LEGISLATIVE ANALYST REPORT

To: Honorable Members of the Board of Supervisors
From: Shauna Johnson, Office of the Legislative Analyst
Date: September 21, 2005
Re: **Sport Utility Vehicles** (BOS File No. 050129) (OLA No. 008-05)

SUMMARY OF REQUESTED ACTION

The Board passed a motion introduced by Supervisor Mirkarimi requesting that the Office of the Legislative Analyst (1) report on the damages caused by overweight and overlength vehicles (primarily sport utility vehicles) to the City's roadways; (2) report on programs and systems employed by other cities to recoup associated costs; and (3) report on the feasibility and effectiveness of creating a fee structure whereby large and luxury sport utility vehicle owners would pay an increased residential parking permit fee.

EXECUTIVE SUMMARY

Consumers have purchased a large number of weighty and lengthy vehicles in recent years. The majority of these vehicles are sport utility vehicles (SUVs). Concerns regarding fuel efficiency have led to reduced purchases of these vehicles over the past year. However, despite this and other environmental and safety concerns, SUVs continue to sell in large volumes.

SUVs have become unpopular with some policymakers due to the aforementioned environmental and safety concerns, which have been widely validated. As well, some policymakers are concerned that large vehicles (particularly SUVs) impose proportionately greater damage to roadways and otherwise more heavily tax public resources, although there appears to be little research substantiating this.

Policymakers around the country have sought various means to address issues surrounding large vehicles. Some jurisdictions have attempted to impose fees, such as supplemental vehicle license fees (VLF), to mitigate costs related to SUV operation. Washington D.C. has successfully adopted the VLF policy option, revenues from which go into the District's General Fund for allocation during the annual budget process.

In California, the State has the exclusive authority to levy VLFs unless State legislation is passed allowing a local jurisdiction to levy a supplemental fee. The City/County Association of Governments of San Mateo County has received authorization to implement a vehicle fee, and will use the revenues to fund traffic congestion and stormwater pollution management programs within the county. San Francisco has lobbied for State legislation that would allow it to charge a local VLF supplement, but has not been successful in securing its passage.

To address safety and quality of life issues, many cities, including San Francisco, have adopted laws that prohibit heavy vehicles (generally those weighing 6,000 pounds or more) from using designated streets. However, anecdotal information suggests that these laws are unevenly and infrequently enforced on SUVs.

If the Board of Supervisors determines that SUVs and other large vehicles are exacting a disproportionate toll on the City's public resources, it can consider the following policy options:

- Direct an appropriate agency to conduct research on the damages caused by SUVs;
- Increase enforcement of weight limits on restricted traffic streets;
- Consider increasing residential parking permit fees for all overlength vehicles; and
- Promote State legislation authorizing San Francisco to enact a local VLF and direct the revenues towards programs to offset the impacts.

BACKGROUND

In 2002, California had the most registered SUVs nationwide – 2.8 million – a 38 percent increase from 1997.[1] The surge in SUV ownership has attracted attention regarding safety and the environment. Some of the widely recognized concerns surrounding SUVs include air pollution, crash incompatibility, rollovers, road damage, noise levels, and gas consumption. Cities and states around the country are attempting to address these concerns and associated public costs through legislative and regulatory measures.

The largest SUVs, mainly those weighing over 6,000 pounds, are of particular concern to lawmakers. These include vehicles such as the Cadillac Escalade, Chevrolet Suburban, Dodge Durango, Ford Excursion, GMC Yukon, Hummer, Lincoln Navigator, Mercedes M320, and Toyota Land Cruiser.[2] According to federal standards, most SUVs are classified as "light trucks." The 6,000-pound weight limit is an arbitrary cut-off to separate larger vehicles from smaller ones.

The California Department of Motor Vehicles (DMV) does not currently track whether registered vehicles are SUVs. Therefore, a precise count of the number of SUVs in San Francisco is not available. However, the U.S. Census Bureau's 2002 Vehicle Inventory and Use Survey found that in 2002 California had approximately one SUV for every 13 people. Assuming that San Franciscans are equally likely to drive SUVs as other Californians, a reasonable estimate of the number of SUVs in San Francisco is approximately 58,000 (San Francisco's 2003 Census population estimate of 751,682/13).

