Virtual Weigh Stations: The Business Case

Technical Memorandum Prepared for

Partners for Advanced Transit and Highways (PATH)
Institute of Transportation Studies
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and

California Department of Transportation (Caltrans)

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1.0   INTRODUCTION

Overweight trucks traveling illegally on the California highway network cause a significant and disproportionate amount of damage to pavements. Truck traffic is expected to account for some percentage of damage to pavements, however the percentage of pavement damage caused by overweight trucks is much greater than the expected damage from measured truck traffic volume on California highways. Many of these overweight trucks travel unmonitored throughout the network and cost the taxpayers millions of dollars every year in maintenance and rehabilitation costs.

Currently, Weigh and Compliance Stations run jointly by the California Department of Transportation (Caltrans) and the California Highway Patrol (CHP) are the sole instrument used to enforce weight and other restrictions on trucks. Currently, 38 weigh stations are strategically located throughout California. When a station is open, trucks not given a bypass signal must enter the scales and have each axle weighed. Trucks not in compliance are cited. The effectiveness of these weigh stations is limited by their operating hours, the routes they can monitor, and their operating and installation costs. Moreover, these stations can cause user delays from extended queue times for trucks waiting to be weighed.

Development of a new technology known as a Virtual Weigh Station (VWS) is currently underway. The VWS utilizes weigh-in-motion (WIM) sensors, located throughout the state, as tools for weight restriction enforcement. Caltrans Division of Traffic Operations traditionally has used these WIMs to provide data about traffic loads applied to California highway pavements. As a truck passes over a WIM, the type of truck, weight of individual axles, speed, and other data are recorded and stored by the WIM. Through the use of cameras, this data can be linked to the truck license plate and/or registration number. This data can then be relayed to the enforcing authorities, at which point trucks violating weight restrictions can be cited appropriately.

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1.1 Purpose and Scope

This memorandum was initiated by Caltrans for the Partners for Advanced Transit and Highways (PATH) in order to explore the idea of installing VWS in California. The study included a literature survey and expert interviews, as well as an analysis of estimated pavement performance benefits from VWS. The Pavement Research Center (PRC) was asked by PATH to estimate these benefits and other pertinent pavement information concerning overweight trucks. Specific objectives were the following:

- Estimate pavement damage caused by overweight trucks on the network.

- Estimate costs of this pavement damage to Caltrans.

- Estimate potential savings induced by the installation of VWS.

1.2 Datamining of the WIM Database

The WIM database includes information regarding the 133 sites throughout the state that Caltrans has installed since 1990. For the purpose of this study, a WIM site/station is defined as the WIM mechanism installed in a single direction on a highway. The WIM database sometimes includes both directions as one WIM site, and other times it records them as separate sites. These different nomenclature methods do not affect the integrity of the data. The system was installed so that Caltrans could record and analyze truck traffic data, which was expected to eventually help understand and improve pavement performance. The PRC downloaded the data and loaded them into the current database. Figure 1 shows a map of the WIM sites in California.

Figure 1. California WIM Sites.

Items contained in the database and used in this study include:

1. Frequency of axles by weight and type:

    a. Steering

    b. Single

    c. Tandem

    d. Tridem

2. Annual Average Daily Truck Traffic (AADTT) by truck class (4–15), as shown in Figure 2.

3. Average number of axles per truck type.

The database used is current through 2001.
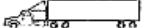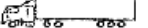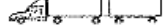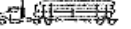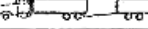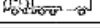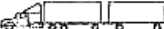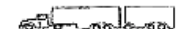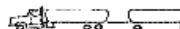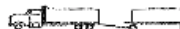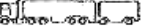
Figure 2. Truck classifications in the WIM database.(*1*)

1.3 Methodology

Analyses were performed using existing WIM data provided to the PRC by Caltrans Division of Traffic Operations, Caltrans cost data from the 2003 State of the Pavement report, and standard damage equations used in pavement engineering.

2.0 DETERMINING PAVEMENT DAMAGE

2.1 Weight Limits

The following total axle loads were used as legal limits for each axle group shown (*2*):

- Steering and Single: 88 kN

- Tandem: 151 kN

- Tridem: 233 kN

Caltrans weight limits, especially for the tridem class axles, are more complicated than the single values used in this study. The Caltrans method uses tables based on weight and length between wheel-sets to determine the maximum allowable weights for each class. For analysis using the WIM database, the legal limits needed to be in terms of a single value. These values are considered the most common for their respective axle class and minimize the error of this single value system.

