) All Trucks	244.1	239.2	267.3	242.8	233.5	230.8	218.8	249.9	221.6	173.9	232.2
	(2)/(1) %	**2.2**	**2.2**	**2.4**	**2.3**	**2.1**	**2.0**	**2.1**	**2.2**	**2.0**	**1.7**	**2.1**
	(3) Large Trucks	307.0	278.0	313.9	293.9	272.1	273.6	284.1	293.4	282.7	230.8	283.0
	(3)/(1) %	**2.8**	**2.6**	**2.8**	**2.8**	**2.5**	**2.4**	**2.7**	**2.5**	**2.5**	**2.3**	**2.6**
Fatal Collisions	(1)All Vehicles	0.5	0.5	0.6	0.3	0.6	0.6	0.4	0.4	0.5	0.4	0.5
	(2) All Trucks	2.1	1.6	1.3	1.2	1.2	2.5	0.3	1.3	1.3	1.3	1.4
	(2)/(1) %	**3.9**	**3.1**	**2.2**	**4.5**	**2.1**	**4.5**	**0.7**	**3.5**	**2.7**	**3.1**	**3.0**
	(3) Large Trucks	2.2	2.1	1.3	1.6	1.2	2.5	0.4	1.8	1.8	1.4	1.6
	(3)/(1) %	**4.0**	**4.1**	**2.2**	**5.9**	**2.1**	**4.4**	**1.0**	**4.7**	**3.9**	**3.5**	**3.6**
Killed Victims	(1)All Vehicles	0.6	0.6	0.6	0.3	0.7	0.6	0.5	0.4	0.5	0.5	0.5
	(2) All Trucks	3.0	1.9	1.3	1.5	1.5	2.5	0.3	1.3	1.3	1.3	1.6
	(2)/(1) %	**4.7**	**3.1**	**2.1**	**5.0**	**2.0**	**4.5**	**0.6**	**3.0**	**2.7**	**2.4**	**3.0**
	(3) Large Trucks	2.2	2.5	1.3	2.0	1.6	2.5	0.4	1.8	1.8	1.4	1.8
	(3)/(1) %	**3.4**	**4.1**	**2.1**	**6.7**	**2.1**	**4.4**	**0.9**	**4.0**	**3.9**	**2.6**	**3.4**
Injury Collisions	(1)All Vehicles	28.6	27.3	26.4	24.7	27.4	33.0	30.9	31.1	31.7	26.0	28.7
	(2) All Trucks	55.3	46.8	51.6	45.0	45.5	53.8	52.6	49.8	53.6	36.0	49.0
	(2)/(1) %	**1.9**	**1.7**	**2.0**	**1.8**	**1.7**	**1.6**	**1.7**	**1.6**	**1.7**	**1.4**	**1.7**
	(3) Large Trucks	71.7	58.2	64.3	54.8	54.7	67.6	72.4	63.6	69.3	48.6	62.5
	(3)/(1) %	**2.5**	**2.1**	**2.4**	**2.2**	**2.0**	**2.0**	**2.3**	**2.0**	**2.2**	**1.9**	**2.2**
Injured	(1)All Vehicles	44.8	42.7	42.0	39.9	41.7	50.2	45.0	45.5	46.6	36.3	43.5
	(2) All Trucks	85.1	76.7	79.8	80.5	67.2	83.9	75.5	73.0	76.6	52.9	75.1
	(2)/(1) %	**1.9**	**1.8**	**1.9**	**2.0**	**1.6**	**1.7**	**1.7**	**1.6**	**1.6**	**1.5**	**1.7**
	(3) Large Trucks	109.3	95.7	97.3	101.4	81.5	105.7	103.7	94.5	100.6	71.2	96.1
	(3)/(1) %	**2.4**	**2.2**	**2.3**	**2.5**	**2.0**	**2.1**	**2.3**	**2.1**	**2.2**	**2.0**	**2.2**
PDO Collisions	(1)All Vehicles	82.3	80.1	86.6	80.8	82.8	79.4	72.7	84.6	81.1	73.3	80.4
	(2) All Trucks	186.7	190.8	214.4	196.5	186.8	174.5	165.8	198.7	166.7	136.6	181.8
	(2)/(1) %	**2.3**	**2.4**	**2.5**	**2.4**	**2.3**	**2.2**	**2.3**	**2.3**	**2.1**	**1.9**	**2.3**
	(3) Large Trucks	233.1	217.8	248.3	237.5	216.2	203.6	211.3	228.0	211.5	180.8	218.8
	(3)/(1) %	**2.8**	**2.7**	**2.9**	**2.9**	**2.6**	**2.6**	**2.9**	**2.7**	**2.6**	**2.5**	**2.7**