EXISTING LAW

Vehicle License Fee

The California vehicle license fee (VLF) is an annual charge imposed on the ownership of motor vehicles. The VLF is paid to the Department of Motor Vehicles (DMV) at the time of annual vehicle registration and a portion of the revenue is distributed to cities and counties. The fee is charged in addition to other fees, such as the vehicle registration fee, air quality fees, and

[1] U.S. Census Bureau
[2] Source: Transportation for a Livable City

commercial vehicle weight fees. The following is a list of the various fees that may be included in an annual vehicle registration payment:[3]

- Vehicle Registration Fee
- Vehicle License Fee
- Weight Fee
- Special Plate Fee
- County/District Fees
- Owner Responsibility Fee

While the VLF's revenues and distribution are controlled by the State legislature, the ultimate recipients of the fees are cities and counties. Therefore, any change to the VLF can substantially affect the revenues of local governments. The current VLF rate is 0.67 percent of a vehicle's value, as computed by DMV.[4]

Weight Fees

Weight fees are charged to ensure that owners of large vehicles pay a fee in proportion to their travel and to the costs they impose on the system. California's vehicle registration system only assesses weight fees for commercial vehicles, although SUVs can be classified as commercial depending upon how they are used.[5] Fees are based on weight ranges, the configuration of the vehicle, and the number of axles. For example, vehicles with two axles or less weighing between 4,001-5,000 pounds are charged $80, whereas vehicles with three or more axles weighing the same amount are charged a fee of $154.[6]

San Francisco Restricted Traffic Streets

State law gives cities and counties the authority to prohibit vehicles exceeding a specified maximum gross weight limit from using designated streets.[7] Several California cities, including San Francisco, Los Angeles, Pasadena, and Santa Monica, use the 6,000-pound weight limit as a cut-off to restrict vehicles on residential streets. Under the San Francisco Traffic Code, it is "unlawful for any person to operate a vehicle with gross weight in excess of 6,000 on designated streets."[8]

The intention of the Code, as noted by the Police Department and the Department of Parking and Traffic (DPT), is to alleviate the effects of large commercial vehicles. However, SUVs and other

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[3] California Department of Motor Vehicles, http://www.dmv.ca.gov/vr/vr_info.htm
[4] Since 1998 the effective rate of the fee has been incrementally reduced from two percent of a vehicle's current estimated value to 0.65 percent, representing a 67.5 percent decline in the rate overall.
[5] A commercial vehicle is a motor vehicle or combination used for hire to transport passengers or property or which: Has a gross vehicle weight rating (GVWR) of 26,001 pounds or more; is designed, used, or maintained for carrying more than 10 passengers, including the driver; tows a vehicle or trailer, which has a GVWR of 10,001 pounds or more; transports hazardous materials, which requires placards; or tows any combination of two trailers or vehicle and trailer.
[6] Department of Motor Vehicles, http://www.dmv.ca.gov/pubs/vctop/d03/vc9400.htm
[7] California Vehicle Code, Section 35701(a)
[8] There are over 100 designated areas. A listing of these locations can be found in Section 28.1 of the San Francisco Traffic Code.

large vehicles weighing over 6,000 pounds are included within the scope of the weight restrictions in the Traffic Code. According to DPT, restricted streets are usually added as subsections to the code as a result of a complaint about the noise and vibration caused by heavy commercial vehicles (such as large trucks or tour buses).

VEHICLE SIZE

Parking

Lines or other markings usually designate parking spaces in parking lots and on some streets. There are also streets (such as residential streets) where parking spaces are not designated and automobiles have autonomy over where they park. According to research conducted by the Department of Parking and Transportation (DPT), parking spaces in the City normally range from 7 to 9 feet wide and 15 to 22 feet long, with the standard metered space being 7 feet wide and 20 feet long. Table 1 compares the dimensions of various SUVs, full-size, mid-size and compact cars. Of the SUVs listed, the average length is 17.9 feet and the average width is 6.6 feet. Whether or not an SUV will fit within a marked space is case specific, but clearly fewer long vehicles can fit within a given unmarked area than short ones.