2.2   ESALs

Pavement damage (the amount of total pavement life used by a pass of a given truck) depends not only on the axle weights but also by the pavement structure and climate. Because this information is not readily available for the entire Caltrans network, a more generalized approach must be considered.

Equivalent single axle loads (ESALs) were used as an alternative that can be calculated from the WIM database and is a reasonably accurate indicator of expected average pavement damage. Each pass of an axle in the WIM database was converted into an ESAL based on the weight of the axle. This method allows different axle types (single, tandem, tridem, etc.) to be directly summed together, is widely used in pavement design as a standard tool, and is directly related to Traffic Index (TI) used by Caltrans in pavement design. The pavement service life is inversely proportional to the number of ESALs carried on a given highway segment.

The equation for ESALs is:

$$ESAL = \alpha \left[\frac{\left(\dfrac{Weight}{\alpha} \right)}{80kN} \right]^{4.2} \qquad \text{(1)}$$

where:

α =   the number of individual axles in an axle group
for steering and singles, $\alpha = 1$
for tandems, $\alpha = 2$
for tridems, $\alpha = 3$.

Examples: 120 kN tandem axle ($\alpha = 2$): $2[(120kN/2)/80kN]^{4.2} = 0.60$ ESALs
180 kN tandem axle ($\alpha = 2$): $2[(180kN/2)/80kN]^{4.2} = 3.28$ ESALs

The most important feature of the ESAL function is that it is exponentially proportional to the weight of the axle. The examples show that a tandem axle with 50 percent more weight is equal to over 450 percent more ESALs, and therefore, damage to the pavement. Table 1 shows the exponentially increasing function in steps around the legal limit.

Table 1   Selected Single, Tandem, Tridem Weights and ESALs

Load and ESALs by Axle Type					
Single, Steering		**Tandem**		**Tridem**	
Weight (kN)	**ESALs**	**Weight (kN)**	**ESALs**	**Weight (kN)**	**ESALs**
75	0.76	130	0.84	200	1.39
80	1.00	140	1.14	215	1.89
85	1.29	150	1.53	230	2.51
90	*1.64*	*160*	*2.00*	*245*	*3.27*
95	*2.06*	*170*	*2.58*	*260*	*4.20*
100	*2.55*	*180*	*3.28*	*275*	*5.31*

Note: weights and ESALs in italics indicate loads above the legal limit.

Figure 3 illustrates the relationship between axle weight and ESALs. Notice the sharp upward trend following the legal limit cutoff line.
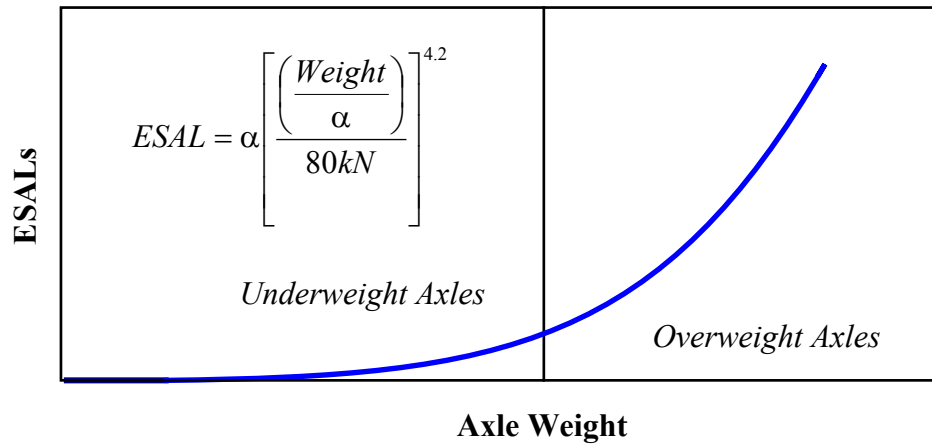
Figure 3. Plot of ESALs versus axle weight.

