

# Assessing the Effects of Heavy Vehicles on Local Roadways

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Research Project Final Report 2014-32



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This report documents the developments the impact of heavy vehicles which were not anticipated at the damage and thus create the need unexpected heavy vehicles could urban waste collection patterns, reasons. The tool described in the analyze a single roadway segments summary statistics over the systemetry of the syst	opment of an analysis proce nicles on local agency paven e time the pavement structur for rehabilitation or reconst d be generated by new indus temporary heavy construction is report implements the pro- nt (for detailed impacts estin- em). The tool provides estim	dure and an associated computation tool to nents. The heavy vehicles of interest are those re was designed, but which cause additional truction sooner than expected. These trial facilities, mining activities, changes in on in a limited geographical area, or for other ocedure, and provides users with the ability to nates) or an agency's entire network (for nates of the percent of originally intended life			
that may be used by the unanticipated vehicles the additional pavement structure that would have been					

required at construction to accommodate the additional vehicles, and the additional damage that they cause. The tool is contained in a macro-enabled Microsoft Excel spreadsheet and does not need additional files or external functionality to conduct an analysis.

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# Assessing the Effects of Heavy Vehicles on Local Roadways

# **Final Report**

Prepared by

W. James Wilde Center for Transportation Research and Implementation Minnesota State University, Mankato

# August 2014

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# **EXECUTIVE SUMMARY**

This report presents the results of the work to develop an analysis method and associated tool for estimating the impacts of heavy vehicles on pavement structures on local roads such as county highways and city streets. The impacts are predicted in two ways: the additional bituminous material that would have been designed into the pavement structure if the additional heavy vehicles had been anticipated at design time; and the portion of the pavement's design life consumed by the additional, unanticipated heavy vehicles. The tool also predicts the additional degradation in terms of pavement condition index, provided that the user's pavement management database contains enough historical information for a prediction to be made.

The expected uses of the analysis and associated tool include evaluating the impacts of new distribution centers or warehouses, large industrial areas, and siting of hog farms or ethanol plants, etc. Additionally, the tool may be used for short-term analyses such as the construction traffic associated with wind farm construction.

# **Chapter 1. INTRODUCTION**

This report describes the development and implementation of a tool to estimate the effects of heavy vehicles on local roads. The main focus of the tool is to determine the effects of additional heavy vehicles that were unknown and could not have been considered at the time the roadway and pavement were designed. This situation could arise due to new commercial facilities bringing additional vehicles on a permanent basis, the temporary additional heavy vehicles required for some major construction activities, the location of new mining activities and associated haul routes, or for other causes.

The tool developed as part of this project compares the impact of the vehicle loading that was expected when the pavement was designed to the impact of vehicle loading including additional vehicles associated with newly constructed or conceived traffic generators.

#### **Project Objectives**

The primary objective of this project was to develop an analysis method and a corresponding tool for local road and highway agencies to use when evaluating the impact of heavy vehicles and large volumes of traffic. Often the vehicles under consideration are comprised of large volumes of unexpected vehicles attributable to specific developments or events, such as the construction of a new warehouse or distribution center, development of wind energy farms, etc.

#### **Report Content**

The report describes the activities of the research team over the duration of the project, the development of the associated tool, and the interactive training program utilized for its implementation and dissemination. The remainder of this chapter includes a review of literature relating to the evaluation of impacts on pavements due to heavy vehicles. Chapter 2 describes the development of the analysis methods incorporated into the tool for assessing the impacts of additional heavy vehicles. Chapter 3 presents the analysis tool and its development and intended use. Chapter 4 presents conclusions and recommendations for the tool's proper use, and suggestions for future development.

#### **Literature Review**

This section includes the review of literature and of other tools for evaluating the effects of heavy vehicles on local roads and city streets. Through the review of the literature and knowledge of pavement design, analysis, and performance, it is clear that three parameters have the greatest effect on the pavement condition and longevity. These include the characteristics of traffic, pavement materials (and construction practices), and the environment. Each of these are discussed below, as well as other topics including various methods of pavement design, types of damage caused by vehicles and by the environment, and the expected impacts on the pavement life.

Much of the discussion in this review draws on work from the Heavy Traffic Generators Project (1) funded by the Minnesota Local Road Research Board. That work focused on the impacts of wind turbine construction on county roads. There are similarities and differences between this work and the Wind Tower project. The primary similarity is the way the two analyze impacts on pavement due to heavy vehicles. Some of the differences include the pavement sections (rural

road vs. urban street) and the nature of the heavy traffic loading (very heavy loads concentrated in time and space vs. legal loads applied consistently over long periods of time, and often in perpetuity).

# Methods of Pavement Design and Analysis

The Heavy Traffic Generators project utilized three methods of pavement design and analysis for estimating the damage and the related cost associated with heavy traffic loads. These are described below.

- **Incremental Design** This method involves the design of two new pavements for future service one without any of the heavy vehicles in question, and one with the additional heavy vehicle loads. The difference in the predicted construction cost of these two pavements is assumed to be the direct result of the additional loads. This additional cost must be considered over the entire life of the pavement, since it represents the additional pavement structure that must be built to accommodate the heavy vehicles over the life of the pavement.
- **Overlay Design** This method uses the standard MnDOT overlay design method for bituminous pavements. After a period of time, defined by the user, the expected damage caused by additional heavy vehicles is computed, and an appropriate overlay thickness is determined to accommodate the additional loads. The cost of the overlay is assumed to be related directly to the additional damage caused by the heavy vehicles in question. Often, however, the computed overlay thickness needed is less than the minimum thickness that is appropriate for overlay construction. In this case, the owner has two options: consider the cost to be that of the minimum overlay thickness, or set aside the small cost and use it in a future overlay to be constructed at some later date.
- **Percent of Life Consumed** Comparing the amount of additional "life" consumed by additional pavement loads each year with the annual or total loads for which the pavement was designed. This approach computes the proportion of the reconstruction cost based on the proportion of the original design life (in terms of ESALs) consumed by the additional loads.

# Pavement Damage Modeling

There are many methods of modeling the damage produced by traffic, and by heavy vehicles in particular. Most of the research utilizes the standard AASHTO concept of serviceability (2) and equivalent single axle load (ESAL) or some variation of that method. The AASHTO method is a sound and viable way of conducting this type of analysis, however, and the references discussed below support this.

# Rutherford, South Dakota Department of Transportation, 1994 (3)

The South Dakota Department of Transportation hired GeoEngineers in 1994 to conduct a study to develop a model for predicting the impact of heavy garbage trucks on city, county, and state roads. This is likely the most comprehensive study undertaken on the subject, and it has many of the components that are necessary to develop the impact analysis tool for the current project. These include considerations of the following parameters.

- Vehicle characteristics
- Pavement structure
- Pavement damage evaluation
- Cost evaluation
- Development of a heavy vehicle damage cost model
- Suggestions for mitigating the damage caused by heavy vehicles

This study is primarily focused on the transportation of solid waste to centralized disposal sites, but the concepts relating to pavement damage are very similar to the topics under consideration in the current project.

The study evaluated nine different vehicles and three different pavement types. It evaluated damage in terms of the number of ESALs required to reach the level of terminal serviceability on city streets and county highways. The terminal serviceability level in the model is selected by the user, thus allowing for a local definition of failure depending on the characteristics and classification of the roadway. Damage due to solid waste vehicles was predicted by estimating the incremental damage due to existing traffic plus additional solid waste vehicles, compared to the existing traffic alone. The study evaluated the damage with 10, 50, and 100% additional solid waste vehicles.

The report states that for low volume flexible pavements in cities and counties, the additional damage was low to moderate for additional traffic up to 50% of existing, and moderate to high for solid waste traffic exceeding 50% of the existing values. As suggested by a another report, on higher volume roads, the additional damage is predicted to be less than that for lower volume roads.