Table 1: Comparison of Vehicle Dimensions[9]

Make and Model	Curb Weight / Gross Weight (lbs.)	Height (in.)	Length (in.)	Width (in.)
Large SUVs				
Chevrolet Suburban	5,773 / 8,600	73.6	219.3	79.8
Ford Excursion	7,230 / 8,900	80.2	226.4	79.9
GMC Yukon	5,268 / 7,000	76.7	219.3	78.8
Hummer 2	6,400 / 8,600	79.2	189.8	81.2
Lincoln Navigator	5,555 / 7,225	77.8	207.5	78.7
Full Size Cars				
BMW 745	4,464 / 5,930	58.7	203.5	74.9
Buick LeSabre	3,567 / N/A	57.0	200.0	73.5
Chevrolet Impala	3,389 / N/A	57.3	200.0	73.0
Chrysler 300	3,766 / N/A	58.4	196.8	74.1
Lincoln Town Car	4,345 / 5,534	58.7	215.4	78.2
Midsize Cars				
Honda Accord	3,203 / 4,080	57.1	189.5	71.5
Kia Optima	3,279 / N/A	55.5	185.8	71.5
Nissan Altima	3,274 / 4,374	57.9	192.9	70.4
Subaru Legacy	3,245 / N/A	56.1	186.2	68.1
Toyota Camry	3,219 / N/A	58.7	189.2	70.7
Compact Cars				
Chevrolet Cavalier	2,676 / N/A	54.7	180.9	67.9
Dodge Neon	2,626 / N/A	56.0	174.4	67.4
Honda Civic	2,606 / N/A	56.7	175.4	67.5
Nissan Sentra	2,625 / 3,487	55.5	177.5	67.3
Toyota Corolla	2,615 / N/A	58.5	178.3	66.9

[9] Source: Manufacturer websites and www.edmunds.com.

VEHICLE WEIGHT

Gross Weight versus Curb Weight

The gross vehicle weight rating (GVWR) or "gross weight" of a vehicle is defined as the "weight specified by the manufacturer as the loaded weight of any single vehicle."[10] The GVWR is an estimate of how much a vehicle would weigh when fully loaded with passengers and cargo. Curb weight is the weight of the vehicle with all standard equipment and the fuel tank at nominal capacity without passengers and cargo. As shown in Table 1, a vehicle's curb weight is significantly less than its gross weight. The distinction between an SUV's gross and curb weights is important for federal and state tax purposes, as SUVs registered as trucks for business use can take advantage of state and federal tax breaks.[11] In addition, the difference is significant in enforcing weight-based traffic regulations and determining the impacts on roadways.

SUVs and Road Damage

According to the Department of Public Works (DPW), the average life span of a street in San Francisco is 18 to 20 years. The life span of a street is reduced with frequent traffic and use by heavy vehicles. On busier streets the asphalt usually lasts for five to ten years while on quieter streets the asphalt can remain functional for thirty years or more.[12]

In general, heavier vehicles cause more pavement damage than lighter ones. In addition to a vehicle's weight, pavement damage is a result of various factors including truck design, truck traffic per day, axle loads, and the type of pavement. Caltrans' Highways Design Manual states that "pavement structural sections are designed to carry the projected truck traffic expected to occur during the pavement life. This truck traffic is the primary factor affecting pavement life. Passenger cars, pickups, and two-axle trucks are considered to be negligible." Additionally, DPW found that the Civil Engineering Reference Manual explains further that the "two-axle trucks with single rear tires" are not considered in the design load analysis.[13] DPW also determined that SUVs are lighter in weight than two-axle trucks with single rear tires, which means that they are not a factor in pavement design.

The OLA identified a formula in a British paper on the cost and price of transport. The report concluded that roadway damage is proportional to weight raised to the fourth power, meaning that damage exponentially increases with heavier vehicles.[14] Although engineers from DPW and the cities of San Jose, San Diego, and Los Angeles indicated that they were unfamiliar with the formula, DPT applied it to the weights of specific vehicles listed in Table 1 and concluded the following:

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[10] Source: http://www.dmv.ca.gov/pubs/vctop/d01/vc350.htm.