2.3   Selection of WIM Sites

The percentage of total ESALs caused by overweight trucks was calculated in order to estimate pavement damage. An average, weighted by site Average Daily Truck Traffic (ADTT) across all 133 WIM stations, provided the percentage of ESALs that result from overweight trucks across the WIM system. The WIM data used was for the year 2001.

Because the selection of WIM locations has been governed by the desire to create a realistic model of the state, the averages calculated across the WIM sites can be extrapolated (with suitable caution) to include the entire California highway system.

2.4   Cost of Pavement Damage from Overweight Trucks

Placing a monetary value on pavement damage across the whole state required two assumptions:

1. The existing WIM sites represent traffic across the entire state.
2. The damage to the pavement is best estimated using the total Maintenance and Rehabilitation costs from the Caltrans 2003 State of the Pavement report (*3*).

The 2003 State of the Pavement report documents pavement maintenance and rehabilitation costs to Caltrans for each year. For fiscal year 2002/2003, this amount was $241 million. In the previous two fiscal years, the amount was $325 million and roughly $946 million. The average of these (approximately $500 million) was used as an estimate of the cost of the damage per year to California pavements. Because the amount of damage to the pavement was determined by maintenance and rehabilitation spending, and the amount of rehabilitation and maintenance that is actually performed is less than the yearly accumulated damage, this estimate is low compared to the actual cost of yearly pavement damage.

Since it has been assumed that pavement damage is directly proportional to ESALs, the percentage of overweight ESALs extrapolated across the entire state multiplied by the yearly cost of maintenance and rehabilitation produces a first estimate of the cost of pavement damage resulting from overweight trucks. Though this method has inherent inaccuracies, the number produced will give an order of magnitude solution.

2.5   Potential Savings from Virtual Weigh Stations

Approximating the potential cost savings to the state from the installation of VWS at existing WIM sites is not possible at this time. Some questions that need to be answered include:

- How many VWS sites will be installed? Will they be installed at every WIM site?

- What are the installation and operating costs?

- What is the level of enforcement of VWS sites?

- How many trucks will still travel overweight?

- Will they be enforced all the time? If not, when?

- What will the fines be? Will they be related to the maintenance and rehabilitation costs?

Though the expected savings from implementation of VWS is not available, the estimated potential gain in pavement service life on a given highway segment can be estimated and shows interesting results.

Calculating the improvement in pavement service life involves redistributing the overweight portion of the axle load to axles at the legal limit. This allows for the same freight throughput, but carried on more axles/trucks. This model shows how many ESALs would cross a WIM station if the VWS were installed and were 100 percent effective in deterring trucks from carrying overweight loads. These results are shown in Section 3.0.

The following assumptions were needed to reach quantitative results:

- When installed, a VWS is 100 percent effective in deterring overweight vehicles.

- ESALs are directly proportional to pavement damage.

- The ESAL calculation is roughly calibrated for both rigid and flexible pavements.

- When hypothetically redistributing the freight, the overweight portions are loaded onto axles at the legal limit. This produces a conservative result.

- Permitted overweight loads are treated as ordinary overweight loadsAxle loads in the WIM database exceeding 1.5 times the legal limit are considered errors.

- The WIM database provides a reliable model of the entire state highway network. The averages from the WIM sites can be used as averages for the whole state.

3.0   RESULTS

On average across all sites, 2.67 percent of axles that crossed a WIM site were overweight. The percentage of total ESALs attributed to these overweight axles was 5.34 percent, with a standard deviation of 3.09 percent. Drastic maximum and minimum percentages of ESALs attributed to overweight axles across the sites (19.44 and 0.61 percent, respectively) were also present. Assuming that some trucks had more than one overweight axle on average, about one to two percent of the trucks traveling over the WIM sites are overweight.

These averages can be assumed to be roughly true for the entire state. However, this assumption neglects some major local hauling locations, such as between ports, rail facilities, and warehouse facilities in the Bay Area and Long Beach areas.

3.1   Cost of Pavement Damage from Overweight Trucks

As discussed in Section 2.3.2, the very rough average of $500 million is the assumed annual cost of rehabilitation and maintenance on California highways. Assuming that the estimated ESALs are equivalent to pavement damage across the state network, then 5.34 percent of the rehabilitation and maintenance costs can be attributed to overweight trucks. Because these numbers are imprecise, an order of magnitude value is the only viable solution. A range of approximately $20–$30 million of pavement damage per year can be associated with overweight axles.