Annualized costs were predicted to be as high as 144% higher than normal when up to 50% additional solid waste traffic is applied to lower volume roadways in cities and counties, and up to 58% higher for higher volume roadways.

The authors acknowledge that the model is sensitive to traffic loading, both in the existing and the additional heavy vehicle traffic. It is also sensitive to the frequency of maintenance and resurfacing activities (defined by the user)

# Liu, Highway Damage Costs, 2009 (4)

This report is a Master's thesis discussing the impact on pavements due to heavy trucks related to the beef industry. This study includes the standard ESAL-damage computations, but also adds a component of environmental "decay" from which the impacts of heavy vehicles can be differentiated. These models are theoretical in nature, however, and may not lend themselves to direct application.

#### Martin, Heavy Vehicle Road Wear Costs, 2002 (5)

This is an Australian research project which attempts to estimate the impacts of heavy vehicles and the cost of road wear attributable to those vehicles. The paper states "The attributable road

wear cost, or load-related road wear, is considered to be an approximation for the marginal cost of road wear. Due to the nature of the high axle loads of heavy vehicles relative to light vehicles, heavy vehicles are considered to be the portion of the overall vehicle fleet primarily responsible for load related road wear."

The paper also tries to develop a method for differentiating between load-related damage and that caused by the environment. Several mathematical models are included to predict the progression of deterioration over time and traffic. It concludes by stating the following.

Estimation of the attributable road wear costs due to heavy vehicles, or the marginal cost of road wear, can lead to a range of estimates depending upon the models and associated assumptions used in making the estimates from the available data sources. The recent estimates for road wear cost vary from 65 to 55% attributable to heavy vehicles for the average level of traffic loading on the bituminous surfaced arterial road network of Australia.

The recent estimates of the attributable road wear cost suggests that the fourth power law-based ESAL-km road use variable can be used for attributing the road wear costs. The use of the ESAL-km based attribution parameter for construction, rehabilitation, and maintenance (road wear) costs will bring attention to the deficiency of the traffic loads being simply characterized by the fourth power law that forms the basis of ESAL estimation. However, no simple replacement for the fourth power law is currently available in Australia for the characterization of traffic load for the attribution of pavement wear costs.

# Hajek, Allocation of Pavement Damage Due to Trucks, 1998 (6)

Hajek, et al., studied the allocation of pavement damage to trucks, using a marginal cost method, which is to say the cost related to damage caused by heavy vehicles compared to that without the vehicles in question. The paper utilizes the overall life cycle cost method to evaluate the total cost of damage attributable to heavy vehicles and to compare that to the damage caused by all other vehicles. The authors developed some linear regression models to evaluate the marginal costs of pavement damage.

# Hjelle, Model for Estimating Road Wear on In-Service Roads, 2007 (7)

This paper presents an approach to estimating road wear on in-service roads in Norway. The paper implies the ability to differentiate between passenger cars and heavy vehicles, but does not provide a method for explicitly dividing the predicted impacts. The models developed are for bituminous pavement rutting, and the paper states that the primary causes of rutting include traffic loads, bearing capacity of the road structure, and seasonal climatic conditions.

# Fee-Based Policies

# Gillespie, University of Michigan Transportation Research Institute, 1992 (8)

The 1992 report by the University of Michigan's Transportation Research Institute provided the following information, which many of the more recent reports have restated.

- Vehicle characteristics affecting pavement damage include axle loads (greatest effect), inequalities in load sharing on tandem axles, axle spacing, tire inflation pressure, tire configuration
- Road characteristics affecting pavement damage include current pavement condition, existing roughness (a road with a PSI of 2.5 is damaged at rate 50% greater than a road with a PSI of 4.0), and high temperatures (rutting can increase by a factor of 16 when pavement temperatures increase from 77 to 120 °F)

# RPI Consulting, Rio Blanco County, Colorado (9)

Rio Blanco County commissioned a study by RPI Consulting, which was completed in 2008, to study the impacts of trucks on their county roads, and to determine an appropriate fee for new truck loads that were not anticipated when the road was designed and constructed. This analysis was directed at all aspects of truck traffic, and other causes of increased traffic loading, such as the gas and oil industry, residential and industrial developments, and others.

In 2001, the Colorado state legislature provided counties with the legal authority to assess impact fees to new development, in order to help fund capital facilities related to those new developments.

The impact fee is based on the computed ESALs produced (or expected to be produced) by the development. The consultant determined that \$9.07 per ESAL is the total damage to the road system and other aspects of the transportation infrastructure. Based on typical number of truck loads, the impact fee schedule reduced this to a fee per unit, as follows.

Development Type	Road Impact Fee		
Residential (per housing unit)			
Single Family	\$600		
Multi-family	\$400		
Non-Residential (per 1000 sf o	f floor area)		
Shopping Center	\$6,500		
Office/Institutional	\$1,700		
General Commercial	\$1,900		
Mixed Industrial	\$1,000		
Warehousing	\$800		
Manufacturing	\$600		
Gas or Oil Well	\$17,700 (per well)		

Table 1. Rio Blanco Road Impact Fee Schedule.

Much of the remainder of the report is devoted to the methodology for estimating the amount and type of traffic expected for each development type.

# Rufolo, Cascade Policy Institute, 1995 (10)

In 1995, Anthony Rufolo produced a "Policy Perspective" on Cost-Based Road Taxation. The following are excerpts from this three-page paper.

- Oregon has been a leader in cost-based road taxation since it adopted the gasoline tax as a primary source of road funding in 1919, and the current system of road finance is based squarely on the principle that those responsible should pay for costs incurred.
- The costs of road construction and maintenance depend to some extent on different factors. Road construction at even the most basic level requires land for right-of-way, design and engineering, and construction to some minimal standard. Construction beyond the minimum standard will be determined by the type of traffic which the road is expected to bear. If a road will carry only small, light-weight vehicles, it can be built to lower standards than one which must carry large and/or heavy vehicles. The incremental cost [of road construction and maintenance] of accommodating larger and heavier vehicles is correctly attributed to these vehicles while the basic cost is associated with all vehicles.
- While roads will deteriorate if simply left unused, most deterioration is associated with use; and the damage caused by vehicles goes up much more than proportionately with size and weight. Hence, costs associated with maintenance are greater for trips made by heavy vehicles. A single large truck can cause as much damage as thousands of automobiles, and the configuration of the truck can affect the amount of damage as well. If the load is spread over more axles, so there is less weight on each wheel, then the damage is reduced.
- The Oregon system attempts to allocate both the cost of new construction and the cost of maintenance to those who generate the cost requirement. Thus, relatively more of the cost of new capacity is assigned to automobiles, while trucks pay a larger share of the cost of road maintenance. It is important that the weight-mile tax rates give appropriate price signals to truckers. The taxes are set based on the weight of the truck, and for larger trucks, the number of axles is also taken into account.

# Municipal Waste Collection

Since the topic of the effect of heavy vehicles on local roadways is gaining importance and interest with respect to the loading imparted by numerous waste removal trucks on the pavement, several studies have been conducted for various municipalities in the Minneapolis-St. Paul metro area as well as others across the nation. In addition, this application is somewhat unique within the analysis methods, and so additional literature review and commentary is included in this section, which describes the findings of several of these studies and provides commentary where applicable.

# City of Falcon Heights, 2004 (11)

- Quoted a Roseville study as saying "limiting the number of garbage trucks... to only one hauler could extend the usefulness of the street 5 to 10 years"
- Quoted Carver County Environmental Dispatch, 1994, saying "There are many benefits to organized garbage hauling including…Lower street repair costs to the city."
- Quoted UMTRI study that "starting and stopping" will increase damage "depending on the speed of the truck and the axle weight of the load". Trucks with longer distances between stops will be going faster when they stop.

