Title

California's Freeway Service Patrol Program: FSP Beat Evaluation Model; Methodology and Parameter Estimation (FY 2014-15)

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California's Freeway Service Patrol Program

FSP Beat Evaluation Model; Methodology and Parameter Estimation (FY 2014-15)

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16. Abstract

The Freeway Service Patrol (FSP) is an incident management program implemented by Caltrans, the California Highway Patrol and local partner agencies to quickly detect and assist disabled vehicles and reduce non-recurring congestion along the freeway during peak commute hours. The first FSP program was piloted in Los Angeles, and was later expanded to other regions by state legislation in 1991. As of June 2015, there were fourteen participating FSP Programs operating in California, deploying over 340 tow trucks and covering over 1,800 (center-line) miles of congested California freeways.

The purpose of this research project was to evaluate the effectiveness of the Caltrans FSP program in reducing incident durations and removal of other obstructions that directly contribute to freeway congestion for Caltrans fiscal year 2014-2015. The project provides valuable information to agencies managing the FSP program so that resources are distributed within the various statewide FSP operations in the most efficient and cost-effective manner possible. The tools used and the operational performance measures provided by this research effort will significantly contribute on the ongoing agencies' efforts to improve the efficiency and effectiveness of the FSP program.

This "FSP Beat Evaluation Model; Methodology and Parameter Estimation" report documents the FSP Beat cost effectiveness model development process, including model validation efforts.

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CALIFORNIA'S FREEWAY SERVICE PATROL PROGRAM

FSP Beat Evaluation Model Methodology and Parameter Estimation (FY 2014-15)

Prepared for the California Department of Transportation

Traffic Operations Division

Prepared by:

Institute of Transportation Studies
University of California at Berkeley

February 22, 2016

EXECUTIVE SUMMARY

Freeway Service Patrol (FSP) is an incident management program designed to assist disabled vehicles along congested freeways and reduce non-recurring congestion through quick detection, response, and removal of accidents and other incidents. The program is jointly administered by the California Department of Transportation (Caltrans), the California Highway Patrol (CHP) and local Transportation Planning Organizations (MPOs). Currently, FSP operates on over 190 freeway sites ("beats") across the State with about 365 tow trucks (during a typical weekday peak period) and covers over 1,800 freeway centerline miles of California's most congested freeway segments.

Research studies conducted from 1995 through 1998 by the University of California at Berkeley, as part of the PATH Program, evaluated the effectiveness of FSP on a section of the I-880 freeway (Bay Area "Beat 3"),[1] and a section of I-10 freeway in Los Angeles ("Beat 8").[2] Detailed evaluation studies at these two test sites found; (1) FSP is cost/effective based on extensive field measurements "before" and "after" the FSP deployment; and (2) the benefits of FSP depend on a beat's geometric and traffic characteristics and the frequency and type of assisted incidents.[3] Using these findings, a simple to use spreadsheet based methodology was developed to estimate the benefit/cost (B/C) ratio of each FSP beat using data commonly available to Caltrans and local agency operations staff. The FSP Benefit/Cost model was developed in close collaboration with FSP program partners who reviewed interim study products and participated in user and training workshops. The resulting spreadsheet based beat evaluation model has been used by Caltrans to calculate the B/C ratio of existing FSP beats since year 2000. The FSP models assist in the assessment and better allocation of resources for the FSP program.

During the Fiscal Year 2013-14 update of the FSPE model, a model validation work effort was completed because the previous model validation efforts were outdated. These efforts were facilitated by new and more comprehensive data sources now available, which were not available at the time of the original 1995-1998 validation efforts. The 2013-14 model validation efforts showed that the FSPE model produces vehicular delay saving estimates that are in the range of the non-recurrent (incident) delay estimates obtained from the empirical PeMS and/or INRIX data. The resulting FSPE model validation report is included as Appendix B of this model development report.

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[1] Skabardonis, A., et al (1995), "Freeway Service Patrol Evaluation," PATH Research Report UCB-ITS-PRR-95-5, Institute of Transportation Studies, UC Berkeley. Available on-line: *http://128.32.172.246/pub/pdf/PRR-95-5.pdf.*

[2] Skabardonis, A., Petty, K. et al (1998), "Los Angeles: Freeway Service Patrol Evaluation," PATH Research Report UCB-ITS-PRR-98-31, Institute of Transportation Studies, UC Berkeley. Available online at Web address: *http://www.path.berkeley.edu/%7Eleap/itsdecision_resources/library.html.*

[3] Skabardonis, A., [et. al.], "Freeway Service Patrol Evaluation," California PATH Program, Institute of Transportation Studies, University of California, Berkeley, [1995].

The end products from this work effort and previously completed phases of the FSP research support project are:

- **Improved FSP beat evaluation model:** The FSP evaluation model (FSPE) has been significantly improved by the implementation of time variant traffic directionality factors (D-factors) and/or empirical hourly traffic volume data. The delay estimation models were revised to more reliably estimate delays by improving the queueing model's capacity assumptions and by including additional user selectable run-time options providing more flexibility at run-time. The FSP model can handle multiple lane HOV facilities; previously the model could only handle single lane HOVs. Additionally, the FSPE model can now facilitate beat evaluations where beat configurations include two different sets or groups of FSP tow trucks (for example, regular light-duty tow trucks and service pickup trucks operating on the same beat).

- **Run-time Diagnostic Reports:** User selectable diagnostic reports are available. These reports list the directional hourly traffic volumes (separate tables for mixed-use lanes and for HOV lanes) and the associated volume-to-capacity (V/C) ratios and may be used for reality checking the model inputs/parameters and as a calibration aid.

- **Updated default values of model parameters:** Several of the FSP model's default parameter values were updated including the on-road mobile source emissions factors, fuel costs and the traveler's value of time estimates. The incident durations and the distribution of incidents by incident-type categories were re-estimated using the FY 2014-15 FSP beat assist data. Additionally, the Caltrans District average diurnal traffic profiles were updated using FY 2014-15 fiscal year traffic profiles provided by Caltrans PeMS.

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CHAPTER 1
INTRODUCTION

1.1 Background

Freeway Service Patrols (FSP) is an incident management measure designed to assist disabled vehicles along congested freeway segments and relieve peak-period non-recurring congestion through quick detection, verification, and removal of accidents and other incidents on freeways. The program is jointly administered by the California Department of Transportation (Caltrans), the California Highway Patrol (CHP) and local Transportation Planning Organizations (MPOs), and has been implemented on many freeway sites ("beats") across the State.

Research studies conducted from 1995 through 2000 by the University of California at Berkeley, as part of the PATH Program, evaluated the effectiveness of FSP on a section of the I-880 freeway (Bay Area "Beat 3"),[4] and a section of I-10 freeway in Los Angeles ("Beat 8").[5] Extensive data on incidents and traffic characteristics were collected "before" and "after" the FSP deployment using specially instrumented floating cars and data from freeway loop detectors. The data were processed, verified and integrated into computerized databases, and new procedures were developed to estimate the incident specific delays. The estimated benefits based on delay savings, fuel consumption, and air pollution reduction showed that FSP was a cost-effective measure at the specific test sites. Following the original FSP Evaluation study, new methodologies were developed (1999 thru 2000) for statewide evaluations of FSP service based on data commonly available to Caltrans and local agency operations staff.[6] For ease of use, these methodologies were incorporated into an Excel spreadsheet. Since then, Caltrans has been using this spreadsheet based FSP Evaluation (FSPE) model to evaluate the cost effectiveness of their FSP beats. Since its original development, the FSPE model has been significantly improved by additional updates through the series of FSP Research Support programs. Major improvements to the model since its original inception are:

- The queueing models were updated to more reliably estimate incident delays on oversaturated beats (i.e., beats or beat segments with unusually high traffic volume to capacity ratios, sometimes in excess of 1.00).
- FSP response times and response time reductions estimations were updated to be dependent on beat length, average assumed FSP truck speeds and the number of FSP trucks on a beat, instead of using static default response times.

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[4] Skabardonis, A., et al (1995), "Freeway Service Patrol Evaluation," PATH Research Report UCB-ITS-PRR-95-5, Institute of Transportation Studies, UC Berkeley. Available on-line: *http://128.32.172.246/pub/pdf/PRR-95-5.pdf.*

[5] Skabardonis, A., Petty, K. et al (1998), "Los Angeles: Freeway Service Patrol Evaluation," PATH Research Report UCB-ITS-PRR-98-31, Institute of Transportation Studies, UC Berkeley. Available online at Web address: *http://www.path.berkeley.edu/%7Eleap/itsdecision_resources/library.html.*

[6] Skabardonis. A., "Freeway Service Patrol (FSP) Research Support Phase I: FSP Beat Evaluation Routine" prepared for Caltrans Traffic Operations, June 2000.

- The model was extended to handle multiple time periods (including all day service) with different number of FSP tow trucks per time period.
- The FSP delay estimation model was completely re-written in a set of *Visual Basic for Applications* (VBA) modules. The updated delay estimation model is called by the user by clicking on a "Run" button located on the primary data entry worksheet. The data entry tables and the beat evaluation results are contained in standard Excel workbooks (as in previous versions of the model). The revised FSPE model was extensively tested, and used to evaluate the cost effectiveness of all the existing FSP beats, statewide.
- Key assumptions and default model parameters have been kept current using the most current empirical traffic data and FSP assist data available, including Caltrans District specific time-of-day traffic flow profiles from empirical traffic volumes from Caltrans loop detectors, and District average FSP assist characteristics. Likewise, the model's default emission factors have been kept current using the most current CARB/EMFAC pollutant emissions factors available.
- In 2003, the FSP Predictor model (FSPP) was developed to predict the benefit to cost (B/C) ratio of new or proposed FSP beats where currently no FSP service is provided. The FSPP model can also be used to forecast the impacts of operational changes on existing beats (e.g. additional service hours, weekend service). FSPP first predicts the number of FSP-assists based on the prospective beat's design and traffic characteristics and the assumed FSP service, and then it calculates the B/C ratio using the same methodology as in the FSPE model. The original FSPP model parameters were estimated using the Fiscal Year 2001-2002 (FY 01-02) FSP beat evaluation data.
- The FSPP model first estimates the number of FSP-assists based on the prospective beat's design and traffic characteristics and the assumed FSP service, and then calculates the B/C ratio using the same methodology as in the FSPE model. The predictor model was incorporated into the FSPE model (i.e. into the same Excel workbook, FSPE menu system, and into the same set of VBA modules). To the end user, the FSP predictor model appears as a simple to select run-time option on the FSP options menu. The current version of the FSPP model was re-estimated and updated using FY 09-10 data.
- The FSPE model was significantly improved by the implementation of time variant traffic directionality factors (D-factors). Additionally, the menus were revised to provide greater flexibility at run-time. For example, the user may choose between using the model defaults or the local field data at run-time; previously the model used field data if it existed, else used defaults. Also, the FSP model can now handle 1, 2 or 3 lane HOV facilities; previous versions of the model could only handle single lane HOV facilities.
- Optional user selectable diagnostic reports were included as an option on the runtime menu. These reports list the directional hourly traffic volumes (separate tables for mixed-use lanes and for HOV lanes) and the associated volume-to-capacity (V/C) ratios and may be used for reality checking the model inputs/parameters and as a calibration aid.