3.2   Potential Savings from Virtual Weigh Stations

After redistributing the overweight axles onto legal axle loads, the average pavement service life saved (as a function of ESALs) over the 133 WIM sites is 4.33 percent. The standard deviation is 2.52 percent, with a maximum and minimum pavement life saved of 15.83 and 0.50

percent across the WIM sites, respectively. Unlike the pavement damage caused by overweight trucks, the savings cannot be extrapolated across the entire highway network. Because VWS can only be installed at WIM sites, the data is valid only at those sites and their immediate corridors. For this reason, a dollar amount is unavailable at this time.

4.0   ANALYSIS OF SELECTIVE VIRTUAL WEIGH STATION INSTALLATION

Results show that many of the WIM sites account for a very small portion of the total ESALs attributed to overweight axles. For these sites, installing and operating a VWS may not necessarily be a cost effective solution. However, focusing efforts on WIM sites with the highest potential benefits from a VWS produces results far above the state averages. Table 2 shows the "Top Ten" WIM sites that would most benefit from enhanced enforcement such as a VWS.

Concentrating restriction efforts at problem locations considerably improves the average pavement service life saved, increasing from 4.33 percent across California to 10.71 percent at the top 10 WIM sites. A more in-depth comparison of the two datasets is shown in Table 3.

4.1   Possible Problem Locations outside of the WIM System

Though the California WIM system is the most complete in the United States, a number of unmonitored sites (those without a WIM) still exist. The absence of data on the unmonitored portion of the highway network makes it difficult to determine which sites may be highly affected by overweight vehicles. Likely locations would be highways situated around air and seaports.

Of particular interest are Sites 33034 and 59060 (ranking 7 and 9) in Table 2. These two sites are located very near the San Francisco International Airport and the Port of Long Beach, respectively. Considering the percentage of overweight axles at these WIM sites, the damage to

Table 2   Top Ten WIM Sites that would Most Benefit from a Virtual Weigh Station

Rank in Terms of Pavement Damage	Site Description	AADTT	Freight Through-put per Day (kN)	ESALs per day Current	Redis-tributed	Pavement Damage due to Overweight Axles*	Percent Increase in Pavement Life**	Percent of Axles Over Legal Limit
1	Site No. 20, District 1, Humboldt County, Route 101, Postmile 65.6 NB, "Loleta"	1710	115598	849	715	19.44%	15.83%	12.60%
2	Site No. 86, District 1, Mendocino County, Route 101, Postmile 21.9 NB, "Ukiah"	2335	129464	739	645	15.71%	12.75%	6.48%
3	Site No. 86, District 1, Mendocino County, Route 101, Postmile 21.9 SB, "Ukiah"	2268	122768	777	678	15.66%	12.72%	7.00%
4	Site No. 20, District 1, Humboldt County, Route 101, Postmile 65.6 SB, "Loleta"	1773	103464	612	537	15.03%	12.22%	7.17%
5	Site No. 89090, District 11, San Diego County, Route 805, Postmile 24.5 SB, "Dekema"	12489	695805	3624	3221	13.62%	11.11%	5.18%
6	Site No. 15016, District 12, Orange County, Route 5, Postmile 25.8 SB, "Irvine"	14165	869913	4636	4168	12.31%	10.09%	4.75%
7	Site No. 33034, District 4, San Mateo County, Route 101, Postmile 17.5 SB, "Burlingame"	11664	540179	2018	1846	10.44%	8.56%	2.01%
8	Site No. 39, District 8, San Bernardino County, Route 30, Postmile 31.7 EB, "Redlands"	3155	183961	1122	1027	10.41%	8.51%	4.86%
9	Site No. 59060, District 7, Los Angeles County, Route 710, Postmile 11.5 SB, "LA - 710"	34732	2072297	9402	8674	9.55%	7.74%	3.99%
10	Site No. 91092, District 11, San Diego County, Route 805, Postmile 5.6 SB, "Poggi"	8574	485638	2288	2114	9.37%	7.58%	4.22%
Total		*92864*	*5319086*	*26068*	*23625*	*13.15%*	*10.71%*	*5.83%*