[11] Under the 2003 Tax Act, pickup trucks and SUVs, primarily used (more than 50% of the time) for business purposes and with a gross weight of more than 6,000 pounds, qualify for the deduction under Section 179 of the federal tax code. The new $100,000 allowance is for tax years beginning in 2003 and returning to the previous $25,000 limit after Dec. 31, 2005.

[12] Department of Public Works: http://www.sfdpw.org/sfdpw/.

[13] Lindeburg, M.R., *Civil Engineering Reference Manual*, 6th Edition, Chapter 16.20.

[14] The Cost and Price of Transport: http://www.transport.intelynx.net/Cost%20and%20Price%20of%20Transport.html#212.

- One Ford Excursion SUV causes more road damage than 23 Honda Accords.
- One Ford Excursion SUV causes more road damage than 7 Lincoln Town Cars.

For the purpose of this report, DPW recently conducted a pavement design analysis to determine how SUVs cause pavement damage (see Attachment 1). Based on their pavement design analysis, DPW found that:

- Standard design manuals suggest that the impact of cars, pickups and two-axle trucks are negligible when designing pavements. The amount of heavy truck traffic is the determining factor.

- City pavements are considered "rigid pavements" due to use of a concrete base. When using the Fatigue Strength Method of design, the pavement will fail if it is subjected to repeated applications of heavy loads causing it to exceed its fatigue strength. Due to their relatively light weights, repeated applications of car and SUV loads will not cause a pavement to exceed its fatigue strength.

- A consultant study may be needed to verify these conclusions and to verify the citation that "roadway damage is proportional to weight raised to the fourth power".

The Board may want to seek clarification on these formulas and conclusions before proceeding with policies that target a specific vehicle category to recoup costs for road damage.

LOCAL VLF LEGISLATION

State law pre-empts local governments from changing the VLF rate to capture additional revenue. However, the Legislature may authorize local jurisdictions to impose an additional VLF charge. A VLF charge may be either a fee or a tax. A regulatory fee may not exceed the cost of mitigating the impact for which the fee is charged. Thus, local jurisdictions must demonstrate a nexus between the source of a fee and its end use. A tax, on the other hand, is subject to voter approval, but need not bear a relationship to its end use.

San Francisco

State legislators have introduced bills that would allow the City to impose a local VLF. However, none have been passed. Most recently, in February 2005, Assemblymember Mark Leno introduced AB 799 that would provide the City with authority to introduce a local VLF tax for General Fund purposes (a general tax). Under this bill, the Board of Supervisors would need to pass the legislation by a two-thirds vote and then put the measure on the ballot for majority approval from the voters. The proposal would authorize the City to impose an additional fee of 1.33 percent of the market value of the vehicle beyond the current state-imposed rate of 0.67 percent. The proposal is expected to generate $60 million, which would go the City's general fund to support public services.

San Mateo

Assembly Bill 1546 (Simitian) was signed into law in September 2004 and authorized the City/County Association of Governments of San Mateo County to impose a fee of up to $4 on all motor vehicles registered in San Mateo County. The fee, which becomes effective July 1, 2005, will be used for congestion management projects and for mitigation of stormwater pollution attributable to automobiles. The fee expires after four years and is expected to generate $2.7 million annually.

Santa Clara

Senate Bill 680 (Simitian), introduced in February 2005, is similar to the San Mateo legislation and would authorize the Santa Clara Valley Transportation Authority*,* by a 2/3 vote of its board, to impose an annual fee of up to $5 on each motor vehicle registered within Santa Clara County. Proceeds would be used for congestion management and for specified street, road, expressway, highway, and transit purposes and are expected to total approximately $7 million per year over an eight-year duration.

Washington D.C

In December 2004, the D.C. city council approved legislation that requires District owners of large, luxury sport-utility vehicles to pay a higher excise tax and registration fee. The legislation raises the excise tax from 7 percent to 8 percent on passenger vehicles that weigh more than 5,000 pounds.[15] The excise tax will cost the owner of a new $60,000 SUV $4,800, an increase of $600 on a one-time basis when an owner registers the vehicle. The annual vehicle registration fee on SUVs also will increase by $40, from $115 to $155.