- For the FSPP model, the incident durations and the distribution of incidents by incident-type categories were re-estimated using the FY 02-03 and again using the FY 09-10 FSP beat data.
- In the FSPP model, the user's option menu was enhanced to allow the user to select either statewide average FSP assist characteristics or Caltrans District average FSP assist characteristics (proportion of assists by FSP incident category and average FSP assist duration).
- The FSPE model's capability was extended to accommodate 24-hour FSP service.
- The FSPE model's capability was extended to handle more complex FSP beat configurations; beats with two independent groups of FSP tow trucks ("Group A" and "Group B"). The total number of tow trucks on a single beat segment and the expected FSP response times are calculated using both Group A and Group B FSP tow trucks.
- The FSP Predictor (FSPP) model was removed during the FY 2013-14 model update, because a more reliable method of predicting the anticipated number of FSP assists on new beats was developed using more comprehensive data (VMT, VHT and incident data) than was provided in the FSP evaluation dataset.
- During the Fiscal Year 2013-14 update of the FSPE model, a model validation work effort was completed because the previous model validation efforts were outdated. These efforts were facilitated by new and more comprehensive data sources now available, which were not available at the time of the original 1995-1998 validation efforts. The 2013-14 model validation efforts showed that the FSPE model produced vehicular delay savings that are reasonable when compared to empirical estimates of non-recurrent or incident related delays (in terms of vehicle-hours of delay per minute of incident duration). The empirical non-recurrent delays were estimated using Caltrans PeMS and/or INRIX Analytics traffic data.

CHAPTER 2
FSPE METHODOLOGY & PARAMETER ESTIMATION

The current FSPE model is the accumulation of several iterations of updates and refinements since the original FSP Evaluation (FSPE) model was developed in 1999. Although the FSPE model itself has been changed, the same effectiveness criteria proposed for the original model are still used to evaluate the cost effectiveness of FSP beats. These measures of effectiveness (MOEs) are briefly discussed in section 2.1. Section 2.2 describes the procedures used to estimate incident induced delays, delay savings, and the associated MOEs.

2.1 Measures of Effectiveness (MOEs)

Table 2-1 presents the performance measures that have been proposed and applied to evaluate the FSP service in other studies[7, 8] and other additional benefits of FSP that exist but are not measured.

Measures of Effectiveness (MOEs)	**Additional Benefits of FSP**
(1) Incident delays (2) Fuel consumption (3) Air pollutant emissions (4) Incident response and clearance times	(1) Benefits to motorists assisted by FSP (2) Benefits to CHP (reduced number of required motorist responses) (3) Improved safety (reduced number of secondary accidents) (4) Improved average freeway travel speeds and improved travel time reliability (5) Increased freeway throughput

Table 2-1: List of MOEs and other additional benefits of FSP

The primary MOEs selected for reporting the cost effectiveness of providing FSP service on freeway "beats" are reductions in; (1) incident-induced vehicular delays; (2) fuel consumption; and (3) air pollutant emissions. Incident response and clearance times although estimated and used by the model are not reported MOEs in the summary reports produced by the FSPE model. The "Additional Benefits of FSP" are extremely difficult to quantify and thus are not estimated by the FSPE model. However, these are briefly discussed in the following.

[7] Skabardonis, A., et al (1995), "Freeway Service Patrol Evaluation," PATH Research Report UCB-ITS-PRR-95-5, Institute of Transportation Studies, UC Berkeley. Available on-line: *http://128.32.172.246/pub/pdf/PRR-95-5.pdf.*
[8] Skabardonis. A., "Freeway Service Patrol (FSP) Research Support Phase I: FSP Beat Evaluation Routine" prepared for Caltrans Traffic Operations, June 2000.

Additional Benefits of FSP

- **Benefits to motorists assisted by FSP:** Drivers and passengers of the vehicles assisted by FSP receive time savings due to FSP's faster response times and direct cost savings from the free FSP service. The cost of a tow-truck attending a disabled vehicle can range from $5 for refueling to over $60 for towing service.
- **Benefits to CHP:** The FSP service results in a fewer number of incidents attended by CHP and reduction in CHP's time spent assisting motorists with vehicle breakdowns.
- **Benefits to the freeway operators:** FSP service provides faster recovery of the freeway to normal conditions when freeway incidents occur, and improves Caltrans/CHP's incident detection capabilities. The roving FSP trucks are able to identify and locate collisions, freeway incidents and other traffic hazards, and then promptly report them to traffic management centers (TMC) and CHP.
- **Improved safety:** FSP vehicles provide motorist with faster clearance of incidents that may contribute to reducing secondary accidents. The determination of the safety improvements, however, requires data on accident rates and traffic volumes on the FSP beats over long time periods.

2.2 Estimation of the Selected Measures of Effectiveness

The procedures for estimating incident-induced delays are presented in section 2.2.1. The fuel consumption and vehicular emissions estimations are discussed in section 2.2.2.

2.2.1 Estimation of Incident-induced Delays and FSP Delay Savings

The FSPE model employs deterministic queuing models[9] to estimate incident induced delays and the associated delay savings attributable to the provided FSP service. The queuing diagram originally discussed in the freeway operations context by Moskowitz[10], was applied in numerous studies to analyze the incident impacts.[11] Figure 2.1 shows a typical queuing diagram that shows cumulative vehicle arrivals, *N*, and departures, *D*, versus time. Notice how the slope of *D* is reduced to C_i at time t_1. The C_i represents the reduced capacity due to an incident and is the flow passing the incident location. When the incident is cleared at time t_2, the capacity of the freeway is restored to *C* and the queue dissipated at time t_3. The lightly shaded area between *N* and *D* is the incident-induced total delay (in vehicle-hours). Figure 2.2 graphically depicts how FSP can

[9] More on deterministic queuing theory can be found in:
(a) Newell, G.F. (1982). *Applications of queueing theory* (2nd Edition), Chapman Hall, London, U.K.
(b) Daganzo, C.F. (1997). *Fundamentals of Transportation and Traffic Operations*, Pergamon-Elsevier, Oxford, U.K.

[10] Moskowitz, K, and L. Newman, 1963, "Notes on Freeway Capacity," Highway Research Record #27, Washington, D.C.

[11] Urbanek, G.L, and R.W. Rodgers, 1978, "Alternative Surveillance Concepts and Methods for Freeway Incident Management," FHWA Report RD-77-58/63, Washington, D.C.

reduce the delay by responding to the incident earlier. Notice how the restoring the capacity at t'_2 reduces the total delay.

N = cumulative vehicle counts (count location within freeway segment in absence of incidents),
V = vehicle thru-flow rate (in absence of incidents),
T_i = the duration of the incident (with no FSP service on beat),
T_{FSP} = the duration of the incident with FSP service provided on beat,
T_{NF} = the duration of the incident-induced congestion (time to normal flow),
C = the freeway's (normal) capacity, and
C_i = the freeway's capacity during the incident.

The incident duration, T_i, is the sum of the response and the clearance time. The deployment of FSP results in shorter response times which in turn reduce the duration of the incident (T_{FSP}) and the incident induced delays. Figure 2.2 illustrates the reductions in incident-induced delays due to the shorter incident durations that are attributable to FSP service.