The 10 year collision averages for SR-60 corridor are shown in the last column of Table 5. The total number of collisions per mile traveled for large trucks is 2.6 times of that of all vehicles. The total number of fatal collisions per mile traveled for large trucks is 3.6 times that of all vehicles. The number of killed victims per mile traveled for large trucks is 3.4 times that of all vehicles. The total number of injury collisions and the number of injured per mile traveled for large trucks are both 2.2 times that of all vehicles. Property damage for large truck collisions is 2.7 times that of all vehicles. It should be mentioned that the real collision ratios of large trucks to non-truck vehicles are even greater than the above ratios, since truck collisions are already included in all vehicle collisions. Graphical comparison of large truck and all vehicle collisions per 10^8 VMT are presented in Figure 3.

FIGURE 3. SCHEMATIC REPRESENTATION OF FATALITY, INJURY AND PDO DATA PER 10^8 MILES TRAVELLED FOR ALL MOTOR VEHICLES AND LARGE TRUCKS, SR-60, 1999-2008.



3.2. Statistical Analysis of Truck Collision

To check if the difference between the mean values of truck collision and all vehicles collisions per mile travel is statistically significant, we conduct a set of one-tail hypothesis tests. The objective is to find if there is enough evidence to reject the hypothesis of "a specific collision rate for truck is smaller than or equal to the rate for all vehicles." To provide a concrete example, one of these tests of hypothesis is stated as follows:

H_0: μ(truck collision rate) ≤ μ(all vehicles collision rate)

H_a: μ(truck collision rate) > μ(all vehicles collision rate)

The null hypothesis (H_0) states that the average (mean or expected value) of trucks' collision rate is less than or equal to the average of all vehicles' collision rate. The alternative hypothesis (H_a) states that the average trucks' collision rate is greater than the average of all vehicles' collision rate. By rejecting the null hypothesis, one can conclude that the alternative hypothesis is true with a specified confidence level. Since the variances of the two populations (the truck collision rate and the all vehicles collision rate) are unknown, we must use a *t*- test. Based on this test, the resulting *p-value* is $2.3(10^{-10})$, therefore the null hypothesis is rejected based on a confidence level greater than 99.9%. Now we conduct a set of additional tests of hypotheses regarding the other rates. As Table 6 shows, all null hypotheses are rejected with confidence levels greater that 99.9%.

Noting that truck collisions are already included in the all vehicle collisions, the following findings are supported with even higher level of confidence.

μ(truck collision rate) > μ(passenger cars collision rate)
μ(truck fatal collision rate) > μ(passenger cars fatal collision rate)
μ(truck killed victims rate) > μ(passenger cars killed victims rate)
μ(truck injury collision rate) > μ(passenger cars injury collision rate)
μ(truck injured victims rate) > μ(passenger cars injured victims rate)
μ(truck PDO collision rate) > μ(passenger cars PDO collision rate)

TABLE 6. TESTS OF HYPOTHESIS RESULTS COMPARING TRUCK COLLISION RATES WITH ALL VEHICLES RATES.

Null Hypothesis	t-value	p-value
μ(truck collision rate) ≤ μ(passenger cars collision rate)	23.40	2.31E-10
μ(truck fatal collision rate) ≤ μ(passenger cars fatal collision rate)	6.23	4.88E-05
μ(truck killed victims rate) ≤ μ(passenger cars killed victims rate)	6.15	5.45E-05
μ(truck injury collision rate) ≤ μ(passenger cars injury collision rate)	12.46	3.94E-08
μ(truck injured victims rate) ≤ μ(passenger cars injured victims rate)	13.61	1.57E-08
μ(truck PDO collision rate) ≤ μ(passenger cars PDO collision rate)	22.28	3.73E-10

To obtain more concrete results, we conducted an additional set of hypothesis tests such as:

H_0: μ(truck collision rate) ≤ μ(all vehicles collision rate) + K
H_a: μ(truck collision rate) > μ(all vehicles collision rate) +K

The objective of this test is to find if there is significant evidence in support of the hypotheses that the truck collision rate is K units greater than the all vehicles collision rate. By gradual increase of the value of K in the above hypotheses, one could find the maximum value for which the null hypothesis can still be rejected. As Table 5 shows, μ(truck collision rate) and μ(all vehicles collision rate) are 232.2 and 109.5 per 10^8 miles, respectively. The largest values of K which still makes it possible to reject the null hypothesis of “ H_0: μ(truck collision rate) ≤ μ(all vehicles collision rate) + K” with more than 99% confidence turned out to be 154. This value is 140% of 109.5 which implies: Truck collision rate is 140% higher than All vehicles collision rate.