Other jurisdictions that have proposed increased fees for SUVs include Maryland, which would require owners of vehicles weighing more than 6,000 pounds to pay a surcharge of $750 in addition to the annual registration renewal fee. States such as Pennsylvania and New Jersey have planned to raise the vehicle license fee for all vehicles, charging SUV and minivan owners a small percentage more.

RESIDENTIAL PARKING PERMIT FEES

Established in 1976, residential parking permits (RPPs) were designed to provide more parking spaces for residents by preventing long-term parking by non-residents. To be eligible to purchase a permit, one must live in an established RPP area. Annual fees are $27. Other types of permits that can be purchased include visitor's permits, rental car permits, and daily and weekly permits. Under State law, RPP permit fees are considered "regulatory" and revenues can only be used to cover the costs directly associated with the RPP program.[16] In San Francisco, these costs include:

- Engineering survey for new and expanded areas (consistent with Traffic Code);
- Installation and maintenance of RPP signs;
- Processing of permits; and

[15] The excise tax is a one-time payment made when an owner registers a vehicle.
[16] Residential Parking Permit fees cannot exceed the costs associated with the program.

- Enforcement of regulations.

DPT recently introduced legislation to clarify the requirements for issuance of RPPs and to increase fees. Under the proposed ordinance (File No. 050329), annual permit fees would increase from $27 to $60. Fees for all other permits issued by DPT would also increase. As of March 4, 2005, the proposed ordinance was assigned to the Budget and Finance Committee.

Increasing Fees for SUVs

According to DPT, the Board of Supervisors has final approval authority for all RPP fee increases. Since the RPP fee is regulatory, the cost of the permits cannot exceed the direct cost associated with a preferential parking system (i.e. administration, enforcement, etc.). Since the inception of the RPP fee, rates have applied equally to all vehicles parking in designated areas.

DPT indicated that while it is possible to restrict fee increases to large SUVs, the process would be costly and pose significant administrative challenges. In order to single out SUVs, there must be an associated impact on the permit program. Creating a fee structure whereby large SUV owners would pay an increased RPP fee would not be feasible, due to the fact that there are other vehicles with similar dimensions (such as mini vans, station wagons, and trucks). There must be a distinctive reason that SUVs stand out among other to charge them a higher fee.

DPT does not currently record or verify the type of vehicle when issuing permits. It would therefore have to expand its system to do so. The City Department of the Environment has identified three databases on the web that provide vehicle length information and could be used with the current permit system to implement a fee structure based on vehicle length. Currently, there are no estimates of how much it would cost to expand the permit system in this manner.

POLICY OPTIONS

The Board of Supervisors can consider various courses of action regarding SUVs, including the following.

Conduct Research on Road and Pavement Damage Caused by SUVs

Identifying whether SUVs cause a disproportionate amount of damage to streets is critical to pursuing related policy solutions. While researchers recognize that heavier vehicles cause more road damage, the exact nature of the relationship is not well understood. Vehicle weight is one of many factors that contribute to road and pavement damage. The Board should consider directing an appropriate agency or consultant to conduct a study on this issue to verify established formulas and conclusions.

Increase Enforcement of Weight Limits on Restricted Traffic Streets

Currently, the Traffic Code is states that all vehicles weighing over 6,000 pounds are restricted from designated streets. Several large SUVs meet or exceed that weight limit, despite the intentions of the Code to target heavy commercial vehicles. The Code is somewhat self-enforcing because many that drive regulated vehicles are familiar with the regulations and use alternate routes. However, the regulation is infrequently (if ever) enforced on SUVs. Thus, many SUVs owners remain ignorant of the regulation. The Board might want to reconsider Traffic Code 28.1 and determine whether or not to direct enforcement upon SUVs.

Increase Residential Parking Permit Fees for All Overlength Vehicles

The Board of Supervisors has the final authority to authorize changes to residential parking permit (RPP) fees. If the Board is looking to restrict fee increases to SUVs, it must demonstrate that there is an associated impact on the RPP program. The fact that SUVs are longer than some other vehicles is insufficient to increase RPP fees for SUVs alone, as the fee would also have to apply to other vehicles with similar lengths, such as minivans, station wagons, and trucks. The Board should consider specially regulating "overlength" vehicles within the RPP program.