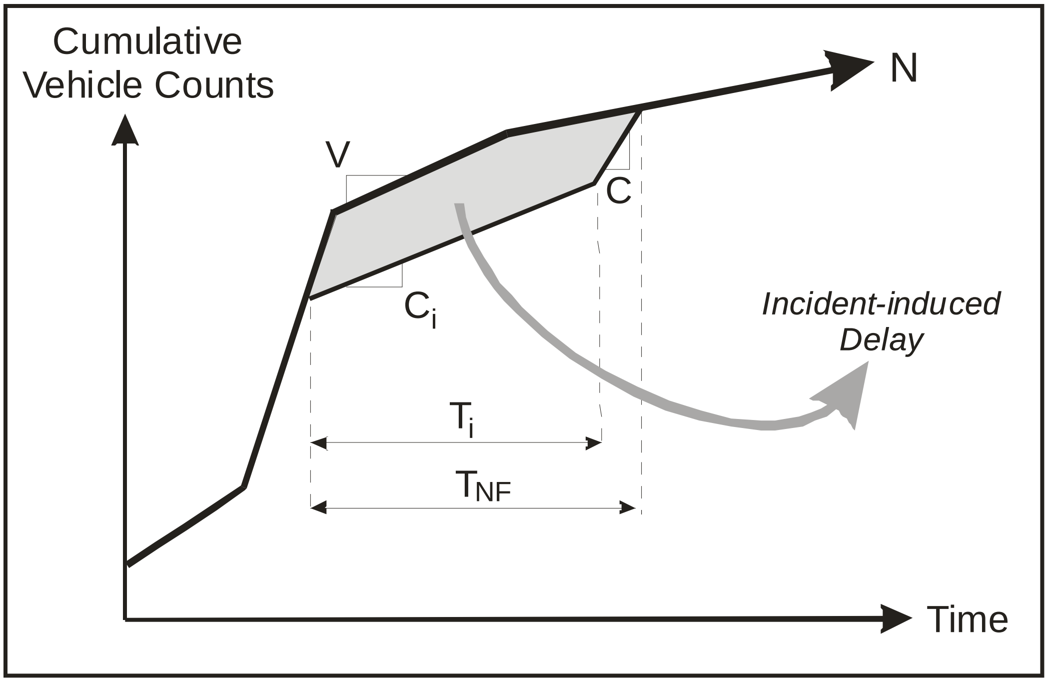


Figure 2.1 Estimation of Incident Delays

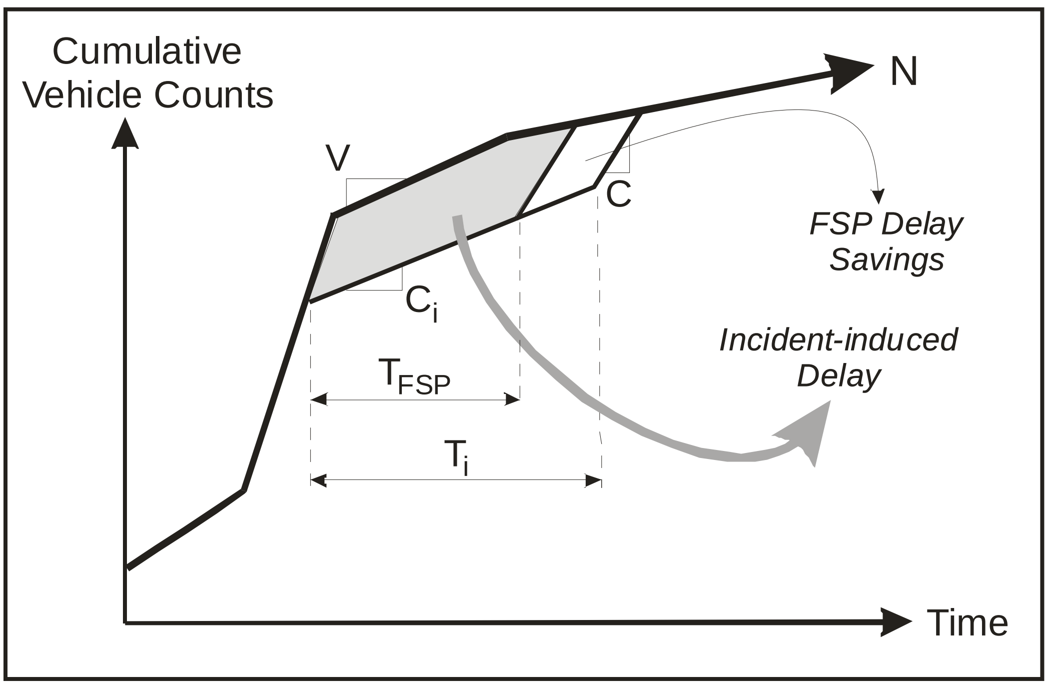


Figure 2.2 FSP Delay Savings

Next, the estimation of the hourly counts used to create FSPE's queueing models is discussed.

Hourly Traffic Volumes

The FSPE model can either use empirical hourly traffic volumes directly (input by the user on the ***FIELDDATA*** page), or it can estimate hourly traffic volumes from annual average daily traffic volumes (AADT) via a set of time-of-day traffic profiles and default time dependent directionality factors. If the user selects "**Use Field Data (FIELDDATA Sheet)**" then the FSPE model directly uses these hourly flows as the without incident flows in its internal queueing model. Figure 2.3 displays the FIELDDATA worksheet and user input hourly traffic volumes for a fifteen segment beat.

TRAFFIC VOLUME DISTRIBUTION--MIXED FLOW LANES (vph)

DIRECTION: EB / NB

Time Interval	Segment 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Midnite-1	178	821	626	691	985	1021	994	798	1172	784	493	331	544	265	214					
1-2	110	513	380	414	652	608	661	535	709	483	289	190	371	164	137					
2-3	74	375	278	303	521	454	545	437	546	375	224	147	313	122	104					
3-4	57	235	159	174	410	334	446	380	486	346	194	135	298	116	103					
4-5	110	354	200	218	494	496	548	524	882	626	284	209	395	186	169					
5-6	434	1010	470	518	874	1251	1064	993	2096	1582	654	509	742	456	380					
6-7	1106	2666	1239	1367	1833	2996	2431	2136	4483	3260	1477	1058	1343	956	762					
7-8	2088	5594	2704	2871	3381	5463	4250	3406	6401	4582	2295	1536	1866	1367	1034					
8-9	2021	6133	3053	3287	3659	5816	4533	3533	6418	4625	2468	1664	2016	1560	1280					
9-10	1482	5270	2826	3182	3740	5643	4438	3484	6042	4357	2476	1737	2113	1527	1235					
10-11	1280	5331	2924	3359	3867	5627	4569	3660	6268	4454	2616	1843	2244	1638	1291					
11-Noon	1329	5915	3259	3787	4295	6116	5047	4013	6906	4809	2907	2028	2445	1806	1377					
Noon-1	1425	6434	3595	4188	4697	6644	5510	4372	7624	5264	3175	2220	2643	1998	1483					
1-2	1492	6698	3901	4551	5105	7176	6010	4672	8184	5620	3385	2394	2786	2150	1587					
2-3	1657	7227	4436	5162	5894	8290	7187	5491	9697	6690	3996	2817	3134	2409	1791					
3-4	1867	7877	5076	5910	6600	9257	8151	6196	11091	7778	4524	3281	3540	2817	2164					
4-5	1876	8022	5298	5898	6619	9194	8371	6289	11099	7835	4386	3272	3602	2925	2276					
5-6	1696	7590	4958	5582	6578	8942	8151	6110	10666	7490	4250	3208	3580	2979	2336					
6-7	1431	6384	3923	4489	5355	7557	6637	4846	8415	5954	3752	2792	3160	2485	1931					
7-8	1094	4899	3043	3548	4073	5370	4698	3548	6168	4373	2844	2063	2446	1804	1385					
8-9	873	4005	2576	3120	3571	4512	3921	2962	5141	3598	2379	1708	2095	1454	1106					
9-10	695	3421	2284	2875	3280	4107	3565	2665	4531	3134	2051	1456	1814	1201	919					
10-11	522	2567	1819	2169	2507	3042	2680	2058	3455	2327	1465	1015	1345	829	660					
11-Midnite	336	1693	1266	1438	1756	2024	1840	1441	2320	1568	987	673	951	546	442					
Maximum	**2088**	**8022**	**5298**	**5910**	**6619**	**9257**	**8371**	**6289**	**11099**	**7835**	**4524**	**3281**	**3602**	**2979**	**2336**					

TRAFFIC VOLU

DIRECTION: WB / SB

Time Interval	Segment 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Midnite-1	198	559	395	393	451	738	607	626	1105	799	462	563	397	347	309					
1-2	108	333	245	246	293	489	405	407	753	558	347	488	302	264	239					
2-3	76	272	195	200	246	414	359	361	663	498	294	453	254	222	197					
3-4	49	294	213	238	308	493	449	416	767	590	369	499	290	229	187					
4-5	92	691	465	566	729	1150	1082	954	1728	1335	879	867	681	467	363					
5-6	388	2024	1428	1804	2375	3593	3381	2911	5029	3882	2503	2122	1929	1197	858					
6-7	1036	4572	3411	4275	5090	7606	7180	5969	8556	6492	4297	3608	3502	2356	1610					
7-8	1505	6628	4970	6472	6882	9955	9208	7623	9832	7479	4883	4119	4152	2902	1975					
8-9	1312	6063	4469	6071	6118	8775	7866	6937	9006	6547	4280	3564	3634	2496	1708					
9-10	1070	5102	3591	4725	4927	7002	6054	5810	7652	5439	3632	2948	3036	2135	1477					
10-11	1067	4863	3376	4333	4378	6270	5386	5311	7138	5035	3301	2612	2731	1946	1353					
11-Noon	1233	5358	3661	4600	4480	6483	5433	5286	7243	5039	3253	2516	2652	1906	1322					
Noon-1	1356	5609	3850	4705	4530	6678	5532	5428	7413	5161	3270	2484	2618	1882	1328					
1-2	1350	5477	3766	4484	4326	6500	5421	5384	7487	5255	3266	2492	2612	1905	1358					
2-3	1458	5623	3844	4532	4445	6725	5581	5562	8074	5695	3413	2616	2763	2058	1444					
3-4	1688	5941	4014	4624	4530	6904	5709	5908	8812	6300	3533	2706	2879	2227	1603					
4-5	1882	6346	4103	4671	4495	6700	5562	5693	8562	6151	3459	2660	2835	2126	1514					
5-6	1935	6734	4278	4814	4683	6822	5678	5699	8394	6087	3363	2574	2711	1999	1413					
6-7	1542	5478	3494	4136	3886	5577	4528	4544	6534	4726	2836	2164	2237	1586	1110					
7-8	1149	4031	2635	3055	2819	4198	3426	3388	4744	3440	2104	1619	1613	1172	851					
8-9	918	3275	2175	2350	2257	3413	2788	2727	3912	2850	1701	1356	1325	982	745					
9-10	825	2872	1936	2063	2055	3119	2440	2399	3436	2503	1410	1156	1089	801	628					
10-11	604	1951	1344	1416	1446	2191	1792	1725	2651	1905	1111	964	872	687	560					
11-Midnite	391	1165	810	816	885	1393	1140	1112	1857	1330	777	759	634	521	443					
Maximum	**1935**	**6734**	**4970**	**6472**	**6882**	**9955**	**9208**	**7623**	**9832**	**7479**	**4883**	**4119**	**4152**	**2902**	**1975**					

Figure 2.3 *FIELDDATA* Worksheet

(User Supplied Hourly Traffic Volumes by Beat-segment and Direction)

If at run-time the user selects to use FSPE's default parameters instead of the "**Use Field Data (FIELDDATA Sheet)**" option, then FSPE estimates the "without incident" hourly traffic volumes using:

- User input peak-period directionality factors (D-factors) on the ***INPUT*** worksheet,
- A time-of-day directionality profile (shown in Figure 2.7), and
- Caltrans District specific time-of-day traffic profile (shown in Appendix A).

Figure 2.4 shows the input data table for containing sample user supplied input data – AADTs and D-factors for a seven segment beat.