Following the same procedure, the available data enabled us to make the following conclusions regarding collisions in SR-60 with more than 99% confidence level:

Truck-fatal collision rate is 352% higher than All vehicles-fatal collision rate.
Truck-killed victims rate is 325% higher than All vehicles-killed victims rate.
Truck-injury collision rate is 143% higher than All vehicles-injury collision rate.
Truck-injured victims rate is 97% higher than All vehicles-injured victims rate.
Truck PDO collision rate is 194% higher than All vehicles PDO collision rate.

3.3. Forecasting for SR-60

The objective of this section is to show how basic forecasting techniques can be used to make prediction for key variables involved in truck collision analysis. We conducted three types of time-series forecasting: linear regression, exponential smoothing, and trend adjusted exponential smoothing for large truck data for SR-60 from 1999 to 2008. The collision data for large trucks per 10^8 miles traveled on SR-60 are shown in Table 7.

TABLE 7. LARGE TRUCK COLLISIONS DATA PER 10^8 VMT ON SR-60.

	VMT(millions)	Collisions	Fatal Collis	Killed Victs	Injury Collis	Injured	PDO
1999	228.7	307.0	2.2	2.2	71.7	109.3	233.1
2000	242.4	278.0	2.1	2.5	58.2	95.7	217.8
2001	227.2	313.9	1.3	1.3	64.3	97.3	248.3
2002	244.7	293.9	1.6	2.0	54.8	101.4	237.5
2003	254.0	272.1	1.2	1.6	54.7	81.5	216.2
2004	241.2	273.6	2.5	2.5	67.6	105.7	203.6
2005	226.6	284.1	0.4	0.4	72.4	103.7	211.3
2006	226.3	293.4	1.8	1.8	63.6	94.5	228.0
2007	220.8	282.7	1.8	1.8	69.3	100.6	211.5
2008	207.9	230.8	1.4	1.4	48.6	71.2	180.8

Given a specific variable such as the number of collisions or the number of injuries we use notation F_t as the forecast for year t and A_t as the actual value. The linear regression forecast for year $t+1$ is stated as $F_{(t+1)} = b_0 + b_1 (t - 1998)$. The values of b_0 and b_1 are calculated and presented in the first two rows of Table 8. The exponential smoothing forecast is stated as

$$F_{t+1} = \alpha A_t + (1-\alpha) F_t \,.$$

The optimal α value minimizing the mean absolute deviation (MAD) is computed and presented in the third row of Table 8.

If N is the number of periods in the moving average, it should be noted that the exponential smoothing and moving average forecasts become equivalent when $\alpha = 2/(N+1)$. Therefore, an exponential smoothing forecast with α = 0.9 (indicated in the third row of Table 8) is equivalent to a 2-period moving average forecast. Similarly, an exponential smoothing forecast with α = 0.1 is equivalent to a moving average forecast with about 19 periods. The smaller the α (i.e., the larger the number of periods in the moving average), the higher the tendency to smooth out the recent fluctuations. Larger values for α (i.e., the smaller the number of periods in the moving average) results in higher responsiveness to recent fluctuations.

TABLE 8. THE OPTIMAL PARAMETERS OF THE THREE FORCASTING PROCEDURES.

	VMT(millions)	Collisions	Fatal Collis	Killed Victs	Injury Collis	Injured	PDO
b0	245.6	309.1	1.9	2.2	64.8	105.8	242.4
b1	-2.5	-4.7	-0.1	-0.1	-0.4	-1.8	-4.3
Optimal Alpha	0.9	0.1	0.1	0.1	0.1	0.1	0.1
Optimal Alpha	0.1	0.1	0.3	0.2	0.3	0.1	0.1
Optimal Beta	0.5	0.4	0.4	0.2	0.2	0.3	0.3

We also applied trend adjusted exponential smoothing in the form of $F_{t+1} = L_t + T_t$, where L_t and T_t are level and trend in period t as defined in Chopra and Meindl (2009).

$$L_{t+1}= \alpha A_t+(1-\alpha)(L_t+T_t)$$
$$T_{t+1}= \beta(L_{t+1} -L_t) +(1- \beta)T_t$$

Assuming the intercept (b_0) and the slope (b_1) of the regression line as level (L_0) and trend (T_0), respectively, the optimal α and β values minimizing MAD are computed and shown in the last two rows of Table 8. The forecast results based on the three approaches for 2009 are shown in Table 9.

TABLE 9. FORECAST RESULTS FOR LARGE TRUCK COLLISIONS IN 2009.

