Benefit/Cost Analysis of Spring Weight Restriction

in Lyon County, Minnesota

by Ning Li and David Levinson

ABSTRACT

Spring Weight Restrictions (SWR) forbid heavy trucks to run on some low-level roads during the spring thaw period. There has been long dispute between trucking industry and road agencies on the effectiveness of this policy. Previous studies showed inconsistent results on this issue. This paper consistently estimates the benefits and costs of the SWR policy in Lyon County, Minnesota. A freight demand model was built to simulate truck flow on the road network. A pavement performance model estimates pavement life in terms of rutting failure based on the traffic provided by freight demand model. The analysis shows that the benefits of SWR to local agencies are exceeded by the costs to truckers, which suggests lifting these seasonal restrictions on 7 and 9-ton roads.

Key words:

Spring Weight Restrictions, Spring Load Restrictions, Benefit/Cost Analysis, EMME/2, Freight Demand Model, Pavement Performance Model, Freight Economics, Truck Weight Restrictions

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INTRODUCTION

Spring Weight Restrictions (SWR) limit the axle loading of heavy trucks during the spring thaw. SWR are implemented in many cold climate countries, including the United States, Canada, France, Norway, Finland, and Sweden. The policy aims to reduce pavement damage and extend the useful life of roads, which enables road authorities to save on maintenance costs.

However, SWR impose costs on the trucking industry due to detouring or increased number of truckloads. A question naturally arises: does the benefit really exceed the cost? Although the SWR policy has been implemented for many years, we are still unclear on this issue. The trucking industry complains the SWR policy imposes costs and inconvenience while the road agency strongly advocates this policy because it reduces required pavement investment and maintenance.

Quantifying the cost and benefit of SWR is difficult because many costs and benefits are intangible and cannot be directly measured. Still some previous studies have evaluated the SWR in limited ways.

A World Bank report indicates that the estimated cost savings associated with SWR during an extreme (20 year) winter in Europe are substantial, ranging from 40 percent up to 92 percent, with an average of 79 percent for the countries analyzed (*1*). The United States Federal Highway Administration (FHWA) also investigated the benefits of SWR in 1990 (*2*) and found that seasonal load restrictions can significantly extend the useful pavement life. However, a study of Norwegian Public Roads Administration showed that the cost of SWR exceeded the benefit; therefore, the SWR policy was lifted in 1995 (*3*). Moreover, there is no indication that the lifting of

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the load restrictions in 1995 resulted in reduced road surfacing serviceability and the actual annual budgets for resurfacing during the same period have been considerably reduced (*4*).

Previous studies to assess the benefits and costs of Spring Weight Restrictions show inconsistent results. This paper quantifies in a consistent and objective manner the effects of Spring Weight Restrictions Policy for Lyon County, Minnesota. The basic idea of the analysis is to build a Freight Demand Model that can simulate truck flow under two scenarios: Without and With SWR, and a Pavement Performance Model which can estimate the pavement life under different traffic scenarios. A flowchart of the framework for analyzing the benefits and costs of SWR is shown in Figure 1 (11).

As preparation for the benefit-cost analysis, a two-round survey was conducted in 2003 using both mail and on-site interview methods (*5*) The survey aimed to provide SWR background information, parameters like truck operating cost, value of time, and trips generated for each freight facility type, which could be used in the benefit/cost analysis.

The next two sections discuss the freight demand model (FDM) and pavement performance model (PPM) respectively. Then the benefit cost analysis methodology and results are presented. The paper concludes with a summary of findings and some thoughts as to why this issue remains contentious.

FREIGHT DEMAND MODEL

Data Preparation

The first step is to obtain the data needed for modeling. A Lyon County GIS map with traffic volume on most of the roads was obtained from the County Traffic Engineer,

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together with a detailed road restriction map (9). The GIS map was transformed to EMME/2 format using Arc/Info and Matlab programming.

EMME/2, a transportation-planning program was chosen here to run our freight demand model. All roads in Lyon County, including trunk highway, county, city, and township roads are classified into four types: 5, 7, 9 and 10-ton roads, which are consistent with the Spring Weight Restrictions map obtained from the Lyon County traffic engineer. This number represents the axle weight limit. There are four corresponding modes in the freight demand model: 'c','l','m','h', which are explained in Table 1. It is assumed that there are three typical types of trucks (2-axle, 3-axle and 5-axle) and their configuration and percentage are listed in Table 2.