C. Beat Traffic Characteristics

Segment #	1	2	3	4	5	6	7
AADT	48,468	192,293	122,958	144,689	157,383	225,127	193,255
AM PEAK Dir.	EB / NB	WB / SB	WB / SB	WB / SB	WB / SB	WB / SB	WB / SB
D factor (%)	57.31	45.88	36.55	32.47	34.69	36.44	33.16
MD PEAK Dir.	EB / NB	EB / NB	WB / SB	WB / SB	EB / NB	EB / NB	EB / NB
D factor (%)	52.64	53.99	49.48	48.16	51.84	50.90	50.87
PM PEAK Dir.	WB / SB	EB / NB	EB / NB	EB / NB	EB / NB	EB / NB	EB / NB
D factor (%)	49.28	54.93	54.62	54.42	58.87	57.17	59.12

Figure 2.4 Traffic Volume Data (user inputs on the *INPUT* worksheet)

District Specific Time-of-day Traffic Profiles

Historic hourly traffic counts were collected, validated, and processed for all FSP beats where reliable traffic counts were obtainable from PeMS. From these, District average hourly traffic flow profiles were created. The resulting District specific traffic flow profiles are shown in Appendix A.

Time Dependent Traffic Directionality Factors

In addition to deriving empirical District specific traffic flow profiles for the FSPE model, a directionality factor function was created using data from several paired sets of Caltrans freeway loop data. For example, a paired set of freeway loop detectors would consist of a northbound detector and a southbound detector at the same location on the freeway – at the same post mile. Figure 2.7 displays FSPE's time specific D-factor function for two different sets of directionality factors (D-factors):

1. AM D-factor = 70%, Mid-day D-factor = 50%, PM D-factor = 35%.
2. AM D-factor = 55%, Mid-day D-factor = 50%, PM D-factor = 45%.

As the reader can see in Figure 2.5, the D-factor function is dynamic; its values change depending upon the user-input AM, Mid-day, and PM D-factors. This D-factor function provides the defaults used by the FSPE model when separating the user-input AADT's by directionality (e.g. segregating northbound from southbound traffic). Note: the user-input AADT's on the ***INPUT*** worksheet are bidirectional; that is they are the combined northbound and southbound daily flows for N/S freeways. Likewise, they are the combined eastbound and westbound daily flows for E/W freeways.

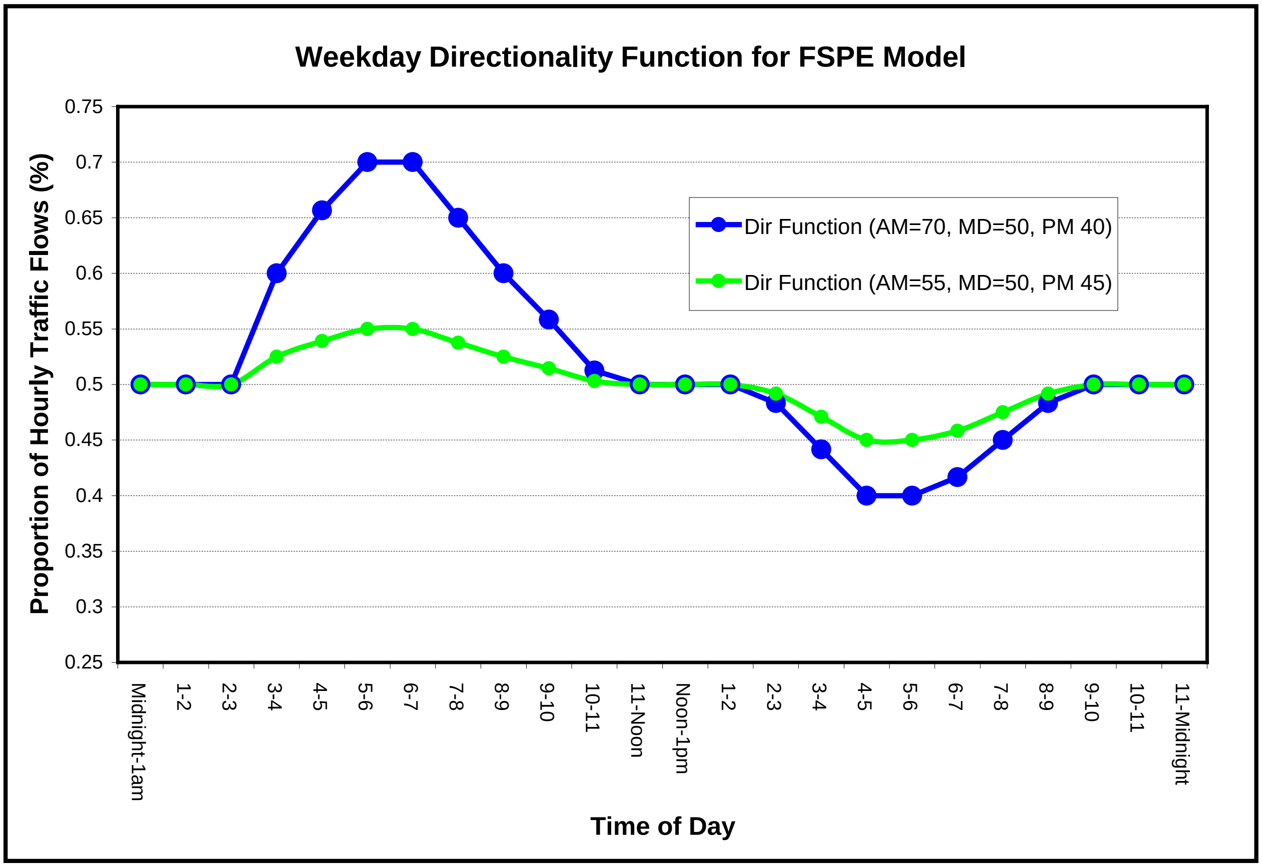


Figure 2.5 Graphical Representation of the FSPE Traffic Directionality Function (with sample user input D-Factors for two different sets of D-Factors)

When the user opts to use "default parameters" at run-time, the FSPE model calculates hourly (directional) traffic volumes by scalar multiplication whereby the directionality factors (a 1x24 vector) and the District time-of-day traffic flow profile (a 1 x 24 vector) are multiplied by the user supplied AADTs, thus estimating directional hourly traffic volumes.

FSP Tow-truck Response Time and Response Time Savings

The response time reduction (RTR) is the difference between the time that the FSP tow-truck arrived at the incident and the time that a tow-truck would have arrived had there been no FSP service on the beat. The RTR is estimated using a probabilistic approach, calculating the expected response time reduction, and is subsequently used for all delay reduction calculations for determining the benefits of FSP beat.

The mean (or expected) response time without the FSP program is a user input with the conservative default of 30 minutes[12]. The expected response time with the FSP program is determined based upon the FSP beat length, the number of FSP tow-trucks on that beat, and the average speed of the FSP tow-trucks, all three of which are user inputs. The default FSP tow-truck speed is 30 mph.

The expected RTR (in minutes) is determined by the following algorithm:

If $\left[V_{FSP} \times T_{AAA} > \frac{2 \times L_B}{N_B}\right]$ then

$$\mathrm{E}[RTR] = T_{AAA} - \frac{L_B}{N \times V_{FSP}},$$

else

$$\mathrm{E}[RTR] = \frac{T_{AAA}}{2} \times \frac{V_{FSP} \times T_{AAA}}{\frac{2 \times L_B}{N_B}} = \frac{V_{FSP} \times (T_{AAA})^2 \times N_B}{4 \times L_B},$$

where:

E[RTR] is the expected response time reduction (in hours)
V_{FSP} is the mean speed of the FSP tow-truck (in miles per hour),
T_{AAA} is the expected response time without the FSP program (in hours),
L_B is the length of the beat (in miles), and
N_B is the number of FSP tow-trucks serving the beat.

Remaining Capacity during Incidents

Previous FSPE's default parameter estimates for "remaining freeway capacity during incidents" were based on Exhibit 10-17 "Proportion of Freeway Segment Capacity Available Under Incident Conditions" page 10-30 of the Highway Capacity Manual 2010. These values were updated based on the Highway Capacity Manual 2010 and shown in Figure 2.6.

[12] This default response time was determined by a rotational tow policy set by the California Highway Patrol.

REMAINING FREEWAY CAPACITY DUE TO INCIDENTS (%)					
Incident		No of Freeway Lanes/Direction			
Type	Location	2	3	4	5+
Accident	Rt Shdr	81.00	83.00	85.00	87.00
	Median	81.00	83.00	85.00	87.00
	1-Lane	35.00	49.00	58.00	65.00
Breakdown	Rt Shdr	95.00	99.00	99.00	99.00
	Median	95.00	99.00	99.00	99.00
	1-Lane	35.00	49.00	58.00	65.00
Debris	Rt Shdr	95.00	99.00	99.00	99.00
	Median	95.00	99.00	99.00	99.00
	1-Lane	35.00	49.00	58.00	65.00

Figure 2.6 Remaining Freeway Capacity During Incidents

2.2.2 Estimation of Value of Time, Fuel Costs, Fuel Consumption and Emissions

The value of time for motorists (in terms of $ per vehicle hour) were obtained from the Caltrans 2011 Performance Mobility Report.[13] The 2011 MPR states that statewide travel time is priced at $17.35 for each vehicle hour of delay, which includes an average vehicle occupancy of 1.30 and a 9 percent truck volume.

The California statewide annual average fuel costs of $3.48/gallon of gasoline for FY 2014-15 was estimated from weekly California statewide average prices are compiled by the U.S. Department of Energy's Energy Information Administration (EIA) from a telephone survey that includes a sample of 38 California gasoline stations. These stations were sampled with a likelihood equal to the company's proportional size to the total annual volume of gasoline, by grade, sold in California.[14]

The fuel consumption rate was updated as 1.719 gallons of fuel saved for each vehicle hour of delay saved, based on the Caltrans Mobility Performance Report 2011. Air Pollutant Emission Rates of ROG, CO, NOx and PM10 were estimated using the current CARB/EMFAC factors (2010) and shown in Figure 2.7. The amount of extra vehicle emissions of CO2 is derived from the figure of 19.4 pounds of CO2 produced for each gallon of gasoline burned based on the Caltrans Mobility Performance Report 2011. The N2O and CH4 emission rates were calculated based on (i) the running emission rate of trucks and autos obtained from the Update of Methane and Nitrous Oxide Emission Factors for On-Highway Vehicles (U.S. Environmental Protection Agency, 2004)

[13] Source: http://www.dot.ca.gov/hq/traffops/sysmgtpl/MPR/pdfs/MPR2011.pdf
[14] Source: http://energyalmanac.ca.gov/gasoline/retail_gasoline_prices.html.

and (ii) the percentage of truck obtained from the 2009 Annual Average Daily Truck Traffic on the California State Highway System (See Figure 2. 8).

