City of Redlands

Pavement Deterioration Analysis Report

September 18, 2012

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Executive Summary

In an effort to determine the approximate pavement deterioration percentage caused by refuse and City utility vehicles, TKE is using a vehicle load factor method developed by the American Association of State Highway and Transportation Officials. Using this method, TKE has calculated typical annual vehicle loads imparted on residential, collector and arterial streets.

The vehicle loading factors for refuse vehicles were averaged between the empty and full load factors to calculate the percent impact. As shown in the tables below, refuse vehicles combine for 56.3% vehicle impact loading on residential streets, 15.5% vehicle impact loading on collector streets and 9.1% vehicle impact loading on arterial streets, while City utility vehicles contribute 1.6% vehicle impact loading on residential streets, 0.9% vehicle impact loading on collector streets and 0.5% vehicle impact loading on arterial streets.

As shown by the percentages, refuse vehicles account for the highest vehicle loading factors regularly operating on residential streets and as such, are the major contributor to residential street deterioration. Due to the higher volume of heavier vehicles on collector and arterial streets, refuse vehicles are a much lower contributor to the deterioration of those streets. The relatively low percentage rates for City utility vehicles are a direct correlation to their low relative traffic volumes and vehicle load factors.

Using the estimated 50 year construction and maintenance costs shown in the tables below for each street type, the relative annualized refuse and City utility vehicle impact cost totals per street mile are $16,500 and $480 for residential streets, $6,300 and $360 for collector streets and $7,000 and $400 for arterial streets. The City of Redlands total street lane miles are as follows, 59% residential (378 lane miles), 20% collector (129 lane miles) and 21% arterial (133 lane miles). Using this information with the vehicle load impact percentages and annualized impact totals per lane mile shown above the annual City wide impact cost is as follows:

> Residential streets relative City wide yearly refuse and City utility vehicle construction cost impact total for 378 lane miles at $8,250 and $240 per lane mile is $3,118,500 and $90,720.

Collector streets relative City wide yearly refuse and City utility vehicle construction cost impact total for 129 lane miles at $2,100 and $120 per lane mile is $270,900 and $15,480.

Arterial streets relative City wide yearly refuse and City utility vehicle construction cost impact total for 133 lane miles at $1,750 and $100 per lane mile is $232,750 and $13,300.

Therefore, there is an annualized City wide total of $3,622,150 of street related damage from refuse vehicle impact loads and $119,500 from City utility vehicle impact loads. In addition to the projected road maintenance costs, it is fair to assume that a percentage of pothole repair costs equal to the impact percentages would be attributed to the corresponding vehicle type.

Introduction

In an effort to determine the approximate pavement deterioration percentage caused by refuse and City utility vehicles, the City of Redlands has consulted with TKE Engineering, Inc. to perform a pavement analysis report. The report will identify the estimated amount of yearly maintenance cost attributed to refuse and City utility vehicles traveling on City streets and will provide a means of visualizing and understanding how the heavy loads affect the streets service life.

Background

Over the past 70 years, the design of paved driving surfaces has evolved through a number of formulas derived from experimental test procedures. Today, engineers have an extensive knowledge and understanding on exactly how pavement surfaces react to the daily stresses they are subjected to. When designing asphalt pavement streets two major factors are considered; (1) the strength of the underlying soil and (2) the degree of traffic loading the street will be subjected to, also called the "Traffic Index" or "TI".

> The strength of the underlying soil is tested by a Geotechnical Engineer and will determine the thickness of the overall pavement section required to support the traffic loads expected for each street. A pavement section is comprised of the asphalt concrete pavement and aggregate base subgrade that is placed beneath the asphalt concrete pavement and above the underlying soil. The weaker the underlying soil is on a specific street, the greater the overall thickness of aggregate base subgrade and asphalt concrete pavement will need to be.
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> Traffic loading represents the weight that a vehicle applies to the pavement surface and how often that weight is applied based on the number of axels the vehicle contains. Since the configuration and weight of vehicles traveling on the streets varies so drastically, the American Association of State Highway and Transportation Officials (AASHTO) and other research and regulatory agencies have developed a method to represent all vehicles in a similar manner called the Equivalent Single Axle Load (ESAL). The Traffic Index formula utilizes a design number of ESAL's a street is expected to handle and converts

it to a usable number for the design of the pavement section. The higher the TI value, the greater number of ESAL's the street was designed to withstand.