The City of Falcon Heights expects that by limiting the number of garbage trucks on each street to one hauler, the usefulness of the streets could be extended 5 to 10 years, and that the overall costs to repair streets will be lower.

The implied expectation that having one hauler with shorter distances will cause less pavement damage is somewhat questionable, however. The report quotes the University of Michigan Transportation Research Institute as saying that with longer distances between stops, vehicles will be going faster when they stop. In reality, it is the rate of deceleration that can cause increased pavement damage, and it is not necessarily true that with longer distances between stops that heavy trucks will decelerate any more rapidly than those that have travelled shorter distances.

# Resource Strategy Corporation, City of Chanhassen, 1993 (12)

In 1993 the City of Chanhassen conducted a review of other studies regarding this issue. Some major findings were from studies conducted for the Metro Council and by Bonestroo which stated the following.

- "As they fill up on the route, many refuse collection vehicles operate overweight, especially during the spring months when waste generation rates increase but road weight limits may be at their lowest... Further, the number of overweight vehicles using roadways increases the potential for paving damage."
- "The damage that garbage trucks inflict on City streets is magnified in the spring when road restrictions typically restrict other trucks from using the same streets" (8).

# R3 Consulting Group, City of Fort Collins, Colorado, 2008 (13)

In the ongoing discussion about the source of deterioration (whether it is primarily caused by the environmental or traffic factors) the City of Fort Collins, Colorado, commissioned a study to evaluate the impacts of numerous garbage trucks on their residential streets. Some of the findings in this study include the following, noted with the sources cited in the R3 Consulting Group's report, where appropriate.

• "While roads will deteriorate if simply left unused, most deterioration is associated with use; and the damage caused by vehicles goes up much more than proportionately with size and weight. Hence, costs associated with maintenance are greater for trips made by heavy vehicles" (10).

The report also recognized that "In general, all other factors the same, moving from an open competition collection system to a districted collection system would be expected to reduce the number of vehicle miles traveled with a corresponding decrease in the associated street maintenance impacts." The ensuing discussion about open competition vs. districted collection presented the following considerations.

• Both the size of the collection vehicles and the average number of passes each vehicle makes down each residential street segment may change under a districted system. As a result the impact per vehicle may be more or less than under the current open competition system.

- At least one hauler provides both residential and commercial service with the same vehicle. If that hauler was not awarded a residential district its vehicles would continue to impact those residential streets it uses to access commercial accounts, assuming it continued to provide commercial service.
- If a hauler(s) not currently providing residential or commercial service in the City was awarded a district under a competitive procurement, that hauler might also compete for commercial accounts with a resulting increase in commercial trash truck impacts.

In conducting an analysis similar to the one proposed for the current project, the R3 Consulting Group projected the impacts of trash and recycling trucks on the City of Fort Collins' streets using the applied and allowable ESAL analysis.

The summary of findings in the R3 report includes the following impacts related to street maintenance.

- Trash trucks are typically the heaviest vehicles regularly operating on residential (local) streets and are a major contributor to wear and tear on those streets.
- The most significant step the City can take to minimize trash truck street maintenance impacts is to reduce the number of trash truck miles traveled on the City's streets.
- In general, all other factors the same, moving from an open competition collection system to a districted collection system (or a City-wide contract for services) would be expected to reduce the number of vehicle miles traveled with a corresponding decrease in the associated street maintenance impacts.
- Potential residential street maintenance savings associated with a districted collection system are estimated to be on the order of +/- \$170,000 annually.
- Requiring that haulers not load vehicles in excess of manufacturer recommendations and legal load weights would also help to control street maintenance impacts.

Other impacts cited in the report include the following.

- Improved air quality
- Improved neighborhood aesthetics (regulating appearance and operational standards)
- Reduction in the number of days per week that collection service occurs in a neighborhood
- Reduction in noise
- Increased neighborhood safety

The report included a table (reproduced below) which has been cited by many other reports to show the residential recycling trucks and residential trash trucks can be equivalent to 274 and 1,279 passenger cars, respectively.

The report indicates that these numbers are supported by "various independent third parties" and cites studies conducted in Minnesota (8, 12, 14) and in California (all conducted by the same company – R3 Consulting Group, [13]). The relative impact of trash trucks in these studies varied from a low of 830 passenger cars (8) to a high of 1,730 (13).

COMPARISON OF TRASH AND OTHER VEHICLE IMPACTS						
Vehicle			Passenger			
	AASHTO	Number	ESAL	Car		
General Classification	Classification	of Axles	Factor	Equivalents		
Cars	Passenger Cars	2	0.0008	1		
Vans/Pickups	Other 2-Axle/4-Tire	2	0.0052	7		
	Trucks					
Large Pickups/Delivery	Panel and Pickup	3	0.0122	15		
Vans	Trucks					
Large Delivery Trucks	3 or More Axle Trucks	3	0.1303	163		
Local Delivery Trucks	2-Axle/6-Tire Trucks	2	0.1890	236		
Residential Recycling		2	0.2190	274		
Trucks						
Buses	Buses	2 or 3	0.6806	851		
<b>Residential Trash</b>		2	1 0220	1 270		
Trucks		3	1.0230	1,279		
Long Haul Semi-Trailers	Various	3-5+	1.1264	1,408		
	Classifications					

Table 2. Comparison of Trash and Other Vehicle Impacts.

#### Schneider, MPCA, 2009 (15)

In 2009, the Minnesota Pollution Control Agency made a presentation on waste and recyclable materials collection arrangements. The following are some of the conclusions reported, relating to the impacts of heavy trucks on roads.

- Impact on roads is variable, based on street type, and relative amount of garbage truck traffic to other traffic.
- Most common data available for making damage comparisons is ESALs. MnDOT uses a formula of one garbage truck equivalent to 1,000 car trips.
- The City of Falcon Heights attributed the impact of garbage trucks on roads as high in alleys (about 86% of impact due to garbage trucks) and low in heavily traveled areas (about 8% due to garbage trucks). This seems reasonable since in heavily traveled areas, garbage trucks make up a much smaller percentage of the total number of heavy vehicles than in urban alleys.
- The City of Arden Hills noted that environmental factors are generally responsible for a majority of pavement deterioration on the city's 9-ton streets.

The presentation also discussed cost estimates of road impacts from various cities.

- The City of Roseville (with an open system) estimates \$20 to \$40 per household per year in pavement damage due to garbage trucks (totaling about \$188,000 to \$376,000 per year).
- The City of Oakdale (also with an open system) reported an estimate of \$120,000 to \$300,000 per year.

• The City of Robbinsdale (with an organized system) set aside \$150,000 from solid waste fees for roads in 2008.

The presentation did not specify how many miles of roads the total cost figures are intended to maintain.

# Foth, MCPA, 2009 (16)

Also in 2009, Foth Infrastructure & Environment produced a report for the Minnesota Pollution Control Agency regarding waste collection service agreements. The report cited the University of Michigan (1992) as saying "fatigue damage to rigid and flexible pavements is most directly determined by maximum axle loads and pavement thickness." The report also cites the R3 (2008) report and the truck / passenger car equivalent concepts, discussed in that report.

The Foth report also cites the University of Michigan's claim that starting and stopping of garbage trucks can increase damage by 50 to 100% (17).

The conclusions of the report, as they relate to pavement damage, include the following.

- Main causes for deterioration include traffic volume, type of traffic, and environmental factors (water, temperature, sun, pollutants).
- A properly designed bituminous surface should be able to handle the traffic loading over its design life including heavy truck loadings.
- Environmental factors are generally responsible for the majority of pavement wear and deterioration.

The Foth report also provided comments by municipalities regarding their perceptions of the impacts of heavy trucks (and garbage trucks in particular) on their streets. These are summarized below.