EMISSION RATES--AUTOS				
SPEED (mph)	ROG	CO	NOx	PM10
	(gr/mi)	(gr/mi)	(gr/mi)	(gr/mi)
5	1.027	7.317	2.203	0.183
10	0.633	5.959	1.642	0.124
15	0.391	5.005	1.287	0.085
20	0.265	4.327	1.130	0.061
25	0.209	3.851	1.068	0.049
30	0.172	3.490	1.026	0.042
35	0.148	3.222	1.001	0.036
40	0.133	3.032	0.992	0.033
45	0.127	2.917	0.999	0.033
50	0.129	2.882	1.025	0.034
55	0.138	2.942	1.070	0.037
60	0.156	3.131	1.140	0.042
65	0.186	3.509	1.244	0.049
FACTOR (gr/hr)	0.081	0.968	0.044	0.016
[Source: http://www.arb.ca.gov/planning/tsaq/eval/emftables.pdf, 02/23/13]				

Figure 2. 7 Air pollutant emission rates of previous and updated values

EMISSION RATES (ADDED)			
Percent Trucks (%)		9	
[Source: 2009 Annual Average Daily Truck Traffic on the California State Highway System]			
N2O Running emission	(Auto)	0.235	gr/hr
N2O Running emission	(Truck)	0.652	gr/hr
CH4 Running emission	(Auto)	0.196	gr/hr
CH4 Running emission	(Truck)	0.374	gr/hr
N2O EMISSION RATE		0.23149	gr/hr
CH4 EMISSION RATE		0.62698	gr/hr
[Source: Update of Methane and Nitrous Oxide Emission Factors for On-Highway Vehicles (2004), U.S. Environmental Protection Agency]			
CO2 EMISSION RATE		8.8	kg/gallons
[Source: 2009 Mobility Performance Report]			

Figure 2. 8 Emission Rates for air pollutants (CO2, N2O, and CH4)

The amount of excess carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx), Particulate Matter (PM10), Nitrous Oxide (N2O), and Methane (CH4) air pollutant emissions from motor vehicles is calculated as follows:

$$F_i = D \times e_i$$

where:

F_i = Emissions

i=1, HC emissions in Kg,

i=2, CO emissions in Kg,

i=3, N0x emissions in Kg,

i=4, PM10 emissions in Kg,

i=5, N2O emissions in Kg,

i=6, CH4 emissions in Kg,

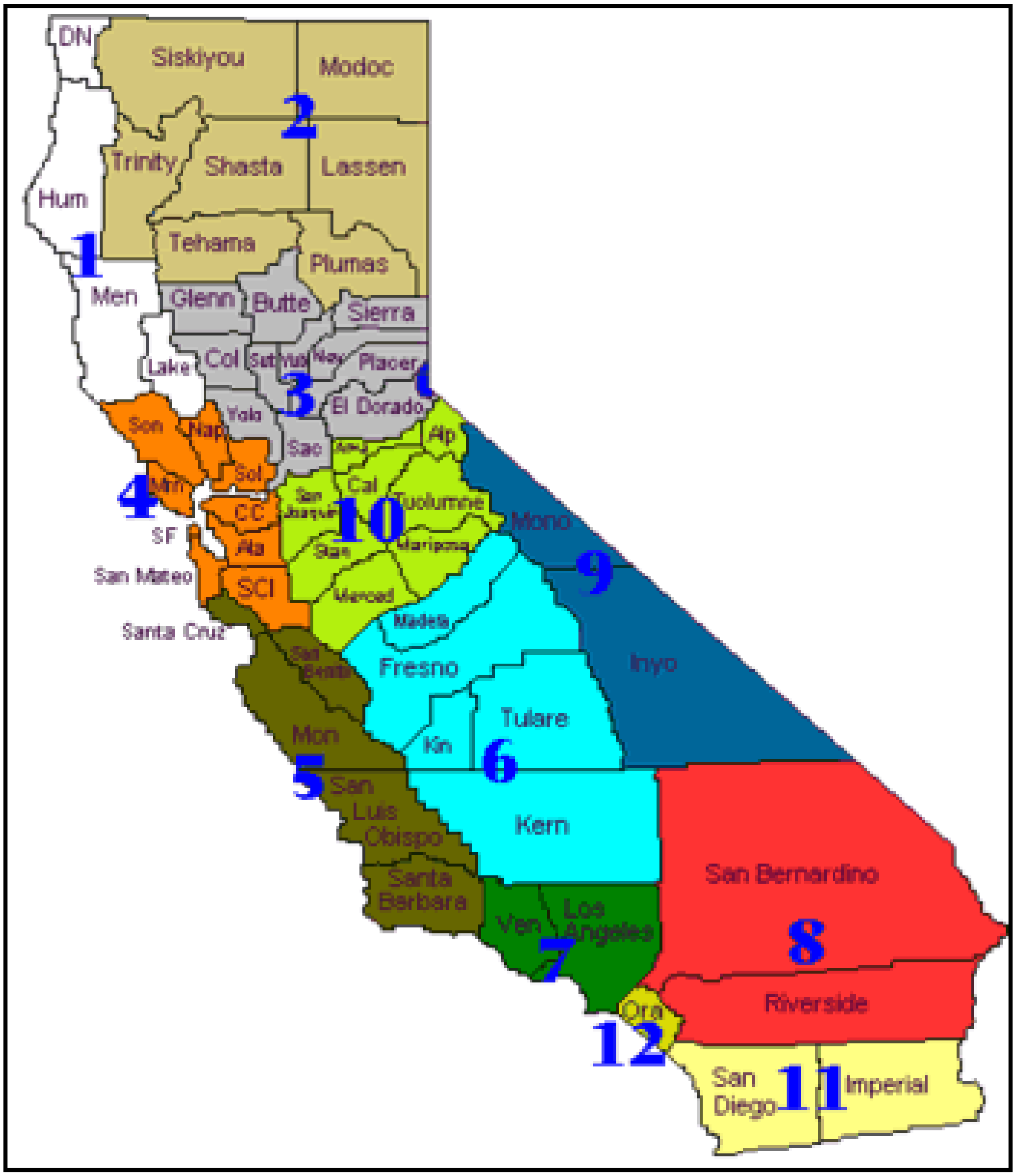
D = incident-induced delays

e_i = Emission factor.

The amount of CO2 air pollutant emissions from motor vehicle is calculated by multiplying CO2 emission rate and the fuel consumption rate. The carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx), and Particulate Matter (PM10) air pollutant emission estimates are based on average vehicular speeds and do not explicitly consider time spent in each driving mode (cruise, acceleration, deceleration, and idling). Thus, the actual amount of emissions would be higher than estimated using the above shown relationships especially for congested freeway segments with significant portions of the time spent under stop-and-go traffic conditions.

Appendix A

Caltrans District Average (Time-of-Day) Traffic Flow Profiles
Source: PeMS – Caltrans Traffic Counts on FSP Beats



TIME Interval	Average Weekday Traffic Profiles District 3	District 4	District 5	District 6	District 7	District 8	District 10	District 11	District 12
Midnite-1	1.10	1.08	1.00	1.26	1.30	1.46	0.74	0.89	1.02
1-2	0.83	0.75	0.79	1.00	0.92	1.16	0.62	0.59	0.71
2-3	0.76	0.66	0.72	0.94	0.82	1.09	0.63	0.51	0.61
3-4	0.88	0.74	0.76	1.07	0.92	1.32	0.95	0.62	0.72
4-5	1.42	1.31	1.04	1.66	1.70	2.37	1.91	1.27	1.54
5-6	2.75	2.94	1.92	3.09	3.77	3.91	3.21	3.34	3.51
6-7	4.95	4.76	3.79	4.59	5.27	4.81	4.88	5.64	5.40
7-8	6.34	6.16	6.16	6.32	5.97	5.41	6.27	6.44	6.30
8-9	5.91	6.19	6.27	5.56	5.71	5.23	5.70	6.08	6.11
9-10	5.32	5.66	5.63	5.00	5.28	4.98	5.31	5.50	5.55
10-11	5.27	5.32	5.65	5.02	5.14	4.99	5.36	5.15	5.20
11-Noon	5.49	5.30	5.93	5.31	5.23	5.18	5.57	5.26	5.24
Noon-1	5.72	5.48	6.12	5.69	5.36	5.38	5.84	5.46	5.37
1-2	5.84	5.70	6.23	5.94	5.50	5.58	6.19	5.66	5.60
2-3	6.27	6.21	6.59	6.38	5.79	5.96	6.86	6.36	6.01
3-4	6.77	6.40	7.10	6.95	5.96	6.22	7.44	6.98	6.23
4-5	6.93	6.44	7.26	7.16	6.02	6.17	7.67	6.93	6.32
5-6	6.65	6.45	7.14	6.92	6.04	6.11	7.41	6.74	6.32
6-7	5.56	5.90	5.67	5.22	5.65	5.41	5.49	5.74	5.71
7-8	4.26	4.89	4.24	4.01	4.90	4.55	3.93	4.35	4.78
8-9	3.57	3.86	3.40	3.48	4.06	4.01	2.98	3.52	3.88
9-10	3.19	3.34	2.90	3.11	3.59	3.58	2.32	3.07	3.43
10-11	2.49	2.64	2.18	2.51	2.98	2.92	1.63	2.34	2.69
11-Midnite	1.73	1.81	1.51	1.81	2.11	2.18	1.08	1.56	1.75
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-1: Fiscal Year 2014-15 Average Weekday Traffic Profiles