Trip generation

Major freight facilities were located using the Minnesota Freight Facility Database. There are eight types of freight facilities in the Lyon County: Farm, Agriculture Chemical Center, Grain Elevator, Manufacturing Plant, Retail Outlet, Trucking Facility, Wholesale Distribution Center, and Other Freight Facilities. For farms, the trip generation rate is calculated according to the total weight of grain produced in Lyon County in the year 2001. Total crop weighs 706,484 tonnes, which is assumed to be carried by a 9-ton truck fleet which has 48 percent 2-axle truck, 27 percent 3-axle truck, 25 percent 5-axle truck in the scenario without SWR. Knowing the payload of each kind of truck from Trimac's study (8), the total number of truck trips to carry grain from farm to elevator can be calculated. If 225 farms are assumed to be evenly located across the Lyon County, each farm has a daily truck trip rate of 0.67 in the scenario without SWR. In the scenario with SWR, the truck trip rate is calculated

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based on the available route between a specific origin and destination, which is higher than the scenario without.

For the remaining freight facilities, the trip generation rates are calculated using a linear regression model (7):

$$Y=c+bx$$

where:

Y = daily freight trips

b,c = model coefficient

x = the number of employees

The values of parameter b and c are obtained using reported trip rates and firm sizes from the survey conducted in Minnesota (12). The imposition of SWR may reduce some trips (trips that are avoided), but other freight requires additional truckloads to carry while satisfying the SWR (trips that are made are more costly). This is discussed below in the section on truck type choice.

Trip distribution

Trip distribution is based on the origin-destination sketch map in Figure 2. Many assumptions based on our survey results are used to determine the trip distribution pattern. For example, the grain produced in each farm was assumed to go to the nearest grain elevator and the trucks were assumed to return to the farm empty. Each farm was assumed to require the nearest agriculture chemical center to deliver the cargo and the trucks were assumed to return to the agriculture chemical center empty. For manufacturing, wholesale, retail, trucking facilities, and other facilities, the

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generated trips of each facility will go to the external points outside the county in proportion to the real traffic counts to these external points. External to external truck traffic is assumed to be 20% of the total traffic stream.

Truck type choice

For truck type choice, the trips between each origin and destination are assumed to utilize the heaviest truck allowed. For instance, if the origin is located in a zone that has the highest road type of 7 tons, and the destination is located in a zone that has the highest road type of 9 tons, the trip between the origin and destination can only use up to the minimum of 7 and 9 tons, so the mode would be 'l', which has an axle weight limit of 7 tons. If no route, which can accommodate the "l" mode, can be found linking the origin and destination, the lower level mode "c" mode must be chosen.

Trip assignment

In the traffic assignment procedure, truckers are assumed to choose the shortest time path assignment. Since rural areas are being modeled, congestion effects are ignored. The volume-delay function is designed to exclude congestion effects, but different road types have different freeflow speeds.

Model results

The freight demand model provides truck volumes on each section of roads under both scenarios. Thus, truck Vehicle Kilometers of Travel (VKT) can be calculated under the two scenarios. The model results show that SWR (with 100% compliance) caused a 30.4% increase of truck VKT in Lyon County.

Model Validation

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The freight demand model is validated by comparing observed truck traffic on links in Lyon County outside the SWR period to their counterpart link counts in the model. Mn/DOT conducted the truck counts on more than sixty locations in Lyon County.

Figure 3 compares the model with observations. It is can be seen from the plot that two data sets have a linear relationship. A regression of this data showed an R-squared value of 0.836. This shows a strong correlation between the model and observation.

Model Calibration

To proceed in calibrating the model, a scaling factor was determined to transform the modeled truck rates to more accurate rates. The sum of the daily truck traffic for all the observation sites was found and compared to the sum of the daily truck traffic on the links representing those sites in the model. The sum of the actual truck traffic is 7612 trucks while the sum of the modeled truck traffic is 6285 trucks. The actual traffic was found to be 1.21 times the modeled traffic. Therefore, the traffic volume for each scenario was scaled up by a factor of 1.21. Table 3 gives the adjusted VKT of the two scenarios.

PAVEMENT PERFORMANCE MODEL

The freight demand model provides calibrated truck volumes by type on each section of the road network as an input to the pavement performance model (PPM). The PPM estimates the pavement life in terms of rutting failure, which is derived from Mn/Pave program developed at the University of Minnesota and maintained by the Minnesota Department of Transportation.