ESAL represents the damaging effect of an axle of any mass can be represented by a number of 18,000 pound equivalent axle loads. For example, one application of a 12,000 pound single axle was found to cause damage equal to approximately 0.23 applications of an 18,000 pound single axle load. Therefore, the 18,000 pound single axle load causes 4 times the damage as a 12,000 pound single axle load. In fact, for a load that is twice as large as an initial load, the damage to the roadway is roughly 16 times greater.

Using the ESAL method, AASHTO has developed a table identifying typical vehicle load factors (VLF's) and the relative damage the vehicle impart on a roadway. Using the table from Appendix D of the 1993 AASHTO Guide for Design of Pavement Structures we find the following values:

Vehicle	VLF	Passenger Car Equivalent
Passenger Car (Assumed Base Line)	0.0004	1
Pre-Mix 7 yd^3 Concrete Truck	1.84	4,600
Pre-Mix 10 yd^3 Concrete Truck	2.03	5,100
Standard Delivery Truck	0.50	1,250
Residential Refuse Garbage Truck (Empty)	2.01	5,000
Residential Refuse Garbage Truck (Full)	4.71	11,800
Residential Recycle Garbage Truck (Empty)	1.20	3,000
Residential Recycle Garbage Truck (Full)	2.82	7,000
Residential Green Garbage Truck (Empty)	1.70	4,200
Residential Green Garbage Truck (Full)	3.99	10,000
Utility Vehicle	0.50	1,250
City Bus	3.49	8,700
School Bus	2.98	7,500
Fire Truck	0.68	1,700

The above table depicts the relative and disproportionate amount of damage a single heavy vehicle can impart on the roadway in relation to a passenger vehicle.

Approach

Using the accepted vehicle loading factors developed by AASHTO, TKE has calculated typical annual vehicle loads imparted on residential, collector and arterial streets. It is assumed that streets will see similar vehicular traffic on a weekly basis due routine patterns within society. Therefore, weekly percentages of vehicle impact loading will also reflect accurate yearly percentages which can be used to calculate related street construction and maintenances costs. Our calculations are based on the following estimated traffic volumes.

Residential streets will have volumes of approximately 200 passenger vehicles per day, one refuse, recycle, and greenwaste trash truck each per week, one City Utility vehicle every other week and 12 standard delivery trucks per week.

Collector streets will have volumes of approximately 2,000 passenger vehicles per day, three refuse, recycle, and greenwaste trash truck each per week, 60 standard delivery trucks per week, 3 City Utility vehicles per week, 2 fire trucks per week, 14 City buses per week, 10 school buses per week and 14 commercial trucks per week.

Arterial streets will have volumes of approximately 12,000 passenger vehicles per day, ten refuse, recycle, and greenwaste trash truck each per week, 200 standard delivery trucks per week, 10 City Utility vehicles per week, 20 fire trucks per week, 50 City buses per week, 50 school buses per week and 200 commercial trucks per week.

The relative vehicle loading factors for refuse vehicles were averaged between the empty and full load factors to calculate the percent impact. As shown in the tables below, refuse vehicles combine for 56.3% vehicle impact loading on residential streets, 15.5% vehicle impact loading on collector streets and 9.1% vehicle impact loading on arterial streets, while City utility vehicles contribute 1.6% vehicle impact loading on residential streets, 0.9%

vehicle impact loading on collector streets and 0.5% vehicle impact loading on arterial streets.

As shown by the percentages, refuse vehicles account for the highest vehicle loading factors regularly operating on residential streets and as such are the major contributor to residential street deterioration. Due to the higher volume of heavier vehicles on collector and arterial streets, refuse vehicles are a much lower contributor to the deterioration of those streets. The relatively low percentage rates for City utility vehicles are a direct correlation to their low relative traffic volumes and vehicle load factors.