TIME Interval	Average Saturday Traffic Profiles								
	District 3	District 4	District 5	District 6	District 7	District 8	District 10	District 11	District 12
Midnite-1	1.71	1.80	1.40	1.92	2.03	2.13	1.03	1.51	1.72
1-2	1.26	1.26	1.05	1.45	1.47	1.61	0.77	1.02	1.18
2-3	1.03	1.02	0.89	1.24	1.24	1.36	0.68	0.82	0.94
3-4	0.90	0.86	0.81	1.15	1.01	1.28	0.69	0.69	0.76
4-5	1.04	0.99	0.91	1.40	1.15	1.47	0.90	0.88	0.96
5-6	1.50	1.49	1.31	2.25	1.82	2.13	1.42	1.53	1.63
6-7	2.42	2.27	2.09	3.09	2.77	3.15	2.37	2.65	2.71
7-8	3.47	3.28	3.17	3.88	3.84	4.11	3.46	3.84	3.88
8-9	4.57	4.45	4.34	4.69	4.70	4.78	4.64	4.90	4.94
9-10	5.46	5.34	5.47	5.35	5.32	5.23	5.82	5.67	5.62
10-11	6.18	5.99	6.46	5.83	5.72	5.63	6.71	6.14	5.97
11-Noon	6.60	6.34	7.04	6.18	6.00	5.95	7.16	6.45	6.24
Noon-1	6.76	6.53	7.18	6.42	6.13	6.08	7.27	6.66	6.33
1-2	6.71	6.60	7.21	6.45	6.13	6.11	7.23	6.66	6.33
2-3	6.65	6.60	7.21	6.54	6.13	6.09	7.20	6.67	6.33
3-4	6.62	6.57	7.21	6.56	6.13	6.05	7.10	6.64	6.32
4-5	6.53	6.39	7.02	6.37	6.09	5.96	7.00	6.53	6.30
5-6	6.25	6.27	6.56	6.05	5.96	5.74	6.61	6.28	6.14
6-7	5.61	5.77	5.68	5.32	5.60	5.32	5.73	5.62	5.66
7-8	4.72	4.98	4.63	4.50	4.96	4.73	4.64	4.77	4.88
8-9	4.13	4.30	3.87	3.99	4.37	4.30	3.87	4.17	4.29
9-10	3.93	4.16	3.47	3.67	4.16	4.09	3.30	3.89	4.10
10-11	3.44	3.86	2.94	3.23	4.00	3.71	2.69	3.46	3.86
11-Midnite	2.51	2.88	2.09	2.46	3.26	3.00	1.70	2.55	2.90
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-2: Fiscal Year 2014-15 Average Saturday Traffic Profiles

TIME	Average Sunday Traffic Profiles								
Interval	District 3	District 4	District 5	District 6	District 7	District 8	District 10	District 11	District 12
Midnite-1	1.91	2.23	1.52	1.00	2.63	2.41	1.13	1.93	2.29
1-2	1.39	1.51	1.15	0.79	1.83	1.72	0.80	1.29	1.51
2-3	1.13	1.18	0.94	0.72	1.44	1.37	0.67	1.00	1.12
3-4	0.91	0.91	0.84	0.76	1.03	1.13	0.62	0.74	0.80
4-5	0.94	0.90	0.87	1.04	0.97	1.12	0.67	0.79	0.79
5-6	1.20	1.18	1.18	1.92	1.31	1.42	0.86	1.21	1.17
6-7	1.79	1.74	1.74	3.79	1.92	2.05	1.21	1.99	1.89
7-8	2.52	2.43	2.42	6.16	2.66	2.81	1.71	2.84	2.71
8-9	3.58	3.42	3.53	6.27	3.60	3.69	2.76	3.94	3.81
9-10	4.95	4.75	4.93	5.63	4.82	4.75	4.47	5.24	5.11
10-11	6.08	5.95	6.46	5.65	5.74	5.60	5.91	6.26	6.02
11-Noon	6.77	6.51	7.32	5.93	6.16	6.16	6.83	6.73	6.47
Noon-1	7.33	6.89	7.81	6.12	6.45	6.57	7.43	7.11	6.72
1-2	7.45	7.12	7.82	6.23	6.62	6.70	7.75	7.01	6.77
2-3	7.35	7.12	7.92	6.59	6.64	6.63	7.81	6.88	6.74
3-4	7.19	7.01	7.65	7.10	6.58	6.55	7.83	6.81	6.73
4-5	6.98	6.84	7.38	7.26	6.47	6.44	7.88	6.79	6.63
5-6	6.64	6.56	6.78	7.14	6.30	6.16	7.74	6.56	6.37
6-7	5.89	6.06	5.77	5.67	5.88	5.88	7.11	5.90	5.90
7-8	5.08	5.37	4.84	4.24	5.46	5.48	6.28	5.32	5.45
8-9	4.48	4.87	3.97	3.40	5.05	5.12	5.23	4.70	5.08
9-10	3.74	4.19	3.16	2.90	4.49	4.42	3.74	3.92	4.40
10-11	2.79	3.18	2.38	2.18	3.54	3.42	2.25	2.99	3.36
11-Midnite	1.90	2.09	1.64	1.51	2.40	2.40	1.29	2.04	2.18
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-3: Fiscal Year 2014-15 Average Sunday Traffic Profiles

Appendix B

Validating the Cost Effectiveness Model for California's Freeway Incident Management Program

CALIFORNIA'S
FREEWAY SERVICE PATROL
PROGRAM

VALIDATING THE COST EFFECTIVENESS MODEL FOR CALIFORNIA'S FREEWAY SERVICE PATROL PROGRAM

Prepared for the California Department of Transportation

Traffic Operations Division

Prepared by:

Institute of Transportation Studies
University of California at Berkeley

February 22, 2016

1. INTRODUCTION & BACKGROUND

The Caltrans Freeway Service Patrol (FSP) is an incident management measure designed to assist disabled vehicles along congested freeway segments and reduce non-recurring congestion through quick detection, response, and removal of accidents and other incidents on freeways. In California, the program is jointly administered by the California Department of Transportation (Caltrans), the California Highway Patrol (CHP) and regional transportation planning agencies. Currently, FSP operates on 193 freeway sites ("beats") across the State with 364 tow trucks over 1,800 centerline miles. California, having a large scale FSP program and performance driven decision making policies, developed an analysis tool to evaluate the performance of FSP service on selected freeway corridors (i.e., FSP beats).

The benefits of providing FSP service depend on the beat's geometric and traffic characteristics, and the frequency and type of assisted incidents. Incidents that occur in-lane tend to be more congestion causing than shoulder incidents. Likewise, incidents occurring on freeways with high traffic demand (relatively little excess capacity) tend to cause more congestion than incidents on freeways with lower volumes. Earlier studies performed by the University of California at Berkeley validated the FSP beat evaluation model by analyzing the effectiveness of FSP on a section of the I-880 freeway in San Francisco Bay Area (1) and a section of I-10 freeway in Los Angeles (2). Extensive data on incidents and traffic characteristics were collected "before" and "after" the FSP deployment using specially instrumented probe vehicles and data from loop detectors. The data were processed, verified and integrated into databases. Then analytical procedures were developed to estimate incident specific delays. The resulting FSP performance evaluation model (FSPE model) estimated benefits based on delay and fuel savings, fuel consumption, and air pollution reduction; and it showed that FSP was a cost-effective measure at the specific test sites.

These previous FSP model validation efforts focused on a very limited set of test sites and previous model validation methodologies were only applicable to those FSP beats with relatively closely spaced PeMS vehicle detector stations. Methods that could be applied to a broader range of FSP beats (including FSP beats serving less congested corridors and/or where PeMS detection stations are sparsely spaced or not available) would be better suited for statewide FSP model validation and performance monitoring purposes.

To address these needs, a method was developed to validate FSP delay savings for freeway corridors which was not dependent on tightly spaced (and fully functional) PeMS detector stations. The FSP's performance measures are directly derived from its vehicular delay savings; So any validation method would need to quantify vehicular delays and delay savings attributable to FSP.

The next section of the paper (Section 2) introduces the concepts for the FSP performance evaluation model. Section 3 discusses the methods used to validate the FSP performance evaluation model. Section 4 introduces the data sources used to develop the validation targets, and discusses data quality and highlights some observations about the data. The results of the FSP model validation efforts and an interpretation of the results follow in Section 5. Section 6, the last section, concludes with lessons learned and possible future work.

2. OVERVIEW OF THE FSP PERFORMANCE EVALUATION MODEL

The FSP performance evaluation model (FSPE model) employs deterministic queuing techniques to estimate incident induced traffic delays and the associated delay savings attributable to the provided FSP service, graphically depicted in Figure B-1. Deterministic queuing and queueing diagrams originally discussed in the freeway operations context by Moskowitz (3) has been applied in numerous studies to analyze the incident impacts (4).

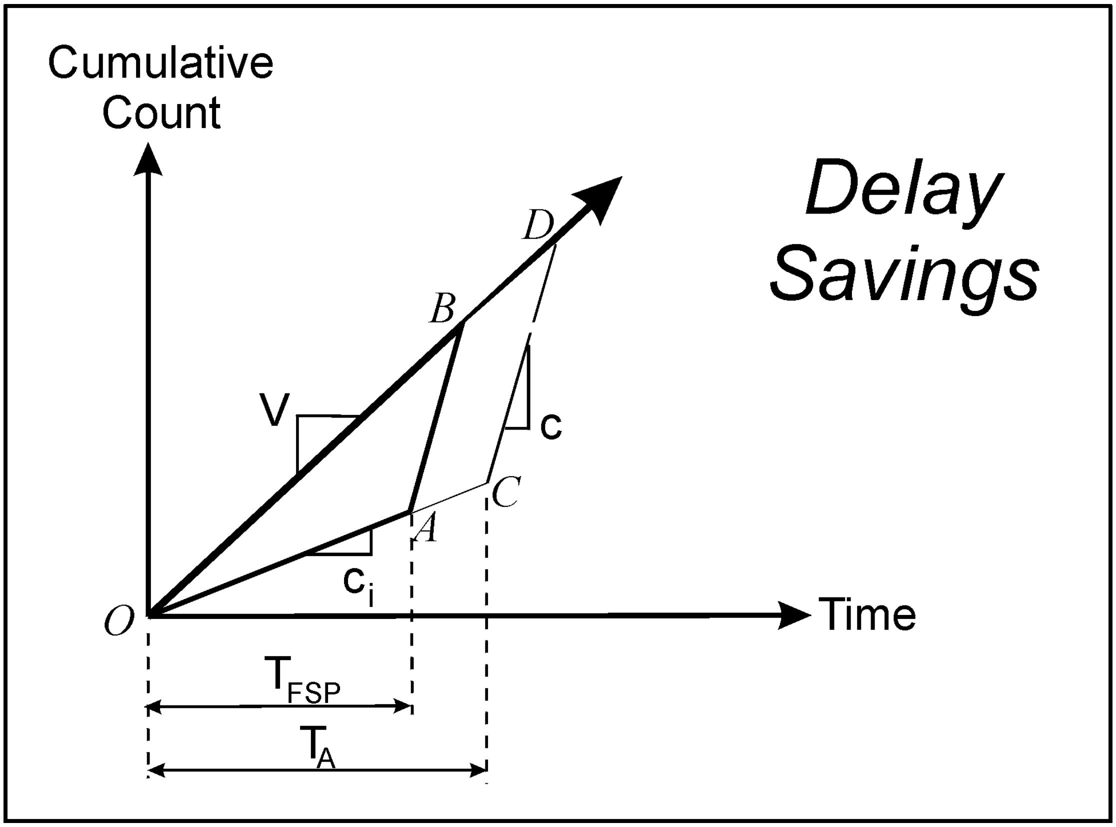


FIGURE B-1 Estimation of Incident Delays and FSP Delay Savings.