• Bloomington

The City engineer put together a memo that references MnDOT studies. This memo also outlines the Bloomington road weight restrictions, comparisons of heavy traffic, and costs for repair. In addition, the City has photos of road wear in cul-de-sacs where garbage trucks are the only trucks entering (school buses and other heavy trucks do not enter cul-de-sacs).

• Lakeville

We do not have a position on how collection vehicles impact our roads. We're sure they do, but it has not recently been addressed or studied.

• Prior Lake

We know there are impacts but we have no studies.

• Rosemount

There have been some comments from the public works department but mostly there have been comments from elected officials.

# • Savage

Anyone who says their public works department has not expressed concern over this issue is out of touch with their public works department. The weight of trucks causes wear and tear on the roadways. There has been some discussion of mandating hauling to become organized or create zones for haulers.

# • Crystal

Our City engineer/public works director recognizes the additional wear and tear on roads from collection vehicle traffic.

# • Maple Grove

One truck is better than five trucks driving down the same street for collecting garbage.

# • New Brighton

The City received an inquiry from a resident concerned about the amount of solid waste trucks on their street on pick-up days. They thought it might be wasteful and had concerns they relayed to a council member and the City manager. The City manager forwarded it to me to do some research on the subject. I looked at studies done by Arden Hills and Falcon Heights on the effects of these types of vehicles driving on residential streets. I compiled a file and if the City Council ever wants to have a discussion on the issue, I am prepared. When compiling the file I talked with our public works department and got their feedback regarding some of the more scientific language in the report. There was interest from the council member and our City manager but I haven't had to follow up yet. Foth received a copy of the file containing these studies from New Brighton.

# • Plymouth

The public works director and superintendent have voiced opinions in public meetings.

• Roseville

Our City has relied on other studies done by other entities that show garbage trucks having significantly greater wear on streets. I don't have copies of any specific reports. Our public works director has referred to a formula from MnDOT that says one garbage truck trip is equal to 1,000 car trips and to pavement design manuals that show cars have a load factor of 0.0007 and that garbage trucks load factor can be as high as 1.6.

The report also includes a response from the National Solid Wastes Management Association (NSWMA) critiquing their report. Regarding pavement impacts, the response cited the Foth report as quoting an engineer from URS Corp as stating the following:

"Although vehicle types and loading contribute to the wear of the pavement section, environmental factors also contribute to the deterioration of the pavement section. A properly designed bituminous surface should be able to handle the traffic loading over its design life including heavy truck loadings experienced in Arden Hills. Reducing the number of heavy truck loadings should have positive effects on the lifespan and quality of local streets, however environmental factors are generally responsible for the majority of pavement wear and deterioration for Arden Hills streets and therefore significant extensions of pavement life are unlikely."

The NSWMA response goes on to state the following.

- a) It must be acknowledged that no data is available as to how much longer a city road will last if government managed collection is implemented. In the cities where it has been discussed, city staff has been unwilling to commit to a specific reduction in road repairs budgets.
- b) In fact, we believe, depending on the configuration of the trucks used, reducing the number of trucks running on the streets may increase road wear. For example, if you have 20 tons of waste in a community hauled by one truck versus having 4 trucks and 4 different haulers you are dividing the 20 tons into 4 loads instead of 1.
- c) If the goal is reduced truck traffic on City streets, the only responsible action is to regulate and reduce all types of traffic including lawn care, delivery vehicles and the postal service.

It is unclear what is meant by statement b, above. Assuming that the intention is to show that one larger truck does more damage than four smaller trucks, consider the following example, using real truck axle weights and payloads.

Payload Capacity, cy	40	11
Axle Configuration		
Front Axle	Single	Single
Rear Axle	Dual Tire,	Dual Tire,
	Tandem Axle	Single Axle
Axle Gross Weights, loaded		
Front Axle, lbs	20,000	12,000
Rear Axle, lbs	46,000	18,000
<b>ESALs per Vehicle</b> (computed by MnDOT's MnPAVE software)	3.61	1.22
Total ESALs and Capacity	3.61 ESALs	4.88 ESALs
	40 cy	44 cy
ESALs per cy	0.090	0.111

Table 3. ESALs per Cubic Yard by Truck Capacity.

This analysis shows that by using four smaller trucks, about 23% more damage is imparted to a typical city street than by using a single, large truck. This is due to, and in spite of, several factors.

• Each of the four smaller trucks has its own empty vehicle weight.

- The four smaller trucks spread their load over only six tires, whereas the larger, heavier truck uses 10 tires.
- While it is true that the heavier axle loads produce significantly higher ESAL values at a rate of approximately the 4<sup>th</sup> power rather than linearly, this is surmounted by the additional tires and the fact that only a single vehicle's empty weight (albeit greater than one of the four smaller vehicles) travels on the city street.

#### Raymond, City of Spokane, Washington, 2004 (18)

The City of Spokane, Washington, contracted with a consultant to evaluate the impacts of heavy vehicles on the city streets. In contrast with the information presented in Table 2, developed by the R3 Consulting Group and others (indicating that a loaded garbage truck can be equivalent to up to 1,750 passenger cars, the paper developed by Raymond suggests that the same vehicles could be equivalent to as many as 13,700 passenger cars.

The remainder of the paper is a general discussion of the impacts of heavy vehicles (and buses in particular) on the streets of Spokane.

# Chapter 2. ANALYSIS DEVELOPMENT

This chapter describes the development of the analysis methods used for computing the impacts of heavy vehicles on local roads. While no new pavement design or analysis methods were developed as part of this project, some existing methods were utilized in different ways to accomplish the analyses required.

In order to estimate the impacts of heavy vehicles on local roads, the basic analysis was developed to compare two traffic conditions – with and without the heavy vehicles in question. The tool that was developed incorporates this overall method and implements it in two modes of analysis – at the level of the individual road segment and at the network level.

# **Analysis Modes**

For an individual road segment analysis mode, more detail may be included in the analysis, including specific numbers and types of heavy vehicles, and the user is able to modify the default pavement structure data if new information is available. Other things that the user is able to modify at the segment level include the traffic (average daily traffic, heavy commercial average daily traffic, etc.) and the condition of the roadway segment over the past three pavement condition surveys.

The network mode conducts the heavy vehicles effects analysis in the same way as for the segment mode, but does not allow the user the flexibility to modify individual components of the inputs such as those described in the previous paragraph. In this mode, the tool takes the data that had been previously imported from a pavement management system (PMS) for the roadway network and uses them in the analysis. In the network mode, the user is still able to specify the number of heavy vehicles and their characteristics. The network mode may take several minutes to conduct its analysis, depending on the size of the network and the speed of the computer.

The next sections in this chapter describe the general analysis methods utilized by the tool, and interpretation of the results that it generates.

# **General Analysis Components**

This section describes the basic analysis conducted by the heavy vehicles impacts tool, including the following steps.

- Collect and validate data
- Compute ESALs (with and without specified heavy vehicles)
- Analyze existing pavement structure
- Estimate additional bituminous material required for the specified heavy vehicles
- Estimate additional pavement life consumed due to the specified heavy vehicles
- Estimate degradation in pavement performance curves with and without heavy vehicles
- Compute quantities and costs
- Report results

Since the segment analysis requires more detailed information than the network analysis, it will be referenced in this chapter much more than the network analysis. Where there are differences between the two modes, they will be specified.

#### Collect and Validate Data

When the segment analysis is called by the user (by pressing the "Analyze and Report" button, with the "Street Segment Level" option selected) the first step is to collect the required data, either from the pavement management data previously imported, or from the user-override data entered after the PMS data was last imported. The data required are as follows.