	VMT(millions)	Collisions	Fatal Collis	Killed Victs	Injury Collis	Injured	PDO
Exponential Smoothing	230.0	280.0	1.6	1.7	62.3	95.0	216.3
Linear Regression	218.3	256.8	1.4	1.3	60.2	86.4	195.3
Trend adjusted Exp. Smoothing	212.0	256.0	2.0	2.0	62.0	86.0	198.0

IV. COST OF COLLISIONS

In this section, we estimate collision costs in SR-60 corridor using two estimates proposed in the reports titled Estimating the Costs of Unintentional Injuries by National Safety Council (2008), and Technical Advisory on Motor Vehicle Collision Costs by FHWA Technical Report (1994). Costs have been adjusted to 2008 dollars using the Gross Domestic Product (GDP) index.

4.1 Economic Cost of Truck Collisions

The NSC makes estimates of the average costs of fatal and nonfatal unintentional injuries to illustrate their impact on the nation's economy. The costs are a measure of the dollars spent, as well as the income not received due to loss of wages and productivity, medical expenses, administrative expenses, motor-vehicle damage, and employers' uninsured costs. The NSC estimates for average economic costs in 2008 were: Death ($1,300,000), Nonfatal Disabling Injury ($63,500), and Property Damage Collision- including non-disabling injuries- ($8,300). Motor vehicle injuries by severity may be also categorized as class A, B, and C. The NSC estimates for average economic costs in 2008 for these classes are as follows; A: incapacitating injury ($67,200), B: non-incapacitating evident injury ($21,800), and C: possible injury ($12,300).

Over the past 10 years, truck-related collisions in SR-60 resulted in annual averages of 5.1 killed, 240 injured and 580 instances of damage to property. In other words, for each person killed (at average economic cost of $1,300,000) there were 47 nonfatal injuries (each at $63,500), and 114 property damage collisions (each at $8,300). Therefore, per death basis, the cost of each truck collision (i.e., fatal, nonfatal injury, and property damage) was $5,200,000. Accordingly, the undiscounted average economic cost of large truck collisions over the past ten years on the 37- mile segment of the corridor was around $27 million per year. According to National Safety Council (2008) and FHWA Technical Report (1994), the average economic costs are appropriate for measuring the economic loss to a community, but they do not represent the dollar value of future loss of benefits because they do not include the value of a person's natural desire to live longer or to protect the quality of one's life.

4.2. Comprehensive Cost of Truck Collisions

The economic loss estimates do not include what people are willing to pay for improved safety. As indicated in the above mentioned reports, comprehensive cost (or willingness to pay) is the most common measure of collision expenditures since it includes all cost components and places a dollar value on all of them. The eleven components of the comprehensive cost are: property damage, lost earnings, lost household production, medical costs, emergency services, travel delay, vocational rehabilitation, workplace costs; administrative, legal, and pain costs, as well as depleted quality of life. According to NSC, the average comprehensive costs in 2008 were: death ($4,200,000), incapacitating injury ($214,200), non-incapacitating evident injury ($54,700), possible injury ($26,000), and no injury ($2,400). We have averaged the cost of the three types of injuries stated above, and have assumed the result as the estimated comprehensive cost of an injury. Therefore, for each person killed (at average comprehensive cost of $4,200,000) there were 47 nonfatal injuries (each at $98,300), and 114 property damage collisions (at $8,300, same as economic cost). Therefore, per death basis, the comprehensive cost of each truck collision (i.e., fatal, nonfatal injury, and property damage) was about $9,800,000, which is roughly twice as much as the economic cost. Accordingly, the undiscounted average comprehensive cost of large truck collisions over the past ten years on the 37- mile segment of the corridor was about $50 million per year.

V. CONCLUSION AND DIRECTION OF FUTURE RESEARCH

In this paper, we analyzed the national truck collision data and compared it with data collected on passenger car and all vehicle collisions. Next, we focused our study on California SR-60 because of its importance in freight transportation from the ports of Los Angeles and Long Beach to the High Desert. Our findings show over-involvement of trucks in fatal, injury, and property-damage-only collisions. We then discussed the economic cost and comprehensive cost of these collisions, and estimated truck collision costs in SR-60 corridor. One direction of our future research is to evaluate the impact of exclusive truck roads on freeway traffic mobility. We can also investigate the environmental impacts as well as stakeholders' perceptions of exclusive truck roads. The ultimate goal would be to incorporate the results of these studies into a comprehensive benefit-cost analysis for integration of exclusive truck roads in Southern California's freight transportation network. By comparing the high construction and land acquisition costs with the estimates of the truck collision costs, exclusive truck roads may not be financially feasible. Public justification of all direct/indirect and tangible/intangible benefits may be required to reach the economic feasibility to built excusive truck roads.

Acknowledgement

This study was partially supported by the Leonard Transportation Center, under grant GT 10132, and the College of Business and Economics, California State University, Research Fellow grant. The supports are gratefully acknowledged.

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