Support State Legislation Authorizing San Francisco to Enact a Local VLF

The Board does not have the authority to enact a VLF. That right is reserved for the State, which can choose to pass legislation enabling local governments to enact a local VLF supplement. AB 799 would give the Board of Supervisors the authority to introduce an ordinance imposing a local VLF for general revenue purposes. The ordinance would need to be approved by two-thirds of the Board and subsequently approved by a majority of the voters.

The Board could also choose to initiate its own bill to implement a local VLF for the specific purpose of funding traffic-related programs. According to the City Attorney's Office, if authorized by State legislation, a local ordinance could be crafted to impose a fee charged exclusively on SUVs. In order for this to occur, a group or agency must take the lead in developing legislation for a VLF in San Francisco County. A State legislator must sponsor the proposal and the proceeds from the fee must be designated for traffic-related projects that mitigate costs attributable to automobiles. Among other things, the legislation must outline the administrative functions of the program and fees charged to automobiles (which must not exceed the cost of the program in order to avoid being characterized as a tax). Based on the San Mateo example, an advisory group would also be useful for developing various aspects of the program.

Attachment 1 – Department of Public Works (DPW) Pavement Design Analysis

This analysis discusses the procedures used to design the thickness of pavements, particularly, Portland Cement Concrete (PCC) pavements, on San Francisco streets and highways, in relation to the effect of heavy SUVs to the life of the pavement. The purpose is to answer the following underlying question: "Do SUVs contribute pavement damage to the existing streets within the City."

In order to answer this question, we have to look at the different parameters used in the design of PCC pavement.

City pavements typically consists of 2" of asphalt concrete laid over 6" or 8" of concrete base. Because of the concrete base, we consider this a "rigid" pavement and therefore focused our analysis on the design of rigid PCC pavements.

Design Loads

According to the Caltrans' Highways Design Manual (December 20, 2004), Section 602.1, the main design parameter used for pavements is stated as follows:

"Pavement structural sections are designed to carry the projected truck traffic expected to occur during the pavement life. This truck traffic is the primary factor affecting pavement life. ***Passenger cars, pickups, and two-axle trucks are considered to be negligible***." [Emphasis added.]

The Civil Engineering Reference Manual by M. R. Lindeburg, Sixth Edition, Chapter 16.20, explains further that the "two-axle trucks ***with single rear tires***" [emphasis added] are not considered in the design load analysis. SUVs are lighter in weight than two-axle trucks with single rear tires.

To determine the truck design factor, the number of trucks and the axle loading of those trucks must be known. The usual sources of truck volume data are traffic counts, which are usually presented as average truck traffic per day. This truck data is used to determine the total truck loads for the typical pavement design life of 20 years.

Equivalent Single-Axle Load

Since there are a number of different truck types with different axle loadings, the overall truck data is translated to an equivalent 18-kip single axle load, or ESAL. This reduces the traffic data into the number of 18-kip axle passes that would cause the same structural damage.

There are a number of methods used to convert different axle loads into the 18-kip ESAL. Two of the methods are described as follows:

Method 1: Convert equivalent axle loads to 18-kip axle loads.

$$ESAL_{18\text{-kips}} = ESAL_{n\text{-kips}} \times (n \text{ in kips}/18)^4 \qquad (1)$$

Method 2: Approximate the equivalent 18-kip axle loading from the number of trucks passing per day multiplied by the truck constants. The current 20-year ESAL truck constants are as follows:

$ESAL_{18\text{-kips}}$ = (1380)(# 2-axle trucks) + (3680)(# 3-axle trucks)
+ (5880)(# 4-axle trucks) + (13,780)(# 5-axle trucks) (2)

Using method 1, the factor to convert the number of axles for a 5-kip axle load to 18-kip axle load is 0.006, or about 1/168; while the factor to convert a 32-kip axle load is about 10. This means that the effect of a heavy 32-kip truck axle load is 10 times more than the effect of an 18-kip axle load, while it requires 168 5-kip axle loads (10-kip trucks) to equal the effect of one 18-kip axle load.