#### Pavement Structure

Surface type / material, and thickness Base type / material, and thickness Subbase type / material, and thickness Subgrade R-Value Standard expected pavement design life Segment width and length

# <u>Traffic</u>

Original design ESALs Traffic volumes Average Daily Traffic, or ADT Option: Heavy Commercial Average Daily Traffic (HCADT) or Percent Trucks, or both Predicted traffic growth rate

# Pavement Condition

Last three pavement condition index values Dates of the last three pavement condition surveys

# Construction and Cost

Year the pavement structure was last reconstructed Cost per inch of bituminous overlay Cost of total reconstruction Minimum overlay thickness desired Increment of overlay thickness design

# Additional Heavy Vehicles

Vehicle type Number of each vehicle type Time interval for vehicle numbers (per day, week, month, etc.) Loading status for each vehicle type (full, <sup>1</sup>/<sub>2</sub>-full, or empty)

Each input from the list above, whether collected from the PMS database or altered by the user, is validated to ensure it is within reasonable limits and that the type of data is what is expected.

# <u>Heavy Vehicle Axle Loads</u>

The axle loads attributed to each vehicle depends on its loading situation. Based on data from the MnDOT Vehicle Classification Scheme (19) and the MnDOT Weigh-in-Motion (WIM) reports (20) the weights of the various heavy vehicle types can be estimated. The vehicle weight information in Table 4 is averaged several WIM reports in 2013 and 2014 from the Owatonna station at MP 30.1 on I-35. The Average ESAL column in the table is taken from the MnDOT Procedure Manual for Forecasting Traffic on Minnesota's Highway Systems (21).

Vehicle	Weight	Weight	Weight <sup>1</sup> /2-	Average
Class	Empty, lbs	Full, lbs	Full, lbs	ESAL
4	15,000	30,700	22,800	0.57
5	8,000	14,000	11,000	0.25
6	19,000	32,800	25,900	0.58
7	11,500	47,700	29,600	0.58
8	31,000	38,900	34,900	0.39
9	33,000	62,600	47,800	1.13
10	33,500	75,000	54,250	1.13

Table 4. Average Vehicle Weight by Classification.

For vehicles that do not fit one of the classifications in Table 4, the user must create a custom vehicle definition and specify the axle loads and tire configurations. From this information the tool calculates ESAL values for each custom vehicle entered. The ESAL calculations for custom vehicles are taken from the AASHTO Guide for Design of Pavement Structures (2).

# Analyze Pavement Structure

The basic method of estimating damage or impacts to the pavement structure is through the MnDOT pavement design methods (22). The pavement analysis routines in the tool utilize the Granular Equivalent method of pavement design, which requires estimates of the Equivalent Single Axle Load expected over the life of the pavement, and the subgrade resistance value, or R-Value. While the R-Value is a measured property of the soil, the ESALs are estimated based on the current and future predictions of traffic volumes and expected vehicle classifications.

The ESAL predictions are based on the ADT, HCADT (or % Trucks), and assumptions of ESAL values per vehicle, according to the MnDOT vehicle classification scheme (19). The following assumptions are made.

- All non-heavy commercial vehicles (passenger cars and pickup trucks) have an ESAL/vehicle of 0.0004.
- All heavy commercial vehicles have an ESAL/vehicle value of 0.58.
- Traffic growth is limited to 1% per year.

The next few sections describe the computations involved to estimate the ESALs with and without the added heavy vehicles, and the original design ESALs (if these were not provided by the user).

#### Expected ESALs Without Additional Heavy Vehicles

In this computation, the expected ESALs are computed for the current traffic situation, assuming 1% growth, and without the additional heavy vehicles under consideration.

$$DailyESALs = 0.0004 (ADT - HCADT) + 0.58HCADT$$
(1)

$$ESALs_{Without} = DailyESALs \cdot 365 \cdot \left[\frac{(1+i)^n - 1}{i}\right]$$
(2)

where:

i = traffic growth rate,

n = analysis period, years

# Expected ESALs With Additional Heavy Vehicles

The expected ESALs contributed by the additional heavy vehicles is computed by considering all the user-entered additional vehicles individually, and summing their contributions to the ESAL calculation for the first year, and then expanding that value to the analysis period. The routine takes the user-entered vehicles from the list shown in the tool's main screen (Figure 6). The vehicle type and its loading state (Full, ½-Full, or Empty) are used in a look-up table to obtain the ESALs per vehicle. The number of vehicles for that type and the time interval selected are used to expand the expected ESAL per vehicle contribution to the first year. An equation similar to equation 2 is used to compute ESALs contributed by the heavy vehicles. The expected ESALs with additional heavy vehicles ( $ESALs_{With}$ ) is simply the sum of this value and the "ESALs Without" value calculated in the previous section.

#### Estimate Original Design ESALs

The result of the two previous sections is the "ESALs Without" heavy vehicles and the "ESALs With" heavy vehicles over the next design period. One of the computations used in the results is the percent of the original life consumed by the additional heavy vehicles. This value requires an estimate of the original ESALs for which the existing pavement structure was designed. In some cases the tool's user may know this information, or may be able to find it in historical design records. In many cases this must be estimated based on the existing pavement structure.

The original design ESALs is estimated by back-calculating the design chart using the layer thicknesses and material types. The first step is to estimate the Granular Equivalent (GE) of the existing pavement, in its as-constructed condition.

$$GE_{Design} = \sum_{i} \left( h_i \cdot LayerGE_i \right)$$
(3)

where:

 $\begin{array}{lll} h_i & = & thickness \ of \ layer \ i, \\ Layer GE_i & = & Granular \ Equivalent \ per \ inch \ of \ the \ material \ in \ layer \ i. \end{array}$ 

Using the  $GE_{design}$  and the subgrade R-Value, the next step is to estimate the original design ESALs for the pavement structure. Using the MnDOT GE pavement design curves (22), shown in Figure 1, this value is determined. The curved portion of the GE curves in the chart are based on an exponential mathematical model, given below.



Cummulative Design Lane 18 Kip ESAL's

Figure 1. MnDOT Bituminous Pavement Design Chart.

$$GE_{Design} = \frac{a}{1 + be^{(c \log ESAL_{Design} + d)}} + f$$
(4)

where:

Table 5 gives the regression coefficients for the GE curves calculated in equation 4. If the subgrade R-value is equal to one of the curves indicated in Table 5, the design ESALs is computed and used directly. If it is between two R-values in the table, the analysis computes design ESALs for the two R-values bounding the actual value at the same  $GE_{Design}$ , and interpolates ESAL<sub>Design</sub> for the pavement structure.

		Subgrade R-Value						
Regression								
Coefficient	5	10	15	20	30	45	60	75
а	27.086	31.639	29.676	28.308	28.095	19.418	22.164	20.954
b	1.967	1.942	1.963	2.201	2.218	2.340	2.467	2.571
с	-2.201	-1.878	-1.969	-2.114	-2.115	-3.020	-2.901	-3.526
d	10.818	9.659	10.446	11.271	11.504	17.645	16.829	20.845
f	15.624	10.104	9.285	7.658	5.035	9.386	4.903	3.794

Table 5. Coefficients for GE Curves in Equation 4.

# Estimate required GE With and Without

This component of the analysis method estimates the GE required as if the pavement were to be newly designed and constructed. In other words, if the additional heavy vehicles were known at the time of design and construction, the pavement design would have been different in order to accommodate them.

Using the pavement design chart, the two ESAL calculations (with and without the additional heavy vehicles) and the subgrade R-value are used to determine the pavement structure GE that would be required both with and without the additional heavy vehicles. While this can be done by hand using the design chart, the  $GE_{Design}$  equation (equation 4) can be used to estimate these values.

With these design GE values – with and without the additional heavy vehicles – their impacts to the pavement in terms of additional bituminous material can be estimated.

# Estimate Impacts

The impacts to the pavement structure attributable to the additional heavy vehicles are computed by the analysis method in three ways – additional bituminous material required at design and construction, pavement life consumed, and pavement performance degradation.