When an incident occurs, the normal freeway capacity *c* is reduced to a lesser capacity, c_i, for the duration of the incident, T_A. If the traffic demand on the freeway, *v*, is greater than the remaining capacity c_i then a queue is formed upstream of the incident. Once the incident has cleared, after T_A minutes, the built-up queue will discharge at the capacity of the freeway, *c*, until the queue is dissipated. The total delay (in vehicle-hours) caused by the incident is the area of the triangle OCD in Figure B-1:

$$delay = \frac{(v - c_i)(c - c_i)T_A{}^2}{2(c - v)}$$

The deployment of FSP results in shorter response times that reduce the incident duration (T_{FSP}) and the associated incident delay (area of triangle OAB in Figure B-1). The delay savings due to FSP is the difference in delays without and with FSP service (area ABDC in Figure B-1). The delay savings is attributable to FSP's faster response time. The FSP response time reduction is the difference between the time that the FSP tow-truck arrived at the incident and the time that a tow-truck would have arrived had there been no FSP service on the beat. It is assumed that without the FSP service, stranded motorists would wait for service by a member tow company or a rotational tow arranged by CHP.

The method predicts no delays when the traffic demand v is less than the remaining capacity under incident conditions, c_i. However, in reality, there is a small amount of delay to the traffic stream because of vehicle slow-downs and rubbernecking. These small delays are ignored. The delay savings (and the benefit-to-cost ratio) depend on incident frequency and characteristics (remaining capacity and duration) and the FSP beat's operating characteristics (traffic demand and freeway capacity). The benefits are greater on heavily traveled FSP beats with a high frequency of lane-blocking incidents than on free-flowing beats with mostly shoulder breakdowns.

The methodology used to validate the FSP performance evaluation model is discussed next, followed by data sources in Section 4.

3. METHODOLOGY FOR VALIDATING THE FSP EVALUATION MODEL

In a previous research effort, a method was developed a method to divide the total congestion along a freeway corridor into six components: the delay caused by 1) incidents, 2) special events, 3) lane closures, and 4) adverse weather, 5) the potential reduction in delays at bottlenecks that ideal ramp metering could achieve, and 6) the remaining delays due mainly to excess demand (5). The Caltrans PeMS system currently hosts a fully automated two-step version of this method. The first of the two steps estimates the components of non-recurrent congestion using statistical regression. The second method locates all bottlenecks and estimates the potential reduction in traffic delays that ideal ramp metering could achieve. The method requires input data on traffic volumes and speeds; the time and location of incidents; special events; lane closures; and adverse weather. It can readily be applied to any freeway corridor with minimal calibration.

This components of congestion model assumes that each incident, special event, lane-closure, and adverse weather condition contributes linearly to the overall delays observed in the corridor. More complicated causality between explanatory variables, such as between the bad weather and the number of accidents, was not considered to keep the number of parameters in the model reasonable. For the components of congestion research efforts, the traffic volume and speed data were obtained from the Caltrans PeMS website. Using these methods, traffic delays caused by incidents can be quantified for any freeway corridor given that adequate traffic and incident data are available for the corridor. These components of congestion techniques were used to provide empirical based estimates of incident induced delays that could be compared to the FSPE model's delay savings estimates.

One of the main outputs of the FSPE model is the annual delay savings, in vehicle-hours, that is attributable to the provided FSP service for a freeway corridor. The expected delay savings per FSP assist can be easily calculated using the FSPE model inputs and outputs. Likewise, the expected delay savings per minute of incident reduction can be easily estimated. For example, if the FSPE model estimated 1,600 VHT of delay savings on a beat, and the FSP tow trucks were involved with 80 assists annually, with an average incident reduction of 5 minutes per assist, then the delay savings per incident-minute would be 1,600/(80*5) = 4.00 vehicle-hours per incident-minute. Traditionally, the crucial challenge for the FSPE model validation efforts was to find comparable and reliable empirical delay estimates to compare to the FSPE model output.

Fortunately, a comparable measure (traffic delays per incident-minute) for a freeway corridor can be estimated using the components of congestion techniques and a combination of Caltrans PeMS and INRIX Analytics data for selected freeway corridors where FSP service is provided.

4. DATA SOURCES FOR FSP MODEL VALIDATION

The two primary data sources for the FSPE model validation dataset were INRIX and PeMS.

The INRIX website provides historical and real-time traffic information, travel times and travel time information to public agencies, businesses and individuals. To do this, INRIX collects trillions of bytes of information about roadway speeds from nearly 100 million anonymous mobile phones, trucks, delivery vans, and other fleet vehicles equipped with GPS locator devices. The data is processed in real-time, creating traffic speed information for major freeways, highways and arterials across North America, as well as much of Europe, South America, and Africa. INRIX "Analytics" and INRIX "User Delay Cost Analysis" modules were used to provide traffic delay (congestion) and corridor travel time measures for preselected freeway corridors (i.e., FSP beats).

The Caltrans Performance Measurement System (PeMS) collects data in real-time from over 39,000 individual detectors spanning the freeway system across all major metropolitan areas of the state of California. PeMS is also an Archived Data User Service (ADUS) that provides over ten years of data for historical analysis. It integrates a wide variety of information from Caltrans and other local agency systems including:

- Traffic Detectors
- Incidents
- Lane Closures
- Toll Tags
- Census Traffic Counts
- Vehicle Classification
- Weight-In-Motion
- Roadway Inventory

The Caltrans PeMS website was used to provide stationary point traffic volume, and delay data (mainly from freeway loops) for the set of preselected FSP beats. The Caltrans PeMS website also collects and reports CHP reported freeway incident data.

The minimum data required to produce an estimate of expected (average) traffic delays per incident are: 1) traffic incident data and 2) traffic delay data. PeMS was used to provide the incident data. Both INRIX and PeMS calculate and report traffic delays. This led to questions about how INRIX and PeMS estimate their traffic delays, how well the two delay estimates compare, and which estimate was the most reliable.

5. STUDY FINDINGS – FSP EVALUATION MODEL VALIDATION RESULTS

Linear regression techniques were used to estimate the expected (average) traffic delays attributable to freeway collisions. For this FSPE model validation effort, one year's worth of CHP, PeMS and INRIX data were compiled – July 1, 2012 through June 30, 2013 for FSP beats (corridors) listed in Table B-1.

TABLE B-1 Beats Selected for FSPE Model Validation

FSP Beat	County	Freeway	Beat Limits	One-way Beat Length (miles)	Weekday FSP Trucks
1	ALA	24	I-580 to Contra Costa County Line	4.39	2
	CC		Contra Costa Co. Line to Oak Hill Road	6.25	
	ALA	980	Interstate 580 to Interstate 880	2.03	
		880	7th Street to Jackson Street	2.04	
12	CC	80	San Pablo Dam Rd to Cummings Skyway	8.39	2
16	SCL	17	Junction SR-9 to Summit Road	7.07	1
18	SCL	880	Junction SR-237 to Alameda County Line	2.08	2
	ALA		SCL County Line to Mowry Avenue	7.18	
22	ALA	580	Santa Rita to Grant Line Road	16.48	3
29	SOL	80	Magazine Street to Abernathy Road	14.04	2
34	SOL	80	Abernathy Road to Vaca Valley Road	12.54	2
37	SOL	80	Junction I-505 to Richards Boulevard	16.40	2

On weekdays in the Bay Area, FSP provides service from 6:00 to 10:00 am and from 3:00 to 7:00pm. Although some beats operate from 5:30 am to 9:30am in the mornings, and Friday afternoon shifts might vary on some beats. Sunday (weekend) FSP service is generally provided with one truck operating from 12:30 pm to 7:00 pm.

Since both the PeMS and INRIX data sources provided traffic delay measures, PeMS from stationary source (loop) detectors and INRIX from probe vehicles, three different measures of vehicular delays were used in the regression analysis to gain insights on how the chosen delay data source affected the regression model goodness of fit and parameter estimates:

1. PeMS traffic delays: from stationary detectors, e.g., loops
2. INRIX traffic delays: from a relatively large sample of probe vehicles
3. Composite of INRIX (per-vehicle) delays & PeMS traffic volumes

Table B-2 displays the FSP Evaluation model validation results.

TABLE B-2 FSP Beat Evaluation Model Validation Results

Bay Area FSP Beat	FSPE Delay Savings (per min.)	Source of Traffic Delay Estimate	Regression Model Traffic Delay (per min.)	Regression Model Std Err of Delay	Regression Model Lower 95% Delay	Regression Model Upper 95% Delay	Regression Model F-Statistic
Beat #1 Weekday	11.44	PeMS	8.11	1.79	4.61	11.61	20.65
		INRIX	10.68	1.84	7.08	14.27	33.81
		PeMS+INRIX	12.77	2.00	8.86	16.68	40.96
Beat #1 Weekend	0.78	PeMS	-1.73	1.27	-4.22	0.77	1.84
		INRIX	-1.33	1.44	-4.15	1.48	0.86
		PeMS+INRIX	-0.48	1.68	-3.78	2.82	0.08
Beat #12 Weekday	5.26	PeMS	4.22	0.83	2.59	5.84	25.76
		INRIX	6.67	1.17	4.39	8.96	33.34
		PeMS+INRIX	6.56	1.08	4.44	8.67	36.83
Beat #12 Weekend	0.91	PeMS	0.20	0.46	-0.70	1.10	0.19
		INRIX	0.60	0.19	0.23	0.98	10.08
		PeMS+INRIX	0.91	0.33	0.26	1.55	7.66
Beat #16 Weekday	3.49	PeMS	n/a	n/a	n/a	n/a	n/a
		INRIX	2.09	0.72	0.68	3.50	45.70
		PeMS+INRIX	n/a	n/a	n/a	n/a	n/a
Beat #16 Weekend	0.75	PeMS	n/a	n/a	n/a	n/a	n/a
		INRIX	0.60	1.38	-2.11	3.31	0.19
		PeMS+INRIX	n/a	n/a	n/a	n/a	n/a
Beat #18 Weekday	7.37	PeMS	3.66	0.83	2.04	5.27	19.63
		INRIX	5.49	1.06	3.42	7.56	26.97
		PeMS+INRIX	5.13	1.01	3.15	7.11	25.79
Beat #22 Weekday	6.43	PeMS	7.61	1.15	5.36	9.86	43.87
		INRIX	17.53	2.16	13.29	21.76	65.77
		PeMS+INRIX	17.47	1.97	13.61	21.33	78.72
Beat #22 Weekend	0.45	PeMS	6.42	1.17	4.14	8.71	30.36
		INRIX	6.50	1.87	2.83	10.17	12.22
		PeMS+INRIX	8.40	1.79	4.88	11.92	21.92
Beat #29 Weekday	5.24	PeMS	1.22	0.71	-0.17	2.62	2.97
		INRIX	4.61	0.82	3.00	6.22	31.32
		PeMS+INRIX	2.00	0.43	1.16	2.85	21.52
Beat #29 Weekend	0.67	PeMS	2.01	0.98	0.09	3.93	4.19
		INRIX	1.95	0.94	0.11	3.78	4.30
		PeMS+INRIX	2.14	1.05	0.08	4.21	4.14