Whether a 10-kip truck would cause damage to a pavement depends on the type of pavement being impacted. This subject is covered in PCC design methods below.

Other Design Parameters

In addition to the number of axle loads to be carried by the pavement, other design parameters needed to design the PCC structural pavement section are as follows:

modulus of subgrade reaction (*k*) for the roadbed soil
modulus of elasticity of the concrete to be used (E_c)
allowable working stress in concrete (f_t)
modulus of rupture for the concrete to be used (MR)

All these parameters, including the $ESAL_{18\text{-kip}}$ data, are plotted on design charts and nomographs to determine the thickness of the PCC pavement, or to check if an existing section is adequate to carry the expected truck traffic.

AASHTO Method

A sample chart for AASHTO (American Association of State Highway and Transportation Officials) Rigid Pavement Design (Exhibit A) shows that a 5,000,000 $ESAL_{18\text{-kip}}$ (20 years) will require a pavement thickness of 8.25 inches. The assumed data for concrete and subgrade are typical values and are used only for illustration here. The resulting PCC pavement thickness could be rounded up to 8.5 inches or 9 inches as the final design thickness.

In this example, considering all the other parameters are the same, an increase in equivalent 18-kip truck loads of 1,000,000 for the 20-year life will require a pavement thickness of 8.75 inches, or 9 inches of final design thickness. This is an increase of half-inch.

Based on formula (1) above, this increase of 1,000,000 18-kip axle loads is equal to 168,000,000 5-kip axle loads, or about 11,500 10-kip trucks or SUVs per day. This is the number of SUVs needed to require a half-inch increase in the pavement thickness, and this must be a very busy street to have that number.

Fatigue Strength Method

The fatigue strength method is better suited for analysis of existing pavement sections or proposed pavement sections than for design, since the layer thickness data are required in the procedure. This design uses several charts and nomographs to determine the required analytical numbers.

According to Lindeburg's Civil Engineering Reference Manual, in a Fatigue Strength Method of PCC pavement analysis, the **small loads are considered to have no effect at all to the life of the pavement**. "As long as the stress induced in the pavement is less than the fatigue strength, an infinite number of repetitions of that stress can be applied without damage to the pavement. This means that, for any given stress above the fatigue strength, there is an allowable fatigue life, or number of allowable repetitions. If the actual number of applications of a stress taken over 20 years is divided by the allowable repetitions for that stress, the fatigue fraction is obtained."

The "stress" in this method represents an axle load determined from loadometer survey. Thus, the actual distribution of axle loads is needed, such as, the number of 18-kip loads, 26-kip loads, 32-kip loads, and so on. To obtain the allowable repetitions for each axle load, the stress ratio is determined. The stress ratio is the stress induced by an axle load divided by the modulus of rupture of concrete used. The stress induced by each type of axle load is determined by using the stress chart, Figure 16.18 or 16.19 of the Reference Manual (Exhibit B). Stress ratio values of 0.50 or less do not need to be analyzed or recorded since this corresponds to the endurance strength of concrete, and unlimited repetitions are allowed. This stress ratio is in turn used to obtain the allowable repetitions from table 16.26 of the Reference Manual (Exhibit B).

If the sum of all fatigue fractions corresponding to different stresses is less than approximately 1.0, the pavement is adequate.

Using the Stress Chart for Single Axle Loads, and assuming k = 100, and the PCC thickness = 0.45 foot, a 10-kip single axle load would induce a stress of about 270 psi. With a Modulus of Rupture of concrete equal to 550 psi, this would calculate to a stress ratio of 0.49. Since the stress ratio is less than 0.50, a 10-kip single axle load will not have a damage effect to a 5.4-inch thick concrete, or thicker.

Based on this analysis, a 10-kip truck or SUV, with an axle load of 5 kips, will have no damage effect to a concrete pavement 5-1/2 inch thick or more.

Caltrans Rigid Pavement Design Method

According to the Highway Design Manual, Caltrans method of rigid pavement design includes the $ESAL_{18\text{-kip}}$, which is connected to a Traffic Index (TI).