# Estimate Additional Bituminous Material at Design

The additional bituminous material that would be required in the original design and construction if the additional heavy vehicles had been known is one way of demonstrating the impacts of those vehicles. This is computed with a simple equation – taking the difference in GEDesign and dividing by the GE provided by bituminous material, as shown in equation 5.

$$h_{1-add} = \frac{\left(GE_{Design-With} - GE_{Design-Without}\right)}{GE_{Bit}}$$
(5)

where:

h <sub>1-add</sub>	=	additional bituminous thickness required,
GE <sub>Design-With</sub>	=	Total granular equivalent with additional heavy vehicles,
GE <sub>Design-Without</sub>	=	Total granular equivalent without additional heavy vehicles,
GE <sub>Bit</sub>	=	Granular equivalent of bituminous material (usually 2.25) (1).

#### Estimate Consumed Life

In most cases, the unexpected heavy vehicles will not be anticipated by the local highway agency at the time of design and construction. One parameter that can be estimated is the percent of the original design life is consumed by the additional heavy vehicles. This is based on the original design ESALs and the ESALs contributed by the additional heavy vehicles.

$$\% Life = \frac{ESALs_{With} - ESALs_{Without}}{ESALs_{Design}}$$
(6)

#### Estimate Performance Degradation

For the estimation of pavement degradation in terms of Pavement Condition Index, the tool uses the methodology used by MnDOT's Pavement Management Unit in a report by Lukanen and Han (23). The pavement performance prediction models in that report allow for prediction of pavement condition indices based on the previous three condition surveys. In cases where three previous surveys are not available, default values for the model coefficients are recommended.

$$PSR = P_0 - \Delta P \cdot e^{-\left(\frac{\rho}{AGE}\right)^{\beta}}$$
(7)

where:

The example below shows how this process is conducted. Since the year of last reconstruction is an integer, and the dates that the pavement condition surveys were completed most often have specific days and months associated with them, it is assumed that for age computation purposes the date of construction is the end of the month of July in the year provided. In this example, the pavement was last reconstructed in 1999.

PCI Date	PCI	Age
5/8/2001	98	1.77
4/13/2009	86	9.70
7/24/2012	64	12.98

 Table 6. Example PCI Prediction Data.



Figure 2. Example of pavement condition degradation curve prediction.

The tool utilizes the MS Excel Solver to estimate the regression coefficients of the curve. As mentioned previously, if three pavement condition survey data points do not exist in the pavement management data, default values are used.

# Compute Quantities and Costs

The impacts in terms of additional bituminous material or lost pavement life must be converted into estimated costs so that equivalent comparisons may be made among different heavy vehicle scenarios. The tool reports cost in the following terms.

- Cost of additional bituminous material for the road segment
  - Cost per square yard
  - Cost for the entire segment (computed by width and length of the segment)
  - Cost of consumed life (based on original construction cost)
  - Cost for the entire segment
  - Cost per lane-mile
  - Cost per ESAL per lane-mile.

# <u>Report Results</u>

•

The results are reported in the small window that contains the tool, and in the sheet "Report-Segment" or "Report-Network" in the tool's spreadsheet. The Segment sheet reports the following information.

- Analysis name (given by the user),
- Segment name,

- From / To termini,
- Segment length in ft and miles,
- Heavy vehicles included in the analysis,
- Percent life consumed,
- Cost of percent life consumed,
- Additional asphalt thickness required,
- Cost of additional asphalt thickness,
- Plot containing predicted ESALs and pavement condition index curves, both with and without additional heavy vehicles, and
- Date the analysis was completed.

The Network sheet reports the following information, which is similar but combined much of the data at the network level rather than for the individual segment.

- Analysis Name (given by the user),
- Number of segments analyzed in the network,
- Total number of segments contained in the network database,
- Heavy vehicles included in the analysis,
- Average percent life consumed,
- Total network cost of consumed life,
- Average additional asphalt thickness required,
- Total network cost of additional asphalt thickness,
- Plots containing network distribution of Pavement Condition Index with and without additional heavy vehicles after 5 and 10 years,
- Plots containing distribution of original pavement life consumed and additional bituminous thickness required.
- Date the analysis was completed.

Sample reports for the Segment and Network analyses are shown in Figures 19 and 22, respectively. These sheets may be printed directly (the print area and other printing options are preset).

# **Interpretation of Results**

As described in the previous sections, the analysis estimates the impact of heavy vehicles on pavement structures including accelerated degradation, cost to accommodate the additional vehicles, and additional bituminous materials that would have been needed at design time to provide an adequate structure. The results of the analysis are provided in the report sheets within the tool. These results are described in more detail in this section.

# Segment Analysis

Figures 17 and 18 in the next chapter show an example of the output for the segment analysis, produced in the user screen. As mentioned before, Figure 19 shows what is printed, which includes all the information from the user screens. Figure 3 shows a different example of the results plot from the segment analysis. In this plot, the predicted ESALs are shown in the vertical axis on the right side, and the predicted PCI values, or pavement degradation, are shown

in the left side axis. The impacts to the pavement condition can be seen in terms of early degradation (more rapid decline in predicted PCI). For example, the PCI is predicted to reach a value of 40 at about  $6\frac{1}{2}$  years from the beginning of the analysis period rather than about 8 years without the additional heavy vehicles. The analysis tool does not incorporate the possibility that the local agency might apply a chip seal or overlay to the pavement. The relative impact to the pavement structure will be the same regardless.

Similarly, the overall accumulation of predicted ESAL applications can be seen in the figure as a result of the expected traffic and the unexpected additional heavy vehicles.



Figure 3. Sample results from segment analysis.

# Network Analysis

The network analysis provides an overview of the entire network with the application of the heavy vehicles specified by the user. The same set of heavy vehicles is applied to all roads in the network. Due to the summary nature of the analysis, detailed information on specific roads cannot be provided in the results pages. The network report provides total impact cost information, assuming that all vehicles are applied to all streets. As described in the previous chapter, the total cost of consumed life, over the entire network is reported, as well as the total cost of additional asphalt to upgrade the network to accommodate the additional heavy vehicles. The two methods of computing the cost of impacts will not provide exactly the same results, since they are computing completely different impacts. They are almost always close to each other however. For example, in the example in Figures 20 and 21 shows that the percent life consumed method predicted about \$994,000 in costs. Considering that these two methods arrived at these values in completely different ways, it is a very close comparison.

Figure 4 shows an example of the distribution of pavement condition index values over a street network with and without additional heavy vehicles, at 5 and 10 years after the analysis begins. The solid bars indicate the distribution of pavement condition without the additional heavy vehicles, and the striped bars indicate the condition distribution with them. As can be seen in the figure, the additional five years of traffic seems to have had a greater impact on the overall network condition, but this is somewhat deceiving, since the analysis also omits the impact of that many years of pavement maintenance and rehabilitation. The relative impact, however, can be seen where the 5-year chart shows fewer pavement sections in the 70-80 category and more in the 50-70 category, indicating an overall decrease in pavement condition across the network.



Figure 4. Sample network PCI distribution after 5 and 10 years.

# **Chapter 3.** TOOL DEVELOPMENT

This chapter describes the development of the heavy vehicles pavement impacts tool and the implementation of the analysis methods described in the previous chapter. It also discusses some of the reviews conducted with stakeholders toward its final version. Finally, this report contains several screen captures of the tool and the basic reports it generates.

Several Technical Advisory Panel (TAP) meetings were held in addition to phone calls with individuals on the panel to discuss the development of the tool. From these meetings and conversations, and throughout the development of the tool, several significant improvements were suggested, as described below.

#### **Significant Improvements**

The Heavy Vehicles Impacts Tool went through many versions and iterations during its development process. At each stage, the TAP made suggestions and requested additional features. These are summarized below.