* based on percentage of total ESALs

** assuming all axles became legal and overweight portion of axles transferred to additional axles

Table 3   Comparison of Statewide Virtual Weigh Station Implementation versus Average of Top 10 WIM Sites

Characteristic	Entire State	Top 10
WIM Sites Considered	133	10
Percentage of Freight that is Overweight	0.40%	0.93%
Percentage of Axles that are Overweight	2.67%	5.83%
Pavement Life Lost to Overweight Freight Throughput		
Minimum	0.61%	9.37%
Maximum	19.44%	19.44%
Average	5.34%	13.15%
Standard Deviation	3.09%	3.32%
Pavement Life Saved by VWS Implementation		
Minimum	0.50%	7.58%
Maximum	15.83%	15.83%
Average	4.33%	10.71%
Standard Deviation	2.52%	2.69%

the pavement from at these locations is substantially higher than expected. This is most likely

due to extremely heavy cargo being transferred from air or sea onto the highway network at these

transportation nodes.

Sites near air and seaports may be overweight "hotspots" where WIM stations and

possibly VWS systems should be installed. Concentrating efforts on monitoring trucks moving

freight in and out of California via these terminals may be an effective use of VWS. Moreover,

these urban settings where traditional weight stations are too large to construct may be ideal for a

compact, space-efficient VWS. Figures 4 and 5 show the locations of WIM stations around the

San Francisco Bay Area and Long Beach/Los Angeles.

4.2   Trucks versus Axles

It is important to note that all results are in terms of axles, not trucks. The WIM database

has only been decoded for axles, and thus, the results reflect that data. Though it is possible to

recover the results in terms of trucks, a unique code must be written to interpret the raw WIM
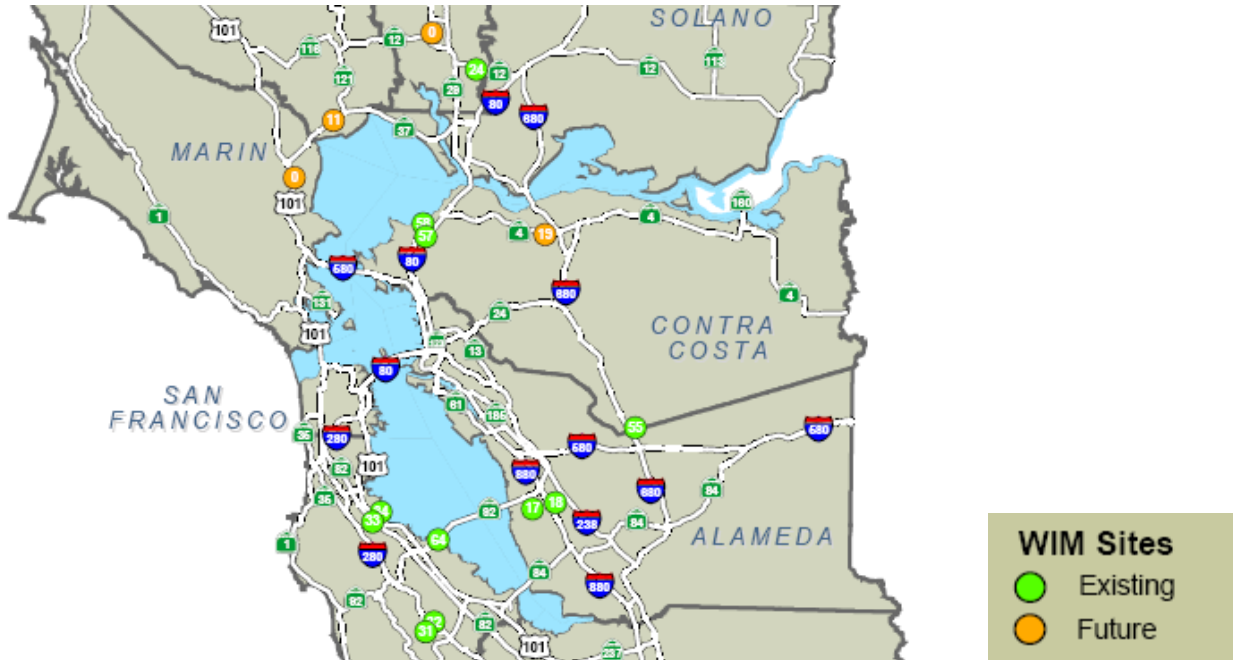
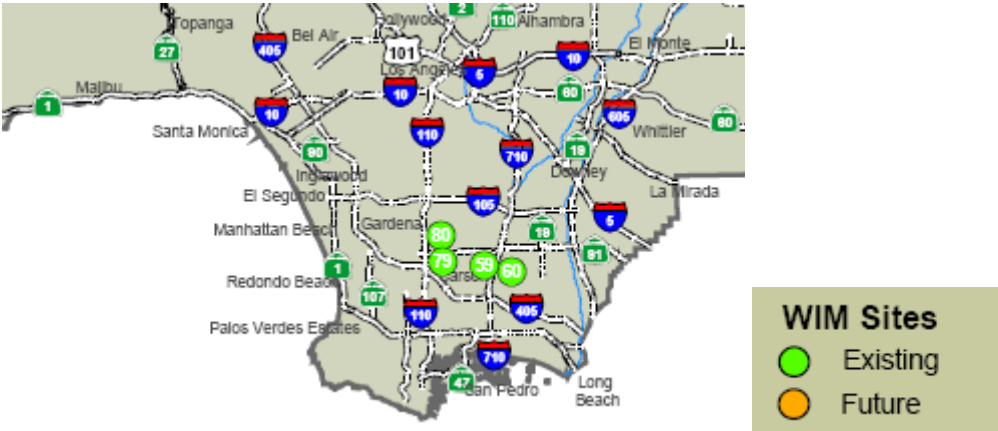**Figure 4. WIM sites in the San Francisco Bay Area.**