The Traffic Index is a measure of the number of ESALs expected in the design lane over the design period. The TI does not vary linearly with the ESALs, but rather according to the following exponential formula:

$$TI = 9.0 \times (ESAL/10^6)^{0.119} \qquad (3)$$

Table 602.4A (Exhibit C) of the Highway Design Manual illustrates this formula and is used to convert ESAL to TI.

This TI is then used to determine the PCC pavement thickness in Table 603.2 (Exhibit D).

According to Table 603.2, an 8-inch thick concrete is designed to handle a TI of 8 or less; 8.5-inch thick can handle TI of 8.5 to 10; 9-inch thick can handle a TI of 10.5 to 12; and so on.

Considering that the standard pavement section of City streets is 2-inch thick asphalt concrete over 8-inch thick PCC, a Traffic Index of 8.0 could be used. This does not take into account the 2-inch asphalt layer on top. If we take this asphalt layer into consideration and assume the concrete pavement to be 9-inch thick (which is the concrete base used for major streets, such as, The Embarcadero and Octavia Blvd), the TI ranges from 10.5 to 12, which correspond to a range in ESALs from 3 to 13.5 million – a spread of 10.5 million ESALs. This means that an increase of more than 10.5 million ESALs is necessary to require a thicker pavement.

According to formula (1) above, if the number of 10-kip SUV traffic for 20 years is 20 million (about 2,740 per day), it is equivalent to 240,000 $ESAL_{18\text{-kip}}$. This is well within the range of the pavement's capacity.

In contrast, a sample calculation for TI using truck traffic data is shown on Table 602.4B (Exhibit C). This table shows how the truck constants are used to calculate the ESAL for 20 years. The total Average Annual Daily Truck Traffic is 2,735, but this number is equivalent to 18,761,800 $ESAL_{18\text{-kip}}$ for the outside lanes of an 8-lane freeway. That is why only truck data are used to design the pavement sections.

Comments on the Legislative Analyst's Draft Report

The Legislative Analyst cited that "formulas commonly used by transportation engineers and researchers indicate that roadway damage is proportional to weight raised to the fourth power, meaning that damage exponentially increases with heavier vehicles."

Although this citation appears to be similar to the Caltrans formula (1) given at the top of page 2 of this analysis, DPW engineers are not familiar with it. A check with engineering colleagues from the cities of San Jose, San Diego and Los Angeles also indicates that they are not familiar with the formula.

Using the internet site referenced by Jeremy Nelson in an email to the Legislative Analyst's office, we found the formula in a British paper on the costs and price of transport. It was given as:

$$D = (A_l / A_c)\,(W_l / W_c)^4 \qquad (4)$$

where D is the proportional road damage, A_l is the number of lorry (truck) axles, A_c is the number of car axles, W_l is the weight of each lorry axles, and W_c is the weight of each car axle.

We should note that "D" has no units. It is the proportional road damage when comparing the effects of truck with that of cars. For example, the paper compared the impacts of a 36-ton 6-axle lorry with a one-ton car and determined from the formula that a 35-ton, 6-axle lorry will cause more damage than 60,000 one-ton cars.

Applying the formula to the weights of vehicles given in the Legislative Analyst's report, one may conclude that:

One Ford Excursion SUV causes more damage than 23 Honda Accords.
One Ford Excursion SUV causes more damage than 7 Lincoln Town Cars.

The British paper referenced the following sources for the formula:

Roth, "Roads in a Market Economy", 1996
Watson, John, "Highway Construction and Maintenance", Longman Scientific and Technical, 1994

While the formula is designed to compare the relative effects of trucks and cars, it is unclear whether the formula is applicable for comparing SUVs with cars.

Conclusions

From this analysis, we find that:

Standard design manuals suggest that the impact of cars, pickups and two-axle trucks are negligible when designing pavements. The amount of heavy truck traffic is the determining factor.
City pavements are considered "rigid pavements" due to use of a concrete base. When using the Fatigue Strength Method of design, the pavement will fail if it is subjected to repeated applications of heavy loads causing it to exceed its fatigue strength. Due to their relatively light weights, repeated applications of car and SUV loads will not cause a pavement to exceed its fatigue strength.
A consultant study may be needed to verify these conclusions and to verify the citation that "roadway damage is proportional to weight raised to the fourth power".

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