• Ability to enter custom truck types and configurations *The tool was modified to allow multiple vehicle types, including multiple styles of:* 

Bus Single Unit Truck Tractor Semi-Trailer Concrete Truck Dump Truck

In addition, the tool was modified to provide the ability to enter customized vehicle parameters including number of axle groups, axle configurations, and axle group weights.

- Ability to run network analysis as well as single segment analysis *This capability had been planned, and was added to the analysis methods.*
- Reporting cost per mile, cost per segment, cost per year, etc. *Additional cost reporting types were added to the tool.*
- What about trucks that are empty, or half-empty? Add capability to model them *The capability to specify if a standard truck from the library is full, empty, or half-full was added. This capability is not included for custom vehicles, since the axle weights of these vehicles are specified by the user.*
- Comparison between "current" and "proposed" situations This is the basis of the tool. The current and proposed situations are both analyzed, and the results can be compared to identify the relative impacts.
- Add discussion in the report/tool about the modeling and the assumptions in the tool

- Clarify "percent life consumed" and other terms
- What are the critical inputs when importing data?

These items are clarified in the report.

- Ability to import a basic pavement database *This capability was added to the tool.*
- Consider damage to the road due to things other than weight and axles? *This capability was outside of the scope of the tool and the project. It was not implemented.*
- Add the capability for trucks with more axles up to 5? *The capability to analyze the effects of vehicles with more than two axle groups was added. The tool will analyze up to five axle groups on a single vehicle.*
- Add capability to select the interval in truck volume (day, week, month, year) *The ability to select the time interval for additional vehicle volume (day, week, month, year) was added.*
- Add capability to define up to 9 trucks *The ability to define up to nine vehicles in a single analysis was added*
- Add capability to select which truck types are listed in drop-down boxes *The ability to unclutter drop-down boxes by hiding unused vehicle types was added (this is implemented in the User Settings area).*

Most of the items listed above were implemented in the current version of the tool. The tool is intended to estimate the impacts of heavy vehicles on pavement structures, and so the comment about pavement damage due to other causes was not incorporated.

The remainder of this chapter provides screen captures of the current version of the heavy vehicles impacts tool, with some commentary as needed.

# **Screen Captures**

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Figure 5. Spreadsheet opening screen.

*HeavyVehiclesSample - Heavy Vehicle	es Impacts Tool
Select Method of Analysis  Network Level  Street Segment Level	Street Segment Level Street Name: 11TH ST Segment: MAPLE ST to WALNUT ST
Cost and Other Information	PMS Information     G Use Database Values     Use Custom Values
Load a Saved Analysis	View/Enter Data
Save Current Analysis	Analysis Vehicles Additional vehicles per Week
Save As New Analysis	Vehide Type Number
Load/Update Street Network	H2 - Tanker Truck V 5 Empty
Analyze and Report	W5 - Waste - Sid€         10         1/2 Full
	Review Vehicle Types
Exit Settings	✓     Define       Custom     Vehicles

Figure 6. Main tool operation screen – Segment Analysis.

*HeavyVehiclesSample - Heavy Vehicle	s Impacts Tool
• Network Level • Street Segment Level	1168     Street Segments       1152     Segments with complete information
Cost and Other Information	
Load a Saved Analysis	
Save Current Analysis	Analysis Vehicles Additional vehicles per Week
Save As New Analysis	Vehicle Type Number
Load/Update Street Network	H2 - Tanker Truck  5 Empty
Analyze and Report	W5 - Waste - Side ↓ 10 1/2 Full
	Image: Constraint of the second
Evit Cetting	Define Custom Vehicles

Figure 7. Main tool operation screen – Network Analysis.

C Network Level Street Segment Level	Enter Top-Level Information that to all analyses.	will apply
Cost and Other Information	Prepared by: City Engineer	
Load a Saved Analysis	Overlay Cost, \$/sy	\$15.00
	Reconstruction Cost, \$/lane mile	\$500,00
Save Current Analysis	Minimum Overlay Thickness, in.	1.5
	Overlay Thickness Increment, in.	0.5
Save As New Analysis	Standard Design Life, yrs	20
Load/Update Street Network		j 1.0
Analyze and Report		

Figure 8. Cost and other information entered by the user.

Figure 9. Pavement management information for individual segment.

*HeavyVehiclesSample - H	Heavy Vehicles Impacts Tool	×
	1	
	Pavement Data Layer Depth, in Type	
	Surface* 3.5 Asphalt -	
	Base* 7 Mn/DOT Class 5 -	
	Subbase* 12 Mn/DOT Class 4 -	
	R-value* 19	
	Year of Last Reconstruction 2008	
	ADT 150 HCADT 50 % Trucks	
	Condition Since Last Reconstruction	
	PCI Date	
	1st 100 5/8/2001	
	2nd 94 4/13/2009	
	3rd 88 7/24/2012 Cancel	
	Values in RED were not provided. Using original database value.	

Figure 10. Pavement management information for individual segment – user modified.



Figure 11. Review of standard truck types.

HeavyVehiclesSample - Hea	vy Vehicles Impacts Tool	×
Fri 2nd 3rd 4th	stom Vehicle Entry         0 - Create New Vehicle         1 - Front Load         4 - Wind Turbine Truck         Axle Load, lbs         Axle Load, lbs         Axle Load, lbs         Axle Set         Axle Set	
	Delete Selected Save Close	

Figure 12. Review of custom (user-entered) truck types.

Heavy Vehicle Impacts To	ol - Database Imp	ort			x
Define colun	nns to import in Dumn Headers	ito ti 🗆 Pi	ne Heavy Vehicles ] reserve Current Data	ímpacts Tool	
Segment Name*	Name	-	*Required Information		
From*	From	-			
То*	То	-			
ADT*	ADT	-			
HCADT	HCADT	-	1st PCI	Segment Width	-
Surface Type	R Value	-	1st PCI Date	Segment Lengt	1 <b>-</b>
Surface Thickness*	Year of Last Reco	on ▼	2nd PCI	1st PCI	-
Base Type	Surface Type	-	2nd PCI Date	1st PCI Date	-
Base Thickness*	Surf Thick	-	3rd PCI	2nd PCI	-
Subbase Type	Base Type	-	3rd PCI Date	2nd PCI Date	-
Subbase Thickness*	Base Thick	-			
Subgrade R value*	Subbase Type	-			
Percent Trucks	Subbase Thick	-			
Yr of Last Recon.	PCI	-			
Segment Width	SR	-		Impo	ort
Segment Length	Percent Trucks	•		Can	cel

*Figure 13. Data import and alignment – with data headers.* 

Heavy Vehicle Impacts To	ol - Database Im	port			x
Define colum	ins to import i blumn Headers	nto th	ie Heavy Vehicles I eserve Current Data	impacts Tool	
Segment Name*	Column 1	•	*Required Information		
From*	Column 2	-			
To*	Column 3	•			
ADT*	Column 4	-			
HCADT	Column 5	-	1st PCI	Column 17	•
Surface Type	Column 6	-	1st PCI Date	Column 18	•
Surface Thickness*	Column 7	-	2nd PCI	Column 19	•
Base Type	Column 8	-	2nd PCI Date	Column 20	•
Base Thickness*	Column 9	-	3rd PCI	Column 21	•
Subbase Type	Column 10	-	3rd PCI Date	Column 22	•
Subbase Thickness*	Column 11	-			
Subgrade R value*	Column 12	-			
Percent Trucks	Column 13	-			
Yr of Last Recon.	Column 14	-			-
Segment Width	Column 15	-		Im	port
Segment Length	Column 16	-		Ca	ncel

Figure 14. Data import and alignment – without data headers.

Select Method of Analysis Network Level Street Segment Level	Street Segment Level Street Name: 11TH ST Segment: MAPLE ST to WALNUT ST
Cost and Other Information	Use Database Values     Use Custom Values
Load a Saved Analysis	Select an Analysis to Load.
Save Current Analysis	Cancel OK Additional venicles per Week venicles
Save As New Analysis	Vehide Type Number
Load/Update Street Network	H2 - Tanker Truck  5 Empty
Analyze and Report	W5 - Waste - Sid€         10         1/2 Full
	Review Vehicle Types
	Define Custom Vehicles

Figure 15. Load analysis screen.