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The PPM calculates the damage each truck imposes on the pavement assuming certain pavement structural configurations and estimates the pavement life. In Lyon County, it is assumed that 7-ton roads are built of 3" asphalt on 6" granular base and 9-ton roads are built on 3.5" asphalt on 15" granular base according to our survey. Also, we assume 50% of roads are built on A6 soil and 50% on A7 soil.

It is assumed there are three types of trucks in the road network. Their configuration is shown in Table 2. Coefficient damage factor is calculated for all these types trucks when they run on 5, 7 and 9-ton roads respectively according to the Mn/Pave Model. From the pavement model we know how many these types of trucks are on each sections of the roads, thus the pavement life in terms of rutting failure can be calculated for two different scenarios.

It is worth noting that the pavement performance model only models the lifetimes of 7 and 9-ton paved roads in terms of rutting failure. (It can also model fatigue failure, but rutting failure occurs sooner and so is the relevant failure mode). For 5-ton gravel roads, we use different assumptions about their lifetime.

BENEFIT/COST ANALYSIS METHODOLOGY

We calculated the average structural and functional overlay cost for 7 and 9-ton roads in Lyon County based on cost and length percentage for each type of road. The cost of pavement overlay is obtained from a survey of county engineers. We adopt the functional overlay cost to calculate the cost of pavement for 7 and 9-ton roads. Thus, a functional overlay of a 7-ton road has an average cost of $42,113 per center-line kilometer and a functional overlay of a 9-ton road has an average cost of $42,853 per

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center-line kilometer. Re-graveling of 5-ton roads has an average cost of $18,750 per center-line kilometer according to the FHWA manual (10)

In both scenarios (with and without SWR), it is assumed that a functional overlay is conducted for 7 and 9-ton roads when the road serviceability drops to a certain level. The functional overlay is assumed to last no more than 17 years for 7 and 9-ton roads with SWR, which means the road will be overlaid whether or not rutting failure is the dominant failure mode. Re-graveling of 5-ton gravel roads is typically performed every 6 years in the scenario with SWR (10) and 5 years in the scenario without SWR.

Pavement life extension benefits on 7 and 9-ton roads are calculated on a link-by-link basis. The PPM estimates the years before rutting failure, which may be longer or shorter than the actual pavement life. We assume an overlay can last at most 17 years due to other types of pavement failure. Thus, when the pavement performance model estimates a pavement life to be more than 17 years, a 17 year pavement life is adopted. For each link, we have the pavement life in the two scenarios. For most links, the pavement life in terms of rutting failure has a longer life in the scenario with SWR than in the scenario without. The overlay costs in both scenarios are discounted to the present value in an analysis period of 42.5 years. The difference of overlay cost is the pavement life extension benefit due to SWR policy.

Figures 4 and 5 show the cash flow diagram of overlay in the two scenarios. For 7 and 9-ton roads, it is assumed that overlay will be performed during a pavement life cycle to maintain a certain level of serviceability. We assume 7 and 9-ton roads in Lyon County are on average in the middle of one overlay, which is half of the previous pavement's time between overlays. We will take one link as an example to show how we calculate the pavement life savings due to SWR.

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One 7-ton road section in Lyon County has a length of 1.584 km. The functional overlay cost of 7-ton roads is $42,112 per km. Each overlay will cost $66,706 for this road section. This road section has estimated life of 14.2 and 14.5 years for the scenarios with and without SWR respectively. In the without SWR scenario, the first, second and the third overlay happen at 7.1, 21.3 and 35.5 year respectively. The first and second overlay cost $66,706.

It is worth noting that the third overlay has a residual life outside the analysis period. The cost of third overlay is multiplied by the ratio of the usable life in the analysis period versus its actual life. Here the road will be used for 7 years (42.5-35.5) in the analysis period while it has a 14.2 years actual life. Thus the third overlay cost is estimated as $32,839 (=7/14.2*66,706).

Each overlay cost is discounted to net present cost (NPC) assuming a 3.5% interest rate. Thus the NPC of the first overlay is calculated as $66,706* $\frac{1}{(1+i)^{7.2}}$ =$52,248. The NPC of these three overlay adds up to $93,981, which is the total overlay cost for this road section in the following 42.5 years.

Similarly, we can calculate the total overlay cost of this road section in the scenario with SWR, which has a NPC of $91,652. Thus the net present value of total savings due to SWR on this road section is $93,981-$91,652=$2,329

The calculation process is listed in Table 4.

For each link, we calculate the net present value of the overlay costs in the two scenarios respectively. Because the calculation involves thousands of 7 and 9-ton

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links, the data is exported into MS Excel and Visual Basic Application Programs are written to perform the analysis.

BENEFIT/COST ANALYSIS RESULTS FOR LYON COUNTY

In Lyon County Minnesota, there are 1,437 km of 5-ton gravel roads, 260 km of 7-ton paved roads and 191 km of 9-ton paved roads.

According to the above methods, the present value of benefits for pavement life extension for the following 42.5 years is summarized in Table 5. We also include the results of alternative assumptions, which assume (in the absence of rutting failure) 17 (base), 15, 20, 25 and 30 years before failure for 7 and 9-ton pavement life. The total pavement life extension benefit in Lyon County in the following 42.5 years adds up to $20,784,085 under the 17 years assumption (base case) (which compare lifting SWR on 5, 7, and 9-ton roads with retaining SWR). As can be seen, the final answer is relatively insensitive to the overall life of the pavement.

The costs to truckers can be calculated using total truck operating cost per kilometer. The method calculates the cost to the truckers due to SWR as the increased VKT multiplied by total truck operating cost per kilometer. According to our freight demand model, SWR caused a 30.4% increase of truck VKT. From Table 2, we can see the total additional truck VKT is 30,628 km per day. Our SWR survey shows the total truck operating cost is $0.69 per km (*6*). Thus, the total cost to all freight shippers and carriers is $21,133 per day. Assuming 8 weeks enforcement of SWR, the total annual cost is $1,183,447**.** The cash flow is shown in Figure 6. The net present value of the cost to truckers in the following 42.5 years adds up to $25,977,572, assuming a 3.5% interest rate.

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Because of uncertainty about the value of SWR on 5-ton gravel roads, we conduct a benefit/cost analysis of lifting SWR on 7 and 9-ton paved roads while retaining SWR on 5-ton gravel roads. We obtained the results summarized in Table 6. It can be seen lifting SWR on 7 and 9-ton road results in a benefit/cost ratio well above 1.0 for all 5 assumptions.

CONCLUSIONS

The benefits and costs of spring weight restrictions (SWR) are assessed in this paper. A freight demand model simulates truck volume on each section of the roads under scenarios with and without. A pavement performance model estimates pavement life on 7 and 9-ton roads under two scenarios. Pavement life extension benefit and cost to trucker is calculated to evaluate the effectiveness of SWR program.

According to the above analysis, the benefit/cost ratio of lifting SWR on 7 and 9-ton roads in Lyon County is 13.81 in our base case, which supports lifting the SWR on those roads. The above result is based on our assumption of 100% compliance with SWR, which of course differs from reality. However a reduction in compliance reduces both benefits (if roads are already "overloaded", the SWR has less effect than shown here) and costs (if trucks are violating the SWR, they don't save time by the elimination of SWR). The result can be used as reference when considering alternative policies. Examining the effects of SWR on 5-ton gravel (and paved) roads, requires better pavement performance models for those facility types.

It is worth noting that the cost of lifting SWR (increased pavement overlay cost) is borne by the road agencies while the benefit of SWR is apportioned among thousands of road users (trucking industry). The interests from both parties make this issue a

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political one. Clearly if the trucking industry were to benefit from lifting SWR more than the costs imposed on road agencies, there are “gains from trade” to be had. A tax, toll, or user fee on trucks to pay for the additional road damage that would be caused without SWR is a win-win solution compared to the current situation with SWR.

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List of Tables and Figures

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TABLE 1 Four modes in the Freight Demand Model

Mode	Representation	Allowed road types to run on
c	truck with small loads	5,7, 9,10-ton roads
l	truck with light loads	7,9,10-ton roads
m	truck with moderate loads	9,10-ton roads
h	heavy truck	10-ton roads only

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TABLE 2 Truck configuration and percentage on different types of roads

Truck Configuration	Net Vehicle Weight (ton)	Gross Vehicle Weight (ton)	Payload (ton)	Weight Restriction (ton)	Actual carrying capacity (ton)	Proportion of fleet
5 ton road	Carrying capacity of a typical 5 ton truck				4.0	
2 Axle	3.4	12	8.6	7.3	3.9	85.4%
3 Axle	8	21	13	12.9	4.9	14.6%
7 ton route	Carrying capacity of a typical 7 ton truck				8.8	
2 Axle Truck	3.4	12	8.6	10.2	6.8	54.2%
3 Axle Truck	8	21	13	18.1	10.1	29.7%
5 Axle Truck	14.4	39	24.6	27.8	13.4	16.1%
9 ton route	Carrying capacity of a typical 9 ton truck				13.0	
2 Axle Truck	3.4	12	8.6	13.1	8.6	47.5%
3 Axle Truck	8	21	13	23.6	13	27.1%
5 Axle Truck	14.4	39	24.6	35.7	21.3	25.3%
10 ton route	Carrying capacity of a typical 10 ton truck				17.4	
2 Axle Truck	3.4	12	8.6	>13.1	8.6	24.8%
3 Axle Truck	8	21	13	>23.6	13	9.8%
5 Axle Truck	14.4	39	24.6	35.7	24.6	65.4%

TABLE 3 Truck VKT of No SWR and With SWR scenarios

Scenario Number	Scenario	VKT (kilometer)	Calibrated VKT (kilometer)
1	No SWR	83184	100653
2	With SWR	108496	131280

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TABLE 4 Pavement life extension benefit for one link

Link 1	From node id:		41	To node id :		9
		Length (km)	1.584		Cost per km ($)	$42,112
			No SWR scenario			With SWR Scenario
	Estimated life (years)		14.2	Estimated life (years)		14.5
Overlay	Year	Cost($)	NPC($)	Year	Cost ($)	NPC ($)
1st overlay	7.1	66,706	52,248	7.3	66,706	51,962
2nd overlay	21.3	66,706	32,053	21.8	66,706	31,530
3rd overlay	35.5	32,839	9,680	36.3	28,455	8,161
Sum of NPC			93,981			91,652
Savings due to SWR						2,329

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TABLE 5 Pavement life extension benefits on different type of roads

Road Type	Total length (km)	Pavement life extension benefit ($) (17 year life)	Pavement life extension benefit ($) (15 year life)	Pavement life extension benefit ($) (20 year life)	Pavement life extension benefit ($) (25 year life)	Pavement life extension benefit ($) (30 year life)
5-ton gravel	1437	20,288,529	20,288,529	20,288,529	20,288,529	20,288,529
7 and 9 ton total	451	495,556	479,902	594,276	627,558	690,008
Total	1888	20,784,085	20,768,431	20,882,805	20,916,087	20,978,537

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Table 6 Benefit/Cost ratio from removing SWR on 7 and 9-ton roads only (retaining SWR on 5-ton roads) assuming different time before failure in Lyon County

Assumption (default life of road)	Cost (Increased pavement cost incurred by road agency) ($)	Benefit (Reduced cost to trucker) ($)	Benefit/Cost Ratio
15	278,446	6,057,602	21.76
17	*438,642*	*6,057,602*	*13.81*
20	500,782	6,057,602	12.10
25	644,082	6,057,602	9.41
30	763,415	6,057,602	7.93

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Flowchart of SWR Benefit/Cost Analysis

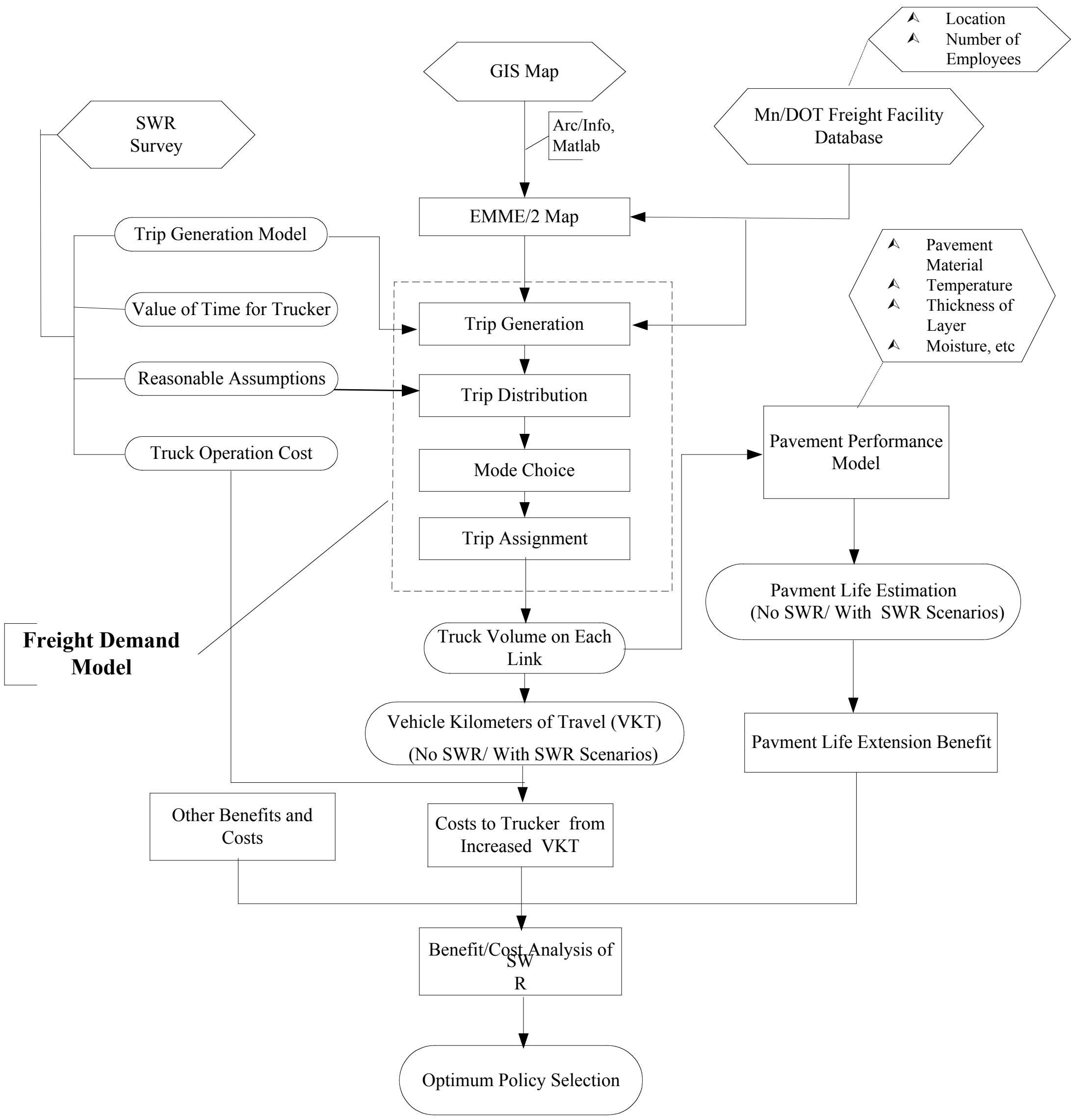

FIGURE 1 Flow chart of the SWR Benefit/Cost Analysis

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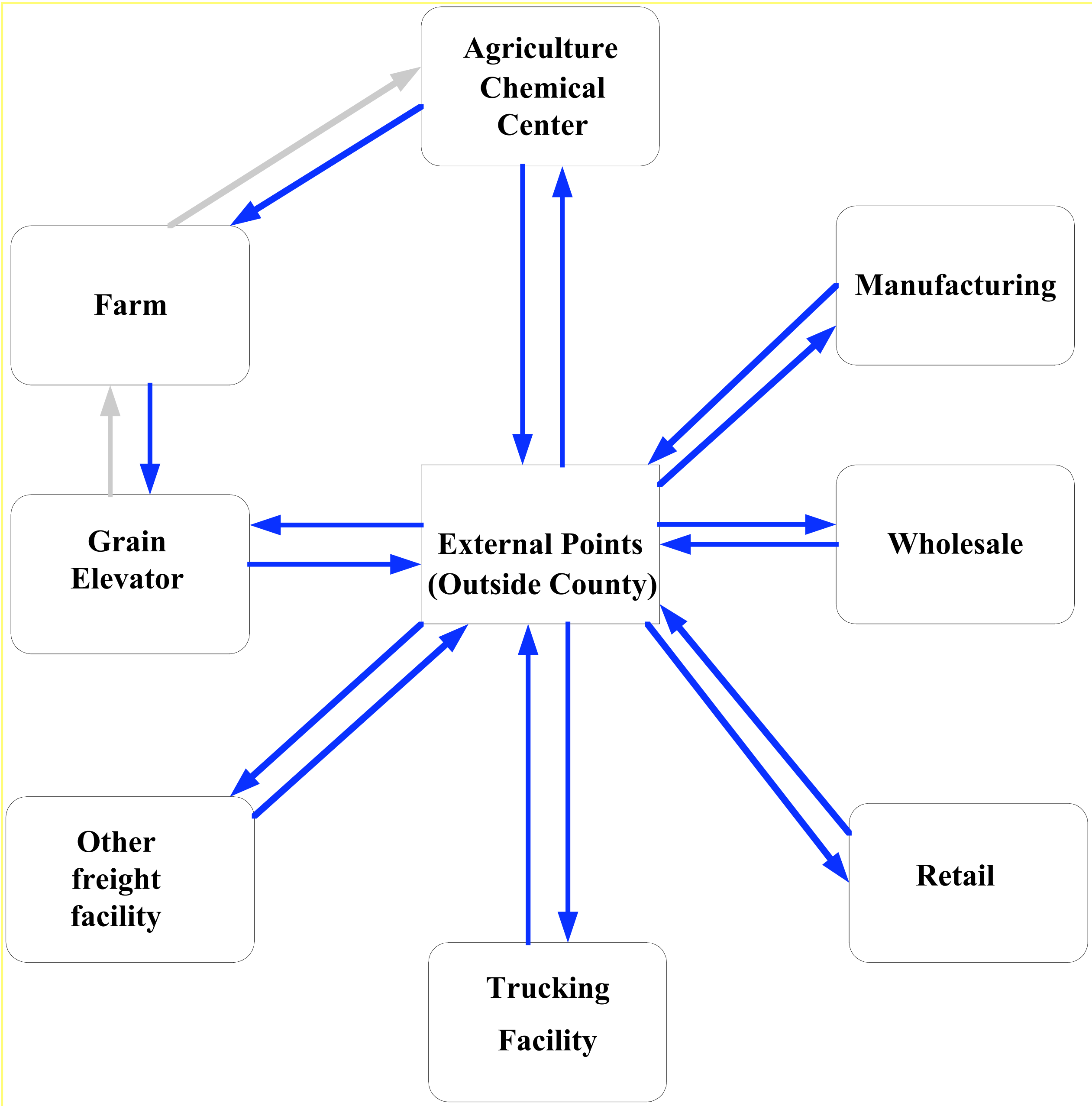

FIGURE 2 Sketch map of Origin-Destination in Lyon County

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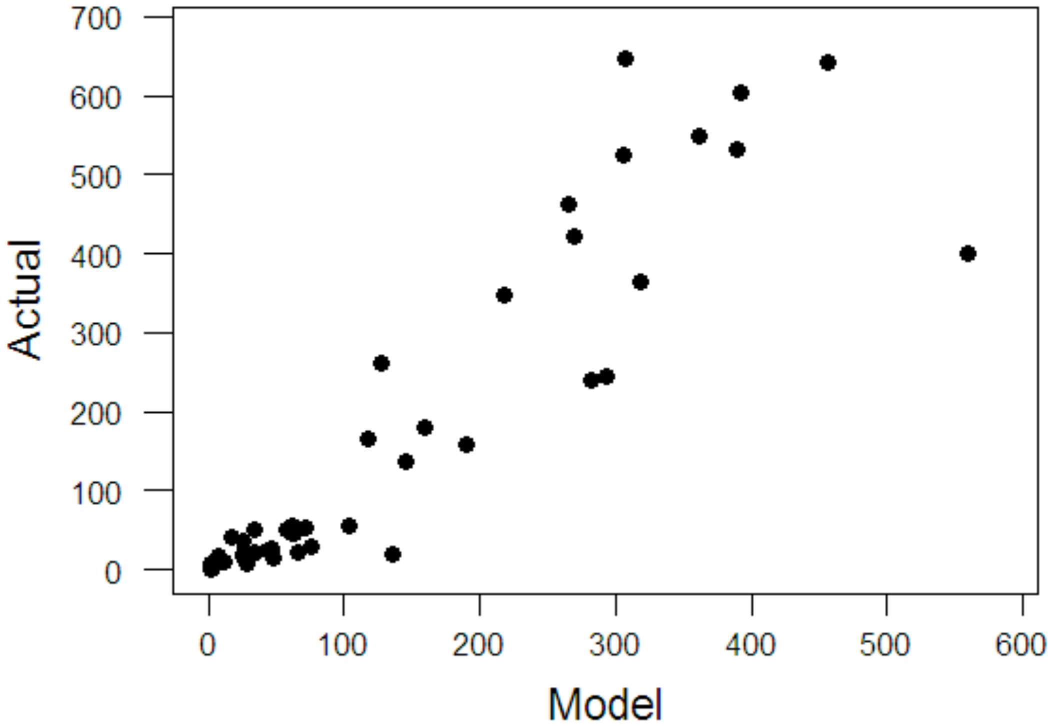

FIGURE 3 Plot of model vs. observed truck AADT for Lyon County

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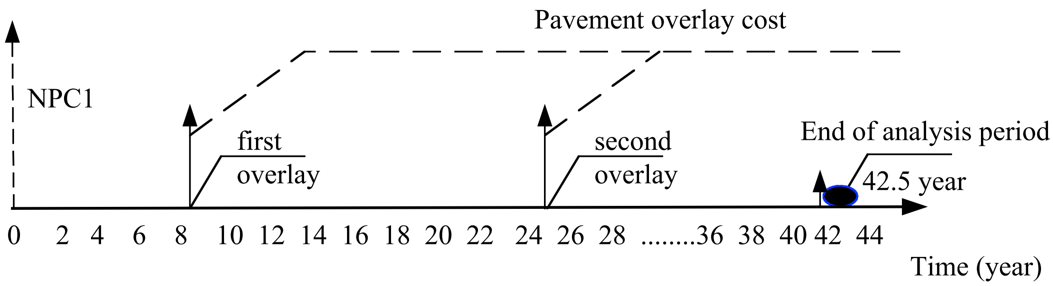

FIGURE 4 Cash flow chart for With SWR scenario

Li, Ning, David M. Levinson, Brian Smalkoski, Michael Corbett (2005) Benefit-Cost Analysis of Spring Weight Restrictions in Lyon County, Minnesota presented at 84th Annual Meeting of Transportation Research Board in Washington, DC, January 9-13th 2005.

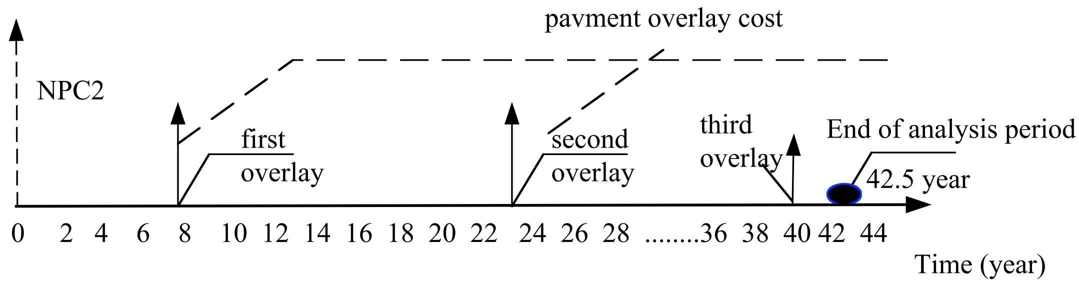

FIGURE 5 Cash flow chart for Without SWR scenario

Li, Ning, David M. Levinson, Brian Smalkoski, Michael Corbett (2005) Benefit-Cost Analysis of Spring Weight Restrictions in Lyon County, Minnesota
presented at 84th Annual Meeting of Transportation Research Board in Washington, DC, January 9-13th 2005.

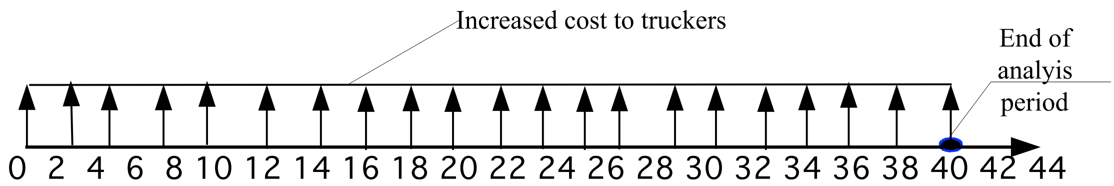

FIGURE 6 Cash flow diagram of increased cost to truckers

Li, Ning, David M. Levinson, Brian Smalkoski, Michael Corbett (2005) Benefit-Cost Analysis of Spring Weight Restrictions in Lyon County, Minnesota presented at 84th Annual Meeting of Transportation Research Board in Washington, DC, January 9-13th 2005.