Residential Streets

Vehicle Type	Vehicle Load Factor	Weekly Vehicle Total	Total Weekly Impact	Percent Impact	Total
Passenger Vehicle	0.0004	1400	0.56	3.6%	-
Refuse	3.36	1	3.36	**21.6%**	
Recycle	2.42	1	2.42	**15.5%**	**56.3%**
Greenwaste	3.00	1	3.00	**19.2%**	
Delivery Truck	0.50	12	6.00	38.5%	-
City Utility Vehicle	0.50	0.5	0.25	**1.6%**	-
City Bus	2.98	0	0.00	0.0%	-
School Bus	3.49	0	0.00	0.0%	-
Fire Truck	0.68	0	0.00	0.0%	-
Commercial Truck	2.03	0	0.00	0.0%	-
			15.59	100.0%	-

Collector Streets

Vehicle Type	Vehicle Load Factor	Weekly Vehicle Total	Total Weekly Impact	Percent Impact	Total
Passenger Vehicle	0.0004	14000	5.60	3.3%	-
Refuse	3.36	3	10.08	**5.9%**	
Recycle	2.42	3	7.25	**4.3%**	**15.5%**
Greenwaste	3.00	3	9.00	**5.3%**	
Delivery Truck	0.50	60	30.00	17.7%	-
City Utility Vehicle	0.50	3	1.50	**0.9%**	-
City Bus	2.98	14	41.72	24.6%	-
School Bus	3.49	10	34.90	20.6%	-
Fire Truck	0.68	2	1.36	0.8%	-
Commercial Truck	2.03	14	28.42	16.7%	-
			169.83	100.0%	-

Arterial Streets

Vehicle Type	Vehicle Load Factor	Weekly Vehicle Total	Total Weekly Impact	Percent Impact	Total
Passenger Vehicle	0.0004	84000	33.60	3.5%	-
Refuse	3.36	10	33.60	**3.5%**	
Recycle	2.42	10	24.15	**2.5%**	**9.1%**
Greenwaste	3.00	10	30.00	**3.1%**	
Delivery Truck	0.50	200	100.00	10.3%	-
City Utility Vehicle	0.50	10	5.00	**0.5%**	-
City Bus	2.98	50	149.00	15.4%	-
School Bus	3.49	50	174.50	18.0%	-
Fire Truck	0.68	20	13.60	1.4%	-
Commercial Truck	2.03	200	406.00	41.9%	-
			969.45	100.0%	-

Construction and maintenance costs for each street type have considerable differences. In general, residential streets are not as wide and are designed with smaller pavement sections resulting in lower cost per paved mile of roadway, while collector and especially arterial streets result in much higher cost per paved mile. To estimate construction and maintenance costs we have assumed the following design standards for each street type.

> Residential streets are 36-feet wide with a pavement section of 3-inches of asphalt concrete pavement over 4-inches of crushed aggregate base.
>
> Collector streets are 40-feet wide with a pavement section of 4-inches of asphalt concrete pavement over 5-inches of crushed aggregate base.
>
> Arterial streets are 64-feet wide with a pavement section of 5-inches of asphalt concrete pavement over 6-inches of crushed aggregate base.

In the tables below, we have shown typical construction and maintenance pavement costs for each street type over a typical replacement life expectancy period of 50 years. The tables include construction costs breakdowns with item descriptions, units, quantities, unit costs and totals for each street type, including street construction (year 1), street slurry maintenance (year 15), street overlay reconstruction (year 30), street slurry maintenance (year 40) and full street reconstruction (year 50). The costs are calculated using a 2012 cost baseline with no assumed inflation and are shown per linear mile of full street width.

For streets that are not properly maintained, additional street maintenance will be required in the form of pothole repair. Pothole repair costs would also be attributed at percentage rates equal to those described in the impact tables above. Therefore, 56.3% of the City's annual pothole repair costs on residential streets would be attributed to refuse vehicles.

Residential Streets 36-Foot Width

Description	Unit	Quantity		Unit Cost		Total
Construction (Year 1)						
Traffic Control	LS	1	$	10,000.00	$	10,000.00
Asphalt Pavement	Tons	3369	$	85.00	$	286,334.40
Aggregate Base	CY	2295	$	55.00	$	126,198.52
Striping	LS	1	$	10,000.00	$	10,000.00
				Subtotal:	**$**	**432,532.92**
Maintenance (Year 15)						
Traffic Control	LS	1	$	10,000.00	$	10,000.00
Asphalt Pavement Slurry	SF	168960	$	0.40	$	67,584.00
Striping	LS	1	$	10,000.00	$	10,000.00
				Subtotal:	**$**	**87,584.00**
Maintenance (Year 30)						
Traffic Control	LS	1	$	10,000.00	$	10,000.00
Asphalt Pavement Grind	SF	168960	$	0.50	$	84,480.00
Asphalt Pavement Overlay	Tons	1684	$	85.00	$	143,167.20
Striping	LS	1	$	10,000.00	$	10,000.00
				Subtotal:	**$**	**247,647.20**
Maintenance (Year 40)						
Traffic Control	LS	1	$	10,000.00	$	10,000.00
Asphalt Pavement Slurry	SF	168960	$	0.40	$	67,584.00
Striping	LS	1	$	10,000.00	$	10,000.00
				Subtotal:	**$**	**87,584.00**
Maintenance (Year 50)						
Traffic Control	LS	1	$	10,000.00	$	10,000.00
Asphalt Pavement Grind	SF	168960	$	1.00	$	168,960.00
Asphalt Pavement	Tons	3369	$	85.00	$	286,334.40
Aggregate Base	CY	2295	$	55.00	$	126,198.52
Striping	LS	1	$	10,000.00	$	10,000.00
				Subtotal:	**$**	**601,492.92**
				Total:	**$**	**1,460,000.00**
				Refuse Impact Total (56.3%):	**$**	**823,000.00**
				Annualized Refuse Impact Total:	**$**	**16,500.00**
				City Utility Vehicle Impact Total (1.6%):	**$**	**24,000.00**
				Annualized City Utility Vehicle Impact Total:	**$**	**480.00**

Collector Streets 40-Foot Width

Description	Unit	Quantity		Unit Cost		Total
Construction (Year 1)						
Traffic Control	LS	1	$	20,000.00	$	20,000.00
Asphalt Pavement	Tons	5053	$	85.00	$	429,501.60
Aggregate Base	CY	3227	$	55.00	$	177,466.67
Striping	LS	1	$	20,000.00	$	20,000.00
				Subtotal:	**$**	**646,968.27**
Maintenance (Year 15)						
Traffic Control	LS	1	$	20,000.00	$	20,000.00
Asphalt Pavement Slurry	SF	190080	$	0.40	$	76,032.00
Striping	LS	1	$	20,000.00	$	20,000.00
				Subtotal:	**$**	**116,032.00**
Maintenance (Year 30)						
Traffic Control	LS	1	$	20,000.00	$	20,000.00
Asphalt Pavement Grind	SF	190080	$	0.50	$	95,040.00
Asphalt Pavement Overlay	Tons	1895	$	85.00	$	161,063.10
Striping	LS	1	$	20,000.00	$	20,000.00
				Subtotal:	**$**	**296,103.10**
Maintenance (Year 40)						
Traffic Control	LS	1	$	20,000.00	$	20,000.00
Asphalt Pavement Slurry	SF	190080	$	0.40	$	76,032.00
Striping	LS	1	$	20,000.00	$	20,000.00
				Subtotal:	**$**	**116,032.00**
Maintenance (Year 50)						
Traffic Control	LS	1	$	20,000.00	$	20,000.00
Asphalt Pavement Grind	SF	190080	$	1.00	$	190,080.00
Asphalt Pavement	Tons	5053	$	85.00	$	429,501.60
Aggregate Base	CY	3227	$	55.00	$	177,466.67
Striping	LS	1	$	20,000.00	$	20,000.00
				Subtotal:	**$**	**837,048.27**
				Total:	**$**	**2,020,000.00**
				Refuse Impact Total (15.5%):	**$**	**314,000.00**
				Annualized Refuse Impact Total:	**$**	**6,300.00**
				City Utility Vehicle Impact Total (0.9%):	**$**	**18,000.00**
				Annualized City Utility Vehicle Impact Total:	**$**	**360.00**

Arterial Streets 64-Foot Width

Description	Unit	Quantity	Unit Cost	Total
Construction (Year 1)				
Traffic Control	LS	1	$ 25,000.00	$ 25,000.00
Asphalt Pavement	Tons	10527	$ 85.00	$ 894,795.00
Aggregate Base	CY	6453	$ 55.00	$ 354,933.33
Striping	LS	1	$ 40,000.00	$ 40,000.00
			Subtotal:	**$ 1,314,728.33**
Maintenance (Year 15)				
Traffic Control	LS	1	$ 25,000.00	$ 25,000.00
Asphalt Pavement Slurry	SF	316800	$ 0.40	$ 126,720.00
Striping	LS	1	$ 40,000.00	$ 40,000.00
			Subtotal:	**$ 191,720.00**
Maintenance (Year 30)				
Traffic Control	LS	1	$ 25,000.00	$ 25,000.00
Asphalt Pavement Grind	SF	316800	$ 0.50	$ 158,400.00
Asphalt Pavement Overlay	Tons	3158	$ 85.00	$ 268,438.50
Striping	LS	1	$ 40,000.00	$ 40,000.00
			Subtotal:	**$ 491,838.50**
Maintenance (Year 40)				
Traffic Control	LS	1	$ 25,000.00	$ 25,000.00
Asphalt Pavement Slurry	SF	316800	$ 0.40	$ 126,720.00
Striping	LS	1	$ 40,000.00	$ 40,000.00
			Subtotal:	**$ 191,720.00**
Maintenance (Year 50)				
Traffic Control	LS	1	$ 25,000.00	$ 25,000.00
Asphalt Pavement Grind	SF	316800	$ 1.00	$ 316,800.00
Asphalt Pavement	Tons	10527	$ 85.00	$ 894,795.00
Aggregate Base	CY	6453	$ 55.00	$ 354,933.33
Striping	LS	1	$ 40,000.00	$ 40,000.00
			Subtotal:	**$ 1,631,528.33**
			Total:	**$ 3,830,000.00**
			Refuse Impact Total (9.1%):	**$ 347,000.00**
			Annualized Refuse Impact Total:	**$ 7,000.00**
			City Utility Vehicle Impact Total (0.5%):	**$ 20,000.00**
			Annualized City Utility Vehicle Impact Total:	**$ 400.00**

Conclusion

Using the estimated 50 year construction and maintenance costs shown in the tables below for each street type, the relative annualized refuse and City utility vehicle impact cost totals per street mile are $16,500 and $480 for residential streets, $6,300 and $360 for collector streets and $7,000 and $400 for arterial streets. The City of Redlands total street lane miles are as follows, 59% residential (378 lane miles), 20% collector (129 lane miles) and 21% arterial (133 lane miles). Using this information with the vehicle load impact percentages and annualized impact totals per lane mile shown above the annual City wide impact cost is as follows:

Annual City Wide Refuse Impact

Lane Type	Number of Lanes	Lane Miles	Refuse Impact Annualized	Refuse Impact per Lane Mile	Annual City Wide Impact
Residential	2[1]	378	$16,500	$8,250	$3,118,500
Collector	3[2]	129	$6,300	$2,100	$270,900
Arterial	4[3]	133	$7,000	$1,750	$232,750
				Total:	**$3,622,150**

Annual City Wide City Utility Vehicle Impact

Lane Type	Number of Lanes	Lane Miles	City Utility Impact Annualized	City Utility Impact per Lane Mile	Annual City Wide Impact
Residential	2[1]	378	$480	$240	$90,720
Collector	3[2]	129	$360	$120	$15,480
Arterial	4[3]	133	$400	$100	$13,300
				Total:	**$119,500**

Notes:

1. Per City staff, residential streets typically have two-lanes per mile with an average width of 36-feet.
2. Per City staff, collector streets typically have two-lanes or four-lanes per mile with an average width of 40-feet. An average of three-lanes per mile was used.
3. Per City staff, arterial streets typically have four-lanes or six-lanes per mile with an average width of 64-feet. An average of four-lanes per mile was used.

Therefore, there is an annualized City wide total of $3,622,150 of street related damage from refuse vehicle impact loads and $119,500 from City utility vehicle impact loads. In addition to the projected road maintenance costs, it is fair to assume that a percentage of pothole repair costs equal to the impact percentages would be attributed to the corresponding vehicle type.