TABLE B-2 FSP Beat Evaluation Model Validation Results (continued)

Bay Area FSP Beat	FSPE Delay Savings (per min.)	Source of Traffic Delay Estimate	Regression Model Traffic Delay (per min.)	Regression Model Std Err of Delay	Regression Model Lower 95% Delay	Regression Model Upper 95% Delay	Regression Model F-Statistic
Beat #34 Weekday	5.58	PeMS	2.87	0.53	1.83	3.90	29.29
		INRIX	12.92	2.04	8.93	16.92	40.23
		PeMS+INRIX	1.03	0.72	-0.38	2.44	2.04
Beat #34 Weekend	0.62	PeMS	-0.42	0.67	-1.74	0.90	0.39
		INRIX	1.08	0.94	-0.77	2.94	1.32
		PeMS+INRIX	0.17	0.21	-0.24	0.57	0.66
Beat #37 Weekday	5.77	PeMS	1.16	0.42	0.33	1.98	7.60
		INRIX	9.32	1.46	6.46	12.18	40.74
		PeMS+INRIX	6.73	1.14	4.49	8.97	34.65
Beat #37 Weekend	0.69	PeMS	0.89	0.74	-0.55	2.33	1.46
		INRIX	1.61	1.32	-0.98	4.21	1.49
		PeMS+INRIX	2.25	1.45	-0.60	5.09	2.40

The root mean squared error term was calculated from the empirical and FSPE model estimated delay values, and the average regression model F-Statistic was calculated for the FSPE model validation dataset (see Table B-3). Overall, the INRIX delay data provided models with better model fit statistics than those created using the PeMS delay data and better those created using the composite PeMS volume and INRIX delays.

TABLE B-3 Overall Regression Model Goodness of Fit Statistics

Average FSPE Model Delay Savings (per min.)	Source of Traffic Delay Estimate	Average Regression Model Delays (per min.)	Average Regression Model F-Statistic	FSPE Vs. Regression Model RSME
3.40	PeMS	2.79	14.48	2.72
	INRIX	5.35	23.22	4.42
	PeMS+INRIX	5.01	21.34	4.48

The overall average error term (RSME) was lowest for the PeMS delay based regression models.

Figure B-2 shows a scatter plot comparing the FSPE model estimated delay savings against the empirically estimated traffic delays.

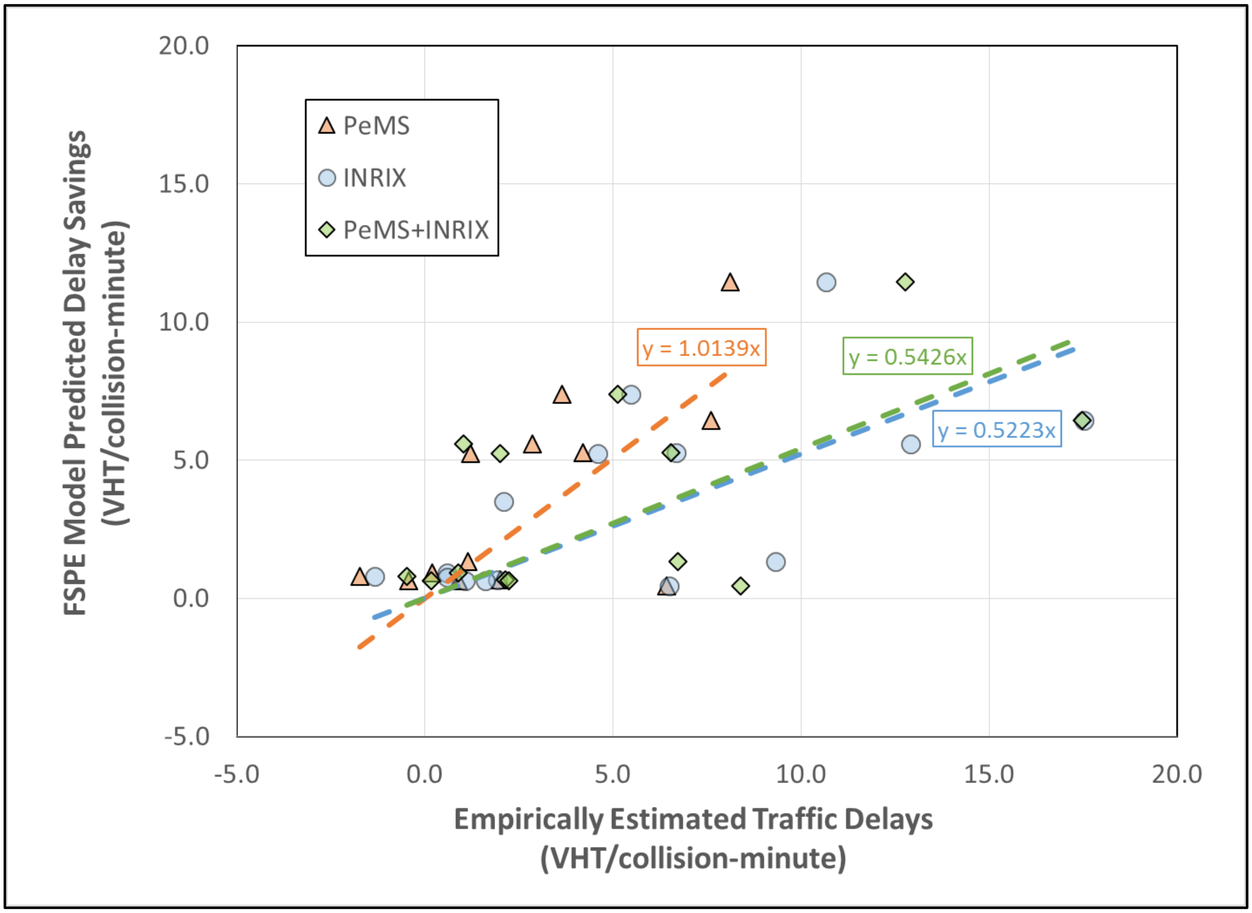


FIGURE B-2 Empirically Estimated Traffic Delays Vs. FPSE Model Predicted Delay Savings

From the trend lines shown in Figure B-2, the FSPE model predicts delay savings that are a very close match to the empirically estimated traffic delays using PeMS delay data. However, the FSPE model fairly significantly underestimates delay savings when compared to the traffic delays estimated using INRIX delay data. It is not clear which delay estimation (PeMS or INRIX) is more reliable without further probing into the PeMS and INRIX data collection and delay estimation procedures, and taking into account measurement and sampling errors associated with PeMS detector spacing and INRIX probe vehicle sample size.

6. CONCLUSIONS

Overall, the FSP beat evaluation model replicated delay savings estimates that were in the range of the empirically estimated traffic delays. However, there is some evidence that the delay savings component of the FSPE model might be underestimating overall delay-savings.

There are set of plausible factors that might be contributing to the FSPE model's underestimate of delay savings. For example, if the FSPE model's default capacities are higher than real world freeway capacities, or if the deterministic queueing methods used in the FSPE model tend to underestimate delays on congested freeway corridors by failing to capture the nonlinear nature of queueing, delays and delay savings.

It should be noted that for this model validation effort, the FSPE model's default capacity and other model parameters were used without calibration or adjustments. No fine tuning was done to the FSPE model's parameters or inputs to improve how well the FSPE model's delay savings compared to the empirically estimated delay estimates. Using the default capacity, like was done for this validation effort, might under estimate congestion for highly constrained merge, diverge or weaving sections. Likewise using the default capacity might result in underestimated FSP delay savings for freeway segments with hills, tight curves, narrow lanes, and other geometric conditions that impact the carrying capacity of freeways. Model users do not take adequate care in assuring the traffic volumes and other inputs are reasonable and in select capacity estimates that are representative of freeway geometry and traffic conditions.

The key to using any model, the FSP beat evaluation model included, is to understand the model's strengths and limitations, take care in preparing the model inputs, and perform reality checks on the model's outputs to assure consistency with observed real world traffic behavior.

Next Steps

These research efforts validated one of the components of the FSP Beat Evaluation (FSPE) model – the FSPE model's deterministic queueing techniques that estimate delay savings. Next steps with respect to FSPE model improvement include exploring whether using stochastic queueing methods instead of deterministic queueing methods would help to improve the FSPE model's ability to replicate real world traffic delays and FSP delay savings.

The research support efforts for the FSP program generally focus on providing information to enable performance based decision making. With this, two plausible and useful work efforts might be to:

- The INRIX Analytics datasets could be used to provide calibration targets for the FSPE model, or perhaps a method could be developed to directly incorporate the INRIX estimated delays into the FSP beat performance evaluation process. This would be especially helpful for freeway corridors (i.e., FSP beats) with limited or no PeMS coverage.
- Compile annual estimates for VMT, VHT and freeway incident for the complete set of California's FSP beats. Compare the level of FSP service provided on each Beat against the Beat's empirical VMT, VHT and incident totals as a performance measure to gauge "How closely does the allocation of FSP resources match demand for freeway incident management services?".
- Perform a "before and after" study on a freeway corridor, directly measuring and taking a detailed look at the overall and incident induced traffic delays along a freeway corridor with FSP service on the corridor and without FSP service on the corridor.

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