Figure 16. Save As... analysis saving screen.

Select Method of Analysis         ○ Network Level         ④ Street Segment Level	Segment Analysis and Report         11TH ST         MAPLE ST to WALNUT ST         Consumed Life       Design         Additional ESALs per year:       3,908         Percent of life consumed over design period, %       13.1         Total cost of consumed life, \$/lane mile       \$65,739         Total cost of consumed life, \$/ESAL/lane mile       \$0.76         Total cost of consumed life, \$, this segment       \$21,581         This analysis reports the portion of the original design life (in ESALs) that is consumed by the additional heavy vehicles over the life of the street segment.         Print Summary       OK
--	--

Figure 17. Sample results screen – Segment analysis, consumed life.

Select Method of Analysis	Segment Analysis and Report         11TH ST         MAPLE ST to WALNUT ST         Consumed Life       Design         Additional bituminous thickness that would be required at design to accommodate the additional heavy vehicles, inch       0.9         Cost of additional bituminous at construction, \$/sy       \$13.21         Cost of additional thickness at construction, \$, this segment       \$30,541
	This analysis reports the difference in bituminous layer thickness, using the Mn/DOT Granular Equivalent method, with and without the additional heavy vehicles. The incremental cost of the bituminous layer is assumed to be the same as for an overlay. Print Summary OK

Figure 18. Sample results screen – Segment analysis, pavement design comparison.



Figure 19. Sample printed report – individual segment.

• Network Level	Consumed Life Design						
C Street Segment Level	Additional ESALs per year: 3,908						
	Average percent of life consumed over 13.1						
	Network cost of consumed life, \$/lane \$993,983						
	This analysis reports the portion of the original design life (in ESALs) that is consumed by the additional heavy vehicles over the life of the street segment.						
	Print Summary OK						

Figure 20. Sample results screen – Network analysis, consumed life.

sis reports the difference in bituminous layer using the Mn/DOT Granular Equivalent
sis reports the difference in bituminous layer using the Mn/DOT Granular Equivalent
vith and without the additional heavy The incremental cost of the bituminous layer d to be the same as for an overlay.
Print Summary OK

Figure 21. Sample results screen – Network analysis, pavement design comparison.



Figure 22. Sample printed report – Network.

Select Method of Analysis	Program Settings	2
Network Level Street Segment Level	<ul> <li>Load Previous Analysis on Startup</li> <li>Begin with Blank Analysis</li> </ul>	
Cost and Other Information	Vehicles to Include in Lists	
Load a Saved Analysis	□     B1 - City Bus       ☑     B2 - Short School Bus       ☑     B3 - Long School Bus	-
Save Current Analysis	□ D1 - 2 Axle Delivery □ D2 - 5 Axle Semi	
Save As New Analysis	D3 - 3 Axle Semi + 2 Axle Trailer D4 - 4 Axle Semi + 2 Axle Trailer	
Load/Update Street Network	G2 - 5 Axle Grain	•
Analyze and Report		
	ОК Са	ncel

Figure 23. User settings screen.

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Не	avy Vehicles In	npacts Tool,	Version	11											
	Releas	ed Jan 2014													
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Guide							-		_				_		
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. To change inputs of set	ungs, press un	e Launon	button	anuua	seure	user	mena	ce un	atop	ena					
er-Defined Settings															
. Click on the "Settings" t	outton to acces:	s user-define	ed settin	as									-		
. Select startup behavior:	Load the prev	ious analysi	s on star	tup, o	r begir	n with	a blar	k an	alysi	s					
Press "Cancel" to exit w	vithout saving th	ne settings cl	hanges,	or "OF	(" to si	ave th	e char	nges	and	exit					
er Inputs															
. Cost and Other Informa	tion														
Click "Cost and Othe	r Information" t	o access this	s area.												
Enter construction co	ost information,	minimum o	verlay th	icknes	s des	ired, t	raffic <u>o</u>	rowt	h rat	e, et	C.				
Press "Cancel" to ex	it without savin	g the change	s, or "Ol	K" to s	ave ar	id exit							_		
Analysis Vehicles		-1						- W-							
Select the Interval de	sired: Addition	nal venicles p	Der" (D	ay, w	еек, м	onth,	Seaso	on, re	ear)				-		
Eor each vehicle, ent	ter the number	avnected ner	choson	inten	al.							1			
Also for each vehicle	indicate whet	her they are t	o be mo	deled	as Fu	II 1/4 F	ull or	Emp	tv				-		
To review vehicle types	and axle confic	urations, cliq	ck "Revie	ew Ver	nicle T	vpes"			-			1			
Select the vehicle typ	e to review by o	licking in the	list												
End by pressing "Clo	ose"	_													
I. To enter a custom vehic	cle types config	uration, click	"Define	Custo	m Vel	nicles	*								
To review characteris	stics of a previo	usly defined	vehicle,	selec	t from	the lis	st								
To create a new vehi	cle definition:														
Select "Create Ne	w Vehicle" from	n the list													
Enter axle load ar	nd configuration	ns (once the	data has	s been	chan	ged, t	he "Sa	ive As	5*	butto	on wi	II become	e active.		
After pressing "Sa	ave As", enter	r a name for	the vehic	cle and	d pres	s "OK				- 11 -	200				
Pressing "Cancel	" Will return to t	ne custom v	enicie da	ata eni	try with	outs	aving	nein	Torm	atio	n		-		
To doloto a customa	exit the custom	venicie data	entry				-						-		
Select a vehicle to	n delete														
Press "Delete Se	lected" - This i	s not reversi	hlel												
Selecting a Street Segn	nent														
To select a specific s	street segment	for the "Stre	et Segm	ent Le	evel" a	nalysi	s sele	ct the	e Stre	eet N	Vame	e first.			
Select a specific Sec	gment from the	drop-down r	nenu		1	12									
To view or modify the	street inventor	ry data													
Press "View/Ente	r Data*														
View or change in	nformation for s	urface, base	, and su	bbase	e thick	ness	and ty	pe							
	formation for a	ubgrade R-V	alue ve	ar of la	astrec	onstr	uction	ADT	HC	ADT	and	% Truck	s, if available	e	
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Figure 24. Extract of User Guide.

# Chapter 4. CONCLUSIONS

The objective of this research, Heavy Vehicles Impacts Tool, was to develop an analysis method and tool for the evaluation of pavement impacts due to unanticipated large volumes of heavy axle loads. This report describes the problem and reviews the relevant literature on this topic and proceeds to document the development of the analysis method and the associated tool for this evaluation. The analysis method does not include any new pavement analysis or design methods, although it utilizes existing methods in different ways that allow for this type of evaluation to be conducted.

The tool that implements the analysis method is a standalone Microsoft Excel spreadsheet in which the default data, user-entered data, pavement management data, and many user-entered analyses are stored. The spreadsheet opens a user screen within which all of the tool's operations are conducted. Associated with the analysis and tool is a training module to teach the operation of the tool and to provide general ideas for its use. Case studies are included that use real-life scenarios (with identifying information redacted) from which users may develop ideas for further analysis in other specific situations.

Recommended future improvements to the tool include the following.

- Include portland cement concrete pavements in the analysis,
- Utilize newer pavement design and analysis methods as they become more accepted, such as mechanistic-empirical methods,
- More direct importing methods from pavement management systems,
- Develop improved vehicle definitions for vehicles and axle loads for empty, full, and half-full modes,
- Add ability for users to include pictures of their custom vehicles,
- Allow users to associate cost and other inputs to specific analyses, not universally to the overall tool.

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