PART 2

Economic Analysis

Procedure To Calculate the Economic Benefit of Increased Pavement Life Resulting from Port of Entry Operations in Idaho

SHAUN PARKINSON, JOHN FINNIE, DENNIS HORN, AND ROBERT LOTTMAN

A calculation procedure has been developed to determine the economic benefit of increased pavement life resulting from operation of a port of entry (POE). Weigh-in-motion data and the AASHTO equivalent single axle load tables are used to evaluate the percentage of overloaded trucks and their equivalents. These values are then used to calculate a reduction of pavement life. The cost of reduced pavement life is based on construction and rehabilitation costs of a typical asphalt highway section with an assumed life of 36 years. The economic benefit of increased pavement life resulting from the Bliss POE ranges from $175,000 to $407,000 depending on the assumed influence of the POE.

Ports of entry (POEs) are operated in the state of Idaho to (a) issue permits and collect fees, (b) enforce truck and axle weight limits and thereby reduce damage to pavement and bridges, and (c) perform other associated tasks, such as regulation of hazardous wastes and agricultural products. Efficient economic management of these ports requires that their costs and benefits be estimated. The objectives of this project are to (a) develop a method to quantify the economic benefit to the state of Idaho that results from prevention of premature pavement failure by the operation of POEs and (b) apply the method to a typical POE. The results for a specific site can be combined with other economic benefits (such as collection of permits and license fees, accident prevention, hazardous waste regulation, and agricultural regulation) and costs (such as personnel, facilities, and reduction in net freight weight per trip) to help determine the economic viability of a POE. A complete economic analysis of POE operations would include all of these benefits and costs. However, these can be considered in further research.

Other economic studies of POEs, the relationships between port operation and truck overloading, and the limitations of weigh-in-motion (WIM) equipment are discussed. The calculation procedure is described and illustrated with examples. The method is then applied to the Bliss POE. A sensitivity analysis is performed to determine how the results change if two key inputs are changed.

S. Parkinson, Idaho Power Company, 1109 Main, Boise, Idaho 83702. J. Finnie, D. Horn, and R. Lottman, Department of Civil Engineering, University of Idaho, Moscow, Idaho 83843.

LITERATURE REVIEW

Only a few publications have attempted to quantify benefits of increased pavement life resulting from POEs. Barros (*1*) estimated the cost of overweight trucks to New Jersey highways. He assumed that approximately 20 percent of the trucks were overloaded, on the basis of portable scale results in New Jersey and weights obtained from strain gages on an I-80 bridge in nearby Pennsylvania. Remaining pavement life was calculated from existing highway conditions and a statewide average truck fleet.

Wyatt and Hassan (*2*) estimated that $1.8 million (1982 Canadian dollars) in pavement damages to the southern Saskatchewan provincial highways system was caused by overloaded trucks.

Nielsen (*3*) calculated the cost of reduced pavement life to recommend fines for overloaded vehicles. He assumed an average truck trip length, an average cost per equivalent single axle load (ESAL) per mile of roadway, and a 3-to-1 factor of actual to apprehended overload violators.

In a related study, Halim and Saccomanno (*4*) compared increased pavement and transportation costs under two different load limits. They determined that, where noncommercial traffic is appreciable, increased operating costs for noncommercial vehicles caused by decreases in pavement serviceability and increased repair costs are not offset by gains in efficiency of commercial vehicles arising from higher axle load limits.

A key component of the present study is the estimation of the effect of POEs on truck weights. However, little information relating weