Evaluation of the Economic Feasibility of Weigh-In-Motion in Canada

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Paper prepared for presentation
at the Pavement Evaluation, Performance and Management Session

of the 2008 Annual Conference of the
Transportation Association of Canada
Toronto Ontario

ABSTRACT

Over weighted trucks is the cause of many issues including pavement premature deterioration, mistimed maintenance, and high pavement life cycle cost. To comply with weight enforcement and to preserve highway, Weigh-In-Motion (WIM) has been focused on using state-of-the-art sensing technology to continuously collect vehicle weights, speeds, vehicle classes, and various types of traffic data as vehicles travel over a set of sensors (embedded or portable), without interruption of traffic flows.

This paper will examine the capability and applicability of WIM from economy prospect in Canada. A complete benefit-cost study in three aspects, delay time benefit, safety benefit, and level of enforcement benefit, for Canadian road network are quantified. Variables that alter the magnitudes of the benefits and costs are carefully chosen. A sensitivity analysis and a break-even analysis are performed. An application of WIM in Canada is addressed to demonstrate the economic feasibility. The analysis result shows that an integrated benefit-cost ratio of 12 can be achieved. WIM deployment is economically feasible for the circumstances in Canada.

INTRODUCTION

A WIM system is comprised of a set of sensors and supporting instruments that are designed to measure the presence of a moving vehicle and the related dynamic tire forces at specified locations with respect to time; estimate tire loads, calculate speed, axle spacing, vehicle class according to axle configuration, and other parameters of a vehicle; and process, display, store, and transmit this information [ASTM 2002]. The use of WIM is to help capture weight violating vehicles, decrease travel time for commercial carriers, reduce congestion, reduce traffic crash risk, exchange traffic information, and eventually help achieve the goal of preserving highway infrastructure at a network level.

Besides the technical performance (accuracy) of a particular WIM system (Zhang, Haas, and Tighe (2007) presented a method for evaluating this aspect), the economic value of WIM and its cost-effectiveness compared to conventional options is also an importance subject. An economic analysis is to determine whether the investment of an ITS component or subsystem is economically beneficial in order to achieve the projected goals, and to rate the return on the investment compared to that of alternatives (WIM systems vs. static weigh stations). It focuses on quantifying the specific monetary values of all impacts on regional and national economies, the users, the agencies, and also the environment. It attempts to reduce everything to a single benefit-cost ratio [Zavergiu et al. 1996, Novak and McDonald 1998, Lee and Klein 1997, Lee 1999]. With limited budgets, an economic analysis helps to make the best decision. The analysis is used by comparing alternatives rather than developing absolute values of benefits or costs, thus many of difficult assumptions tend to cancel out and the analysis can provide useful results [Peng et al. 2000].

ECONOMIC ANALYSIS TOOLS FOR ITS

To quantify benefits and costs of ITS applications, several tools have been developed. The major analysis tools include Screening for ITS (SCRITS) and ITS Deployment Analysis System (IDAS) developed by FHWA.

SCReening for ITS (SCRITS)

To quantify benefits and costs of ITS applications, several tools have been developed. The major analysis tools include Screening for ITS (SCRITS) and ITS Deployment Analysis System (IDAS) developed by FHWA. SCRITS is an Excel based screening level tool to obtain an initial indication of benefits of various ITS applications. There are 16 applications identified in a spreadsheet, including WIM, traffic signal systems, and bus priority systems. It produces the estimates of user benefits on a daily basis. To start the tool, users need to provide the baseline data including travel statistics and other specific parameters used in a study. Currently, the primary applications of SCRITS are the following: approximation of user benefits for evaluating transportation alternatives, approximation of users' benefits for ITS strategic planning, and sensitivity analysis of the benefits to certain input assumptions [SAIC 1999]. Among these applications, sensitivity analysis is one of the best applications since it can be used to identify serial assumed variables that can have a significant influence on the benefits and the overall structuring of an analysis.

ITS Deployment Analysis System (IDAS)

The IDAS analysis tool is designed for detailed, comparative benefit-cost analysis for ITS applications. The capacities of the IDAS include comparison and screening of ITS alternatives, estimation of life cycle costs, sensitivity and risk analysis [IDAS 2000]. IDAS comprises five modules including an Input/Output Interface Module (I/O), an Alternatives Generator Module (AGM), a Benefit Module, a Cost Module, and an Alternatives Comparison Module (ACM). It is capable of analyzing more than 60 types of ITS investments, such as WIM systems, transit vehicle signal priority, and safety readiness. Required input data include node coordinate information in a roadway network, information of facility type, capacity, traffic volume, and traffic speed between nodes. In practice, this analysis tool is complicated and expensive to perform.

WIM vs. STATIC SCALE VALUES

In practice, WIM systems and static weigh stations are used to complement each other, because a citation for a weight violation to a trucking company can not be legally issued unless the truck weight measurement is better than 99 percent accurate [ORNL 2000], which is usually done by static weigh stations. High-speed scale systems of WIM are installed on main road sections, where trucks are prescreened to be overweight or not, then those pre-identified overweight trucks shall be pulled over to the weigh stations for precise weighing. In order to accommodate the increasing traffic volume, rather than expanding the weigh station facilities, adding high-speed scales of WIM systems is a solution. Although WIM systems and traditional static weigh stations are practically used together for enforcement management, in order to evaluate the benefits and costs of WIM systems, static weigh stations and WIM systems are treated as a pair of significant alternatives. The economic analysis will weigh the differences between the two alternatives in the following situations:

- Increased percentage of trucks that can bypass weigh stations after deployment of WIM
- Increased percentage of overweight trucks detected after deployment
- Saved travel time after deployment
- Reduced overweight truck accidents after deployment
- Reduced load damage and pavement cost after deployment (presented in [Zhang, Haas, and Tighe 2007]

ECONOMIC MODELS

To assess the benefit values of WIM systems compared to static weigh stations, it is necessary to understand how WIM functions in highways. A typical WIM system is used with other Commercial Vehicle Operation (CVO) technologies, such as Automatic Vehicle Identification (AVI), visual cameras, and importantly the static weigh scales to confirm overweight. WIM systems are usually located close to a static weigh station near the main lanes of a highway. As a truck approaches a WIM system at the highway speed, the WIM system measures the truck's weight, axle load and configuration, as well as vehicle type if capable. Data is processed by transportation management software, which compares the measured data with the preset axle loads and GVWs to decide whether the truck is overweight or not. If a truck is detected to be possibly overweight, a message is displayed on a roadside sign, directing the truck to a nearby static weigh station for further inspection. Otherwise, no message will appear and the truck can continue without stopping. Image information of a truck can also be monitored through a camera mounted at the road side. Figure 1 is a diagram of how a WIM system works on a highway main lane.

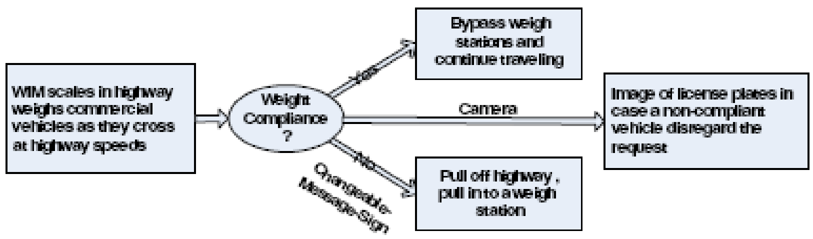

Figure 1: Operating Diagram of a Typical WIM System at Highways

Weight Enforcement - Delay Time Benefit Model

WIM allows for all trucks passing WIM to be weighed, and only possible overloaded vehicles are requested to enter the static scales, and unnecessary delays at the scales are eliminated. It creates increased time for enforcement by personnel. To evaluate the delay benefit, the tool of SCRITS is used to develop the model in terms of saved delay time, Figure 2 is the diagram to evaluate delay benefit-cost ratio after evaluating the costs and benefits, which are estimated using LTPP online spreadsheet and SCRITS accordingly. From a user's perspective, the delay benefit comprises two components: the annual "truck time cost" saving that results from reduced delay time after WIM deployment; the other component is the annual "vehicle operating cost per stop" saving that results from less travel distance for bypass vehicles. Critical components include:

- Truck time cost ($Va_{TruckTime}$): a combined number that captures the wage and benefits of drivers, time value for inventory, and vehicle depreciation cost per hour;
- Vehicle operating cost (C_{Stop}): a separate factor for truck costs, in addition to time cost, including the cost of fuel, tire. It is expressed as the cost per vehicle mile traveled.

The initial cost (costs of hardware, software, and installation) and annual operating and maintenance costs are estimated from LTPP online resource, "LTPP WIM Cost Online" [LTPP 2007]. It works as a spreadsheet and allows users to estimate the cost of a new WIM system. It is based on the inclusion of the following: the initial hardware cost, sensor failure rate, calibration cost, and other parameters. The required basic inputs are the number of WIM scales to be purchased and the type of WIM sensors. The spreadsheet then calculates rough estimates of the cost to keep the site operating at the level expected by LTPP. The total cost is expressed as the Equivalent Uniform Annualized Cost (EUAC), which is obtained by multiplying the present value of cost by an annualization factor. To determine the delay benefit model, the following variables are included. In addition, a break-even and a sensitivity analysis are conducted to study the impact of input assumptions in the model.

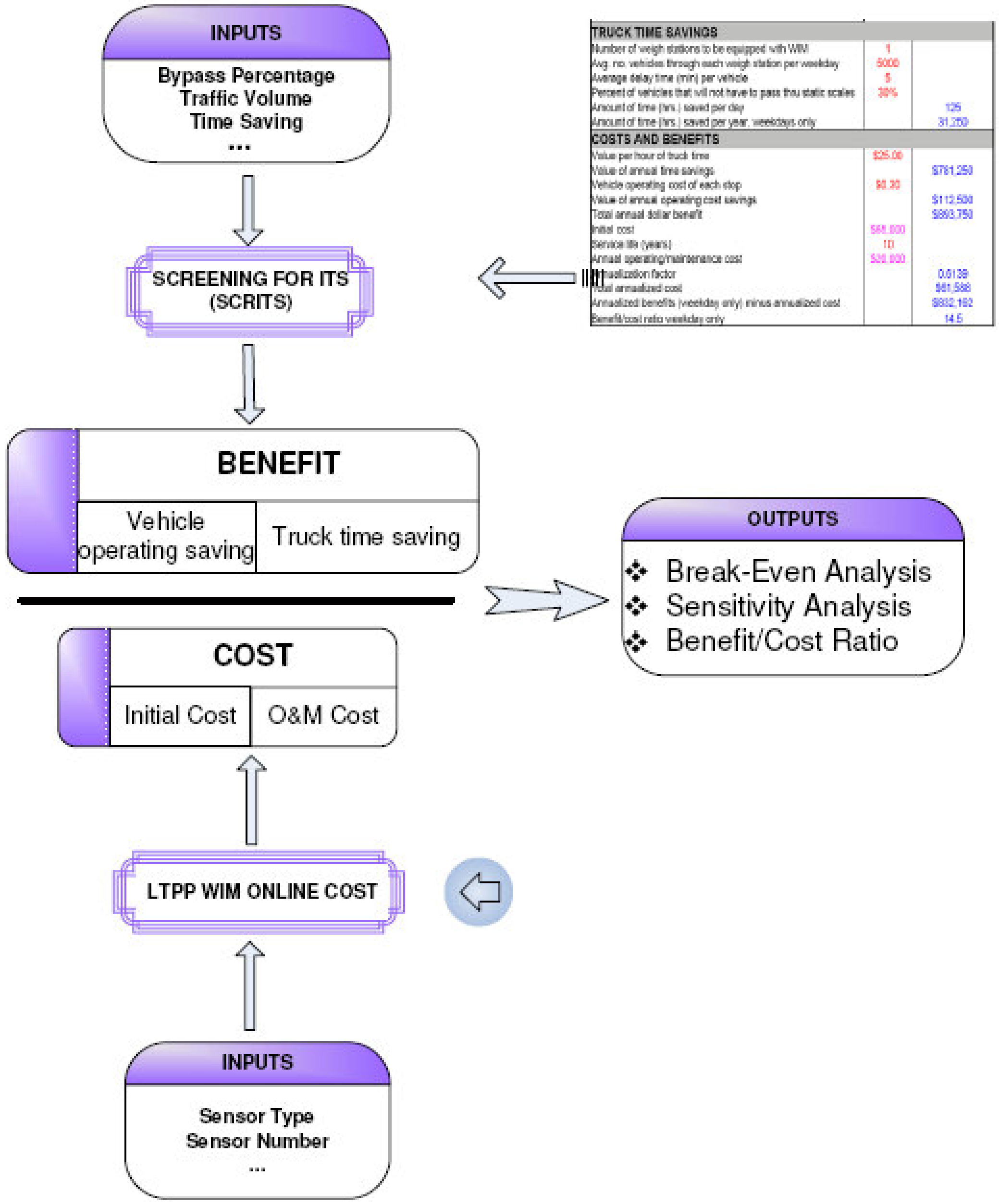

Figure 2: Diagram of Delay Benefit-Cost Ratio Evaluation

$$
\begin{aligned}
WS_N &= \text{Number of weigh stations (static scales) to be equipped with WIM} \\
Veh_N &= \text{Average Number of Vehicles through each WIM} \\
T_{\text{Delay}} &= \text{Average Delay Time per vehicle (minutes)} \\
ByPa &= \text{Percentage of vehicles that will not have to pass through static scales,} \\
& \text{i.e. BYPass static scales} \\
C_{\text{Stop}} &= \text{Vehicle operating Cost of each stop (\$)} \\
C_{\text{Initial}} &= \text{Cost of WIM installation (\$)} \\
C_{\text{O\&M}} &= \text{Cost of annual operating/maintenance of WIM (\$)} \\
Va_{\text{TruckTime}} &= \text{Value of Truck Time per hour (\$)} \\
SL &= \text{Service Life of a WIM system (years)} \\
T_{\text{Workday}} &= \text{work days per year} \\
TD_{\text{Saved}} &= \text{Amount of time saved per day (hours)} \\
TY_{\text{Saved}} &= \text{Amount of time saved per year (hours)} \\
Va_{\text{Oper}} &= \text{Value of annual operating cost savings (\$)} \\
Va_{\text{TimeSaved}} &= \text{Value of time saving annually (\$)} \\
B_{\text{Delay}} &= \text{Total annual monetary delay benefit (\$)} \\
C_{\text{Annual}} &= \text{Total annualized cost (\$)} \\
f &= \text{Annualized factor}
\end{aligned}
$$

$$
\begin{aligned}
TD_{\text{Saved}} &= T_{\text{Delay}} \times Veh_N \times ByPa \times WS_N / 60 \\
TY_{\text{Saved}} &= TD_{\text{Saved}} \times T_{\text{Workday}} \\
Va_{\text{TimeSaved}} &= Va_{\text{TruckTime}} \times TY_{\text{Saved}} \\
&= Va_{\text{TruckTime}} \times \frac{T_{\text{Delay}}}{60} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workday}} \\
Va_{\text{Oper}} &= C_{\text{Stop}} \times Veh_N \times BaPa \times T_{\text{Workday}} \\
B_{\text{Delay}} &= Va_{\text{Oper}} + Va_{\text{TimeSaved}} \\
C_{\text{Annual}} &= C_{\text{Initial}} \times f + C_{\text{O\&M}} \\
\frac{B}{C} &= \frac{B_{\text{Delay}}}{C_{\text{Annual}}}
\end{aligned}
\tag{4.2}
$$

i.e.

$$
\frac{B}{C} = \frac{C_{\text{Stop}} \times Veh_N \times ByPa \times T_{\text{Workday}} + Va_{\text{TruckTime}} \times \frac{T_{\text{Delay}}}{60} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workday}}}{C_{\text{Initial}} \times f + C_{\text{O\&M}}}
$$

To demonstrate the delay benefit model 4.2, Scenario I is designed as follows: a single static weigh station is with 500 vehicles per day usage, and an average delay time is 5 minutes per vehicle. The initial cost of a two lane single load-cell based WIM system was estimated to be \$122,000 with a 10-year service life, and annual operating and maintenance cost of \$31,920. Vehicle operating cost at each stop was assumed to be 30 cents, and the value per hour of truck time is \$25 according to the America Highway Economic Requirement Model and the study of Peng et al. [Peng et al. 2000]. The result shows that the annual benefit is \$159,298 and the annual cost is $49,244. The benefit/cost ratio (the equivalent uniform annual benefit to the equivalent uniform annual cost) would be 4.2. It indicates a high benefit.

Table 1: Scenario I - Delay Benefit [FHWA 1999]

ANALYSIS OF WIM DELAY BENEFIT		User Input	Calculated Value
Date of analysis		Feb/07/2007	
Scenario		I	
Analyst		Alanna	
Description : A single load-cell WIM system at a typical highway main lane		Less travel time	
TRUCK TIME SAVINGS			
Number of weigh stations to be equipped with WIM	WS_N	1	
Avg. no. vehicles through each weigh station per weekday	Veh_N	500	
Average delay time (min) saved per vehicle	T_{Delay}	5	
Percent of vehicles that dot not have to report to static scales	$ByPa$	70%	
Workday per year	T_{Workday}	250	
Amount of time (hrs.) saved per day	TD_{Saved}		29
Amount of time (hrs.) saved per year, weekdays only	TY_{Saved}		7,292
COSTS AND BENEFITS			
Value per hour of truck time	$Va_{\mathrm{TruckTime}}$	$25.00	
Value of annual time savings	Va_{TimeSave}		$182,292
Vehicle operating cost of each stop	C_{Stop}	$0.30	
Value of annual operating cost savings	Va_{Oper}		$26,250
Total annual dollar benefit	B_{Annual}		$208,542
Initial cost (2 lanes)	C_{Initial}	$122,000	
Service life (years)	SL	10	
Annual operating/maintenance cost	$C_{\mathrm{O\&M}}$	$31,920	
Annualization factor	f		0.142
Total annualized cost	C_{Annual}		$49,244
Annualized benefits (weekday only) minus annualized cost			$159,298
Benefit-cost ratio weekday only	B/C		4.235

Break-even Analysis

The purpose of break-even analysis is to examine the tradeoff between the potential benefits of an ITS project and its costs, by estimating the minimum level of performance required to have an equivalent cost and benefit. It can be used to identify and quantify critical variables (performance measures) to achieve an acceptable benefit-cost ratio. The critical performance measures identified here can be further used in sensitivity analysis. Apply Scenario I to demonstrate the break-even analysis: submit the values of $WS_N = 1$, C_{Stop} = $0.30, $Va_{TruckTime}$ = $25.00, and other inputs from Table 1, along with the initial cost and O&M cost from "LTPP WIM Cost Online"; change bypass rate from 10% to 30%, static scale usage rate (traffic volume) from 100 to 2500 vehicles per weekday. The required time saving to have an equivalent cost and benefit is presented as formula (4.3) and as Figure 3.

Let $B/C = 1$, i.e.,

$$\frac{C_{\text{Stop}} \times Veh_N \times Bypa \times T_{\text{Workday}} + Va_{\text{TruckTime}} \times \frac{T_{\text{Delay}}}{60} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workda}}}{C_{\text{Initial}} \times f + C_{\text{O\&M}}}$$

then

$$C_{\text{Initial}} \times f + C_{\text{O\&M}} =$$
$$C_{\text{Stop}} \times Veh_N \times Bypa \times T_{\text{Workday}} + Va_{\text{TruckTime}} \times \frac{T_{\text{Delay}}}{60} \times Veh_N \times ByPa \times WS_N \times T_{\text{Work}}$$

Hence,

$$\begin{aligned} T_{\text{Delay}} &= \frac{(C_{\text{Initial}} \times f + C_{\text{O\&M}} - C_{\text{Stop}} \times Veh_N \times ByPa \times T_{\text{Workday}}) \times 60}{Va_{\text{TruckTime}} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workday}}} \\ &= \frac{(C_{\text{Initial}} \times f + C_{\text{O\&M}}) \times 60}{Va_{\text{Truck Time}} \times Veh_N \times ByPa \times T_{\text{Workday}}} - \frac{C_{\text{Stop}} \times 60}{Va_{\text{TruckTime}}} \end{aligned} \tag{4.3}$$

Substitute values from Scenario I,

$$\begin{aligned} T_{\text{Delay}} &= \frac{29230 \times 60}{25 \times 250 \times Veh_N \times ByPa} - \frac{0.3 \times 60}{25} \\ &= \frac{280.608}{Veh_N \times ByPa} - 0.72 \end{aligned}$$

It shows that as the bypass percent (*ByPa*) increases, the required time saving (T_{Delay}) for break-even points decreases. The same trend shows between traffic volume and required time saving. In order to be beneficial, for example, 5 minutes time saving requires about 250, 350, and 550 of traffic volume with respect to bypass rate of 30%, 20%, 10% correspondingly. That is, larger traffic volume will require less time saving such that the created benefits easily covers the annual costs for the WIM system. The curve indicates the break-even points are relatively low number in all cases as the traffic volume is greater than a certain amount. WIM deployment that eliminates unnecessary travel time is a valuable investment in nearly all cases except when the traffic volume is very low.

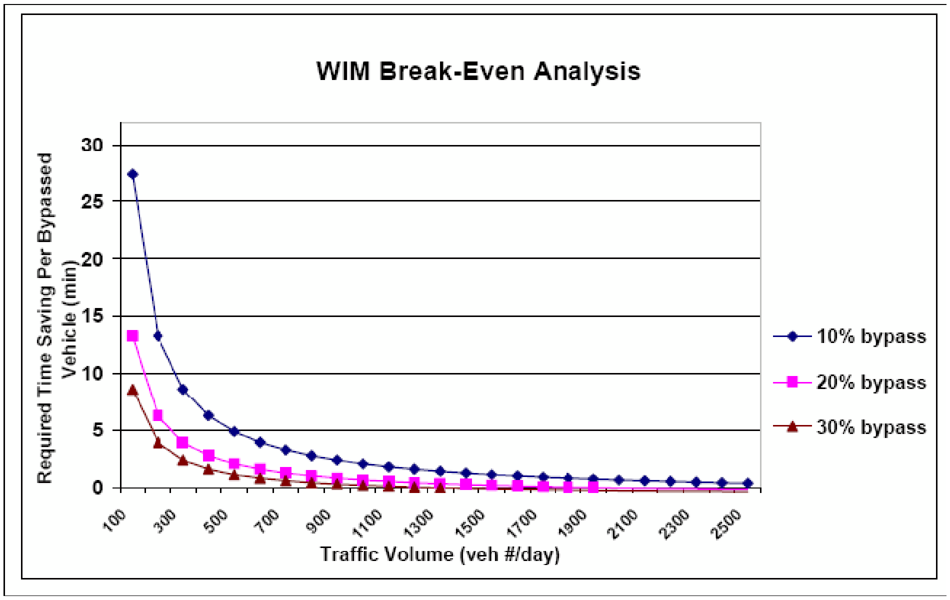

Figure 3: Break-Even Analysis of Delay Benefit

Sensitivity Analysis

Given the uncertainty of variables/assumptions in a model, a sensitivity analysis is the process of varying the variables/assumptions over a reasonable range and observing the relative changes in the model response, to demonstrate the impact of inputs on the model output. In this study, the key variables and their varying ranges follow:

1. Traffic volume per weekday (100 -1000)
2. Percentage of vehicles bypassing static scales (10% - 90%): bypass rate after applying WIM
3. Delay time saved per vehicle (2 -10 minutes)
4. Value of truck time ($10 - $30): capture drivers' wage and benefit, time value of inventory, and vehicle depreciation cost
5. Vehicle operating cost (VOC) of each stop ($0.30 - $1.00): cost per vehicle mile traveled

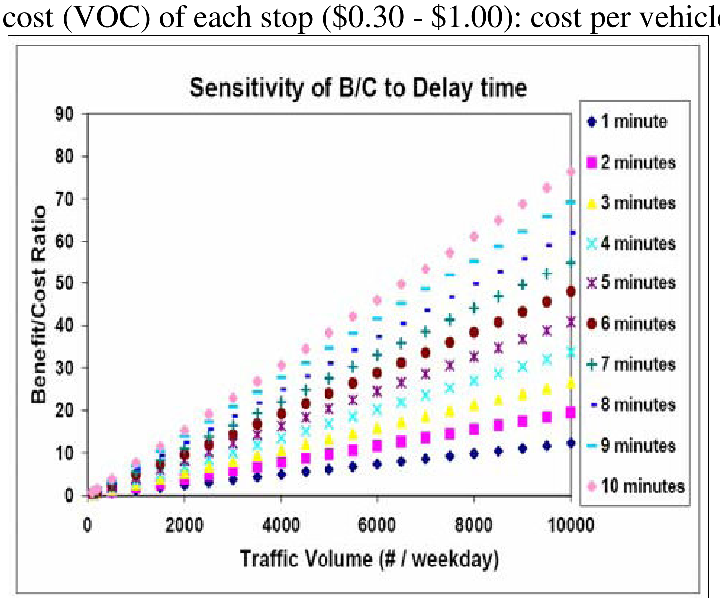

Figure 4: Sensitivity of Benefit-Cost Ratio to Delay Time

Model 4.2 indicates a linear positive trend between each of these variables and the benefit-cost ratio. Certain relationships also exist among some of these inputs, such as delay time at a weigh station could increases as traffic volume increases. Figure 4 and Figure 5 respectively present the sensitivity of B/C ratio to the delay time and the traffic volume. There is a linear relationship between delay time and B/C ratio, the slope of each trend (the change rate of B/C) increases as the traffic volume or delay time increases. Similarly, the model responses to other inputs follow the same trend.

In summary, the sensitivity analysis indicates that as the value of a key variable changes in the range, the value of B/C adjusts in the same direction. Some variables affect the behavior of the model to a larger extent than others. For example, improving percentage of bypass is very attractive since with the 100 percent of bypass, there would be no need for static scales. The break-even analysis indicated that WIM are beneficial except under very low traffic volume and delay time conditions.

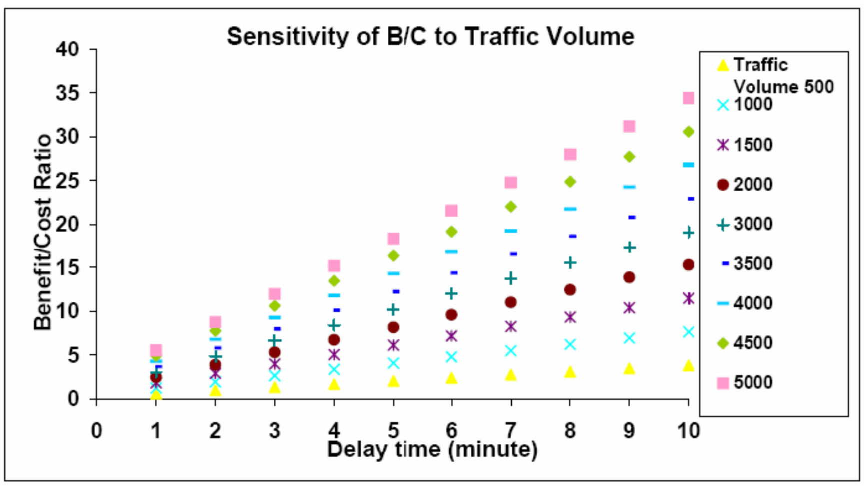

Figure 5: Sensitivity of Benefit-Cost Ratio to Traffic Volume

Capability Enhancement Benefit Model

There are two aspects of weight enforcement benefits: one is that the delay time reduced for commercial travelers since fewer vehicles are required to report to scales after WIM deployment, which has been assessed antecedently. The other benefit is that the number of trucks with unauthorized bypass is decreased since weigh stations do not have to be closed during peak hours to avoid congestion. The capability enhancement benefit is evaluated in terms of the amount of fines.

Define the variables and follow with Scenario II to demonstrate the benefit:

$LE(w)$ = Increased Level of Enforcement: inspection rate, the number of trucks out of compliance inspected as a percentage of all trucks using WIM, a function of w

Veh_N = Average Number of Vehicles through each WIM, ie. traffic volume per day

$ESAL_{ow}$ = ESAL-km, average ESAL traveled in total distance by overweight vehicles per day; an indicator of the total load repetitions imposed, depending on the level of enforcement[Edward et al. 1995]

T_{Workday} = Work days per year

$Pe_{ow}(w)$ = Penalty per ESAL-km, a function of w

w = GVW limit, in USA = 36.3 tons, in Canada = 39.5 tons [Edward et al. 1995]

B_{ce} = Total annual monetary capacity enhancement benefit

Then

$$B_{ce} = Pe_{ow}(w) \times (ESAL_{ow} \times LE(w) \times Veh_N) \times T_{\text{Workday}}. \tag{4.4}$$

Table 2: Scenario II - Capacity Enhancement Benefit

ANALYSIS OF WIM CAPACITY ENFORCEMENT BENEFIT			
		User Input	Calculated Value
Date of analysis		Mar/03/2007	
Scenario		II	
Analyst		Alanna	
Description: A single load cell WIM system at a typical highway mainlane		Higher level of enforcement	
WEIGHT ENFORCEMENT LEVEL ANALYSIS			
Avg. no. vehicles through each weigh station per weekday	Veh_N	500	
% Increased level of enforcement after deploying WIM	$LE(w)$	20%	
Weekdays per year	T_{Workday}	250	
Avg. no. overweight vehicles reduced per year due to higher level enforcement			25,000
Average ESAL-km of overload per day	$ESAL_{ow}$	100	
COSTS AND BENEFITS			
Penalty per ESAL-km	$Pe_{ow}(w)$	\$0.06	
Annual pavement cost saving due to higher level of enforcement			\$150,000
Installation cost		\$122,000	
Service life (years)		10	
Annual operating/maintenance cost		\$31,920	
Annualization factor			0.142
Total annualized cost			\$49,244
Annualized benefits minus annualized costs			\$100,756
Benefit-cost ratio			3.046

Safety Benefit Model

Overweight vehicles and safety concerns are closely related. Many studies ([Jacob 2002a, Compbell et al. 1988, Fancher 1998]) have concluded that vehicle weight is an aggravating factor in traffic accident rate. WIM can effectively and efficiently detect overweight trucks and decrease traffic congestion. The safety benefit is evaluated in terms of reduced number of accidents.

Define the variables and follow with Scenario III to demonstrate the model:

$$
\begin{aligned}
OW_{\mathrm{Re}} &= \text{Percentage reduction of overweight trucks after deploying WIM} \\
AcR_{\mathrm{ow}} &= \text{Accident rate of overweight trucks in total number of trucks per year} \\
C_{\mathrm{owAc}} &= \text{Accident-related costs per occurrence for overweight accidents} \\
Veh_N &= \text{Average number of vehicles through each WIM, traffic volume} \\
T_{\mathrm{Workday}} &= \text{Work days per year} \\
B_{\mathrm{safety}} &= \text{Total annual monetary safety benefit}
\end{aligned}
$$

Then,

$$B_{\mathrm{safety}} = C_{\mathrm{owAc}} \times AcR_{\mathrm{ow}} \times (Veh_N \times OW_{\mathrm{Re}} \times T_{\mathrm{Workday}}) \tag{4.5}$$

Table 3: Scenario III - Safety Benefit

ANALYSIS OF WIM SAFETY BENEFIT			
		User Input	**Calculated Value**
Date of analysis		Mar/03/2007	
Scenario		III	
Analyst		Alanna	
Description: A single load cell WIM system at a typical highway mainlanes		Deduction of accident rate	
ACCIDENT ANALYSIS			
Avg. no. vehicles through each weigh station per weekday	Veh_N	500	
% reduction of overweight trucks after deploying WIM	OW_{Re}	20%	
Weekdays per year	T_{Workday}	250	
Avg. no. overweight vehicles reduced per year			25,000
Accident rate of overweight trucks per year	AcR_{ow}	0.002	
Annual accident reduction of overweight trucks			50
COSTS AND BENEFITS			
Accident-related costs per occurrence for overweight accidents	C_{owAc}	\$5,000	
Value of annual savings in accident-related costs			\$250,000
Installation cost (2 lanes)		\$122,000	
Service life (years)		10	
Annual operating/maintenance cost		\$31,920	
Annualization factor			0.142
Total annualized cost			\$49,244
Annualized benefits minus annualized costs			\$200,756
Benefit-cost ratio			5.077

The estimated benefit value from fewer accidents is \$250,000. The benefit-cost ratio is 5.077, which is significantly high and shows that the system is beneficial to reduce congestion and have the road safer. Assumptions shall be carefully re-examined in the table of Scenario III, such as a reasonable value or range for percentage reduction of overweight trucks after deploying WIM, accident rate of overweight trucks, and related cost of overweight accidents. Model 4.5 indicates that the B/C ratio is sensitive to these variables, with the similar relationship as that of the delay benefit model.

Weight enforcement, delay time, and road safety improvement are the main components of WIM benefits as discussed formerly. To express the economic value of WIM as a benefit-cost ratio, these components are integrated with Model (4.2), (4.4) and (4.5). Table 4 combines the estimated benefits of the three scenarios. Figure 7 integrates the benefit models of weight enforcement. Since highway wear is not immediately quantifiable, the benefit of traffic data collection was evaluated through the study of overloaded pavement MEPDG simulation, instead of a quantified model [Zhang, Haas, and Tighe 2007]. Figure 6 illustrates the cost model.

Table 4: Integrated Benefits of a Typical Single Load-Cell WIM System

Estimation of WIM values	Annual Monetary value
Estimated annual delay benefit	\$208,542
Estimated annual enforcement capacity benefit	\$150,000
Estimated annual safety benefit	\$250,000
Total	\$608,542
Estimated annual cost	\$ 49,242
Benefit/cost (B/C) ratio	\$ 12.358

In summary, the economic benefits of WIM outweigh the costs. Commercial industry experiences more efficient services in a new way, which leads to less delay time, less number of stops, and reduced incidents. The enforcement staff experience better effectiveness and efficiencies of weight enforcement by targeting suspected vehicles only. The transportation engineers have access to specific valuable traffic data for transport planning, highway design, construction, and maintenance strategies. The taxpayers enjoy lower costs for roads and transportation. Highway infrastructure benefits from less overloading damage, longer service life, and better service level. WIM systems are economically feasible for road networks in northern environments.

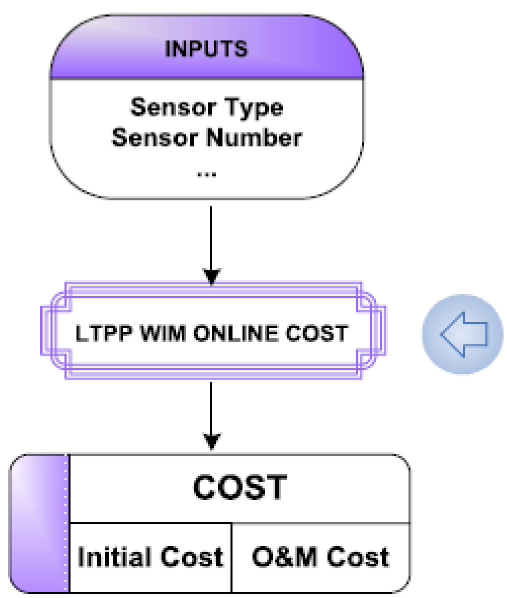

Figure 6: Cost Model of WIM Value

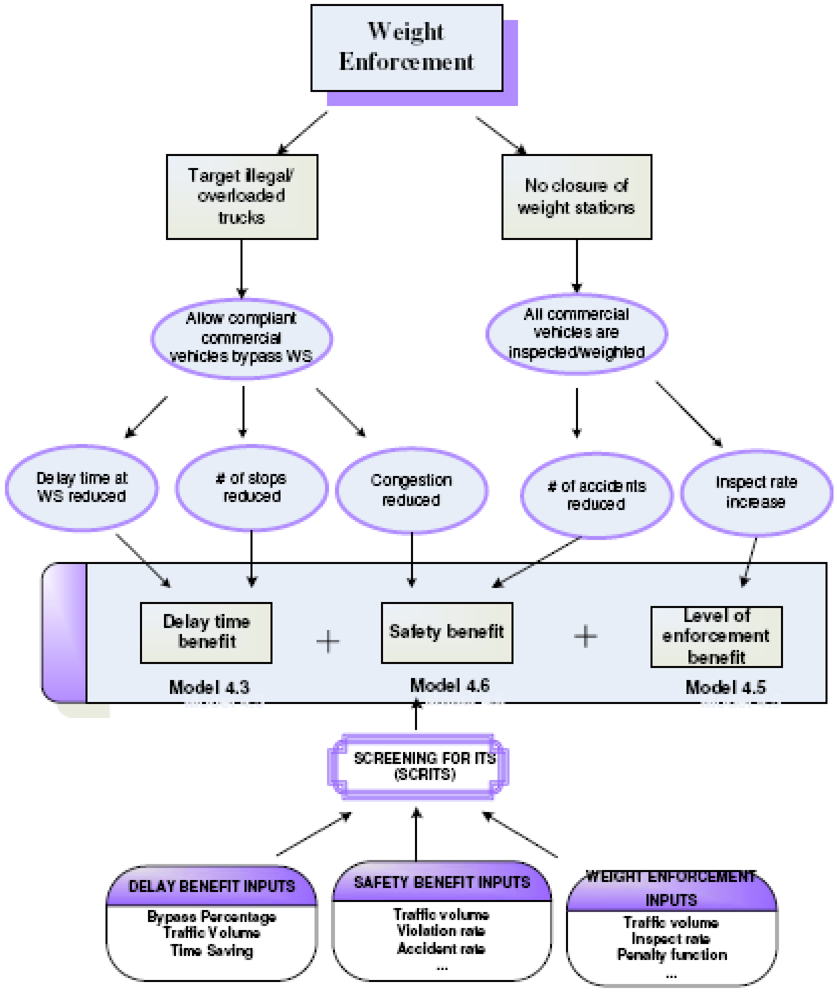

Figure 7: Benefits Diagram of WIM

Economic Data and Tradeoff Analysis: A Case Study

To evaluate the effectiveness of WIM, a New Brunswick Department of Transportation (NBDoT)'s WIM system near Longs Creek in New Brunswick was studied. The Longs Creek weigh station had been experiencing congestion due to time-consuming weighing procedures. Vehicles are either allowed to bypass the scales or selected to report to the static scales during peak hours. This compromised the effective enforcement of overweight commercial vehicles.

A WIM system ([Davis 2003] and [Nash 2006]) was designed for the purpose of pre-screening vehicles and reducing the number of commercial vehicles reporting to the scales. It was installed in the eastbound (two lanes) of Route 2 on the Trans-Canada Highway, and opened on October 2002. The system is comprised of two single load cells, two piezoelectric sensors, 11 inductive loops, two changeable message signs, and two freeze-frame cameras [Davis 2003].

Accuracy of the system was evaluated by NBDoT during the first four months of operations and April 2003. The accuracy results are within the specified accuracy by ASTM E2-1308. To examine the operational benefits of the WIM system, a 24 hour traffic survey was conducted between September 18, 2003 and September 30, 2003. These field data include [Davis 2003]:

- Total truck volume, subdivided into Tractor Trailers, Trains, and Straight Trucks
- Number of trucks signalled to report to static scales in a 24 hour period
- The average time for trucks to exit from main lanes, to report to static scale, and return to the main lanes
- The average distance traveled for trucks to exit from main lanes, report to static scale, and to return to main lanes
- The average time for trucks to bypass the static scales
- The average distance traveled for trucks to bypass the static scales

Given traffic volume and delay time, the average operating costs for each class of truck can be determined. "Operational Costs of Trucks in Canada - 2000" prepared by Trimac Logistics Ltd. was used for the operating cost calculation. All costs and benefits were adjusted for inflation to 2001 dollars with inflation rate of 1.7% (The Consumer Price Index, 2002). The costs and benefits were compared over a five year period from 2002 to 2006, 5% discount rate was used for the analysis.

Approximately 655 commercial trucks per day or 76.5% AADT benefit from the WIM system. This value (655) was multiplied by the percentage of AADT for each type of trucks, to obtain the number of each truck types permitted to bypass per day. These savings then multiply by 365 days and summed to be the total estimated benefit for a year. This computation was over five years, start from year 2002 until 2006. The benefit value varied for each year according to the amount of bypass vehicles. All the estimations (benefits and costs) were discounted to 2001 dollar. The AADT growth rate during the five years was estimated to be 4.3% per annum. The proportion of each type of trucks is assumed to be the same for the five year period. Estimation of the WIM system cost is divided into [Davis 2003], [Nash 2006],

- System supply and installation including 1st year of system supply and service - $443,800
- Changes made to fixed and changeable message signs - $29,900
- Annual maintance costs per site, including regular maintenance (twice a year), service calls, software upgrades - $20,000
- Extra freeze frame camera - $15,600
- Extra options purchased by NBDoT, including left lane sensors- $6,500

The total estimated cost of the Longs Creek WIM system is $610,567 over the five yeas, and the total estimate benefit is $2,253,598. Therefore, the benefit-cost (B/C) ratio is 3.69 for the five year period. This illustrates that appropriate WIM deployment are very beneficial to the commercial industry. In addition, the construction cost only of a static weight station in NB is estimated to be more than $1,200,000.00, including the acceleration lanes, the deceleration lanes, and the ramps [Nash 2006]. It is much more than the cost of the WIM system. Increased safety of traffic traveling are recognized from the WIM system, since only 23.5% AADT are required to report which means less backup on the highway. It follows that the enforcement efficiency are also improved by re-allocating resources. Data for quantifying these benefits are not available at the moment.

This study [Davis 2003] also brought up that the beneficial result is site specific. There exists tradeoff to the attractive benefits. Careful consideration of the site selection, the anticipated road usage, the required accuracy, and the acceptable costs governs each site specific WIM values. Particularly, proper maintenance and calibration are critical because the local seasonal and climatic changes can seriously affect the system accuracy [Davis 2003].

CONCLUSIONS AND RECOMMENDATIONS

Weigh-In-Motion is becoming a state-of-the-practice tool for highway preservation because of its high processing rate without interrupting traffic flow, and the capability of collecting site specific and real time traffic data for highway system management. This paper investigated all significant potential benefits of a typical WIM system compared to conventional static weigh stations with regard to delay time benefit, capacity enhancement benefit, and safety benefit. An integrated benefit-cost ratio of 12 can be achieved by WIM deployment. Only by a single benefit of delay, benefit-cost ratio is 3.8 at the Longs Creek WIM system project in New Brunswick over the first five years. WIM deployment is economically feasible for circumstances in Canada. On the other hand, WIM value is subject to accurate system calibration, harsh Canadian environment, and other site specific circumstances. More economic data from industry practice are required to verify the benefits, such as environmental benefits. It is essential that more resources including engineers and funds are assigned for further WIM development in Canada.

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