Figure 5. WIM sites near the Los Angeles and Long Beach ports.

data in that manner. The most notable change in results would be the percentage of trucks (not axles, as is currently found in the results) that are carrying loads illegally. In order for a truck to be considered overweight, one or more axles must exceed the restricted limits. Therefore, given that the percentage of overweight axles is 2.67 percent, the number of overweight trucks highway is somewhat lower than that. A value of around 1 or 2 percent can be reasonably expected.

5.0   CONCLUSIONS

Across all WIM sites in California, an average of 2.67 percent of the axles are overweight. These axles contribute 5.74 percent of the pavement damage at these sites. When these figures are extrapolated to the entire state highway network, this roughly translates to between $20 and $30 million per year spent in maintenance and rehabilitation costs.

Assuming that with the installation of a VWS, all overweight axles distribute their loads onto additional axles at the legal limit, the average pavement life saved across the WIM sites is 4.33 percent. Across the top ten WIM sites with the most potential benefit, the average pavement life saved is 10.71 percent.

Because pavement damage costs depend on site-specific details such as pavement structure, climate, and other data, a definitive savings amount is unreasonable at this time. Installation of VWS systems still has these and many other questions to be answered before an accurate cost-benefit analysis can be performed.

6.0   RECOMMENDATIONS

Two of the top ten most affected WIM sites are located near ports. Freight terminals are optimal points for weight enforcement efforts because most of the overweight freight carried by the highway network originates at these locations. Focusing weight restriction efforts at these nodes may have a tremendous positive effect on the whole state network because the overweight trucks would be stopped at their origin. Using VWS as the enforcement tool is advantageous because they are typically located in crowded urban areas where traditional weigh stations may be too costly and space-consuming to install.

Figure 4 shows that the Oakland port is unmonitored by any WIM stations. Through experience, highways around this location are known to carry overweight freight to and from

warehouse and train terminals. Setting up a WIM station (either temporary or permanent) on the highways surrounding the Oakland port and closely monitoring the axle weights in this area will likely prove that greater weight enforcement efforts are needed here. Once that data has been analyzed, a VWS may prove to be the best option.

A recommended next step regarding working with the existing data would be to rerun the calculations using the latest WIM data available. Changes to the traffic stream and addition of WIM stations would alter the results and should be accounted for. Also, the number of overweight trucks (as opposed to axles, as considered in this study) should be determined so that necessary enforcement resources can be more accurately ascertained.

7.0   REFERENCES

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3. California Department of Transportation. *2003 State of the Pavement.* Division of Maintenance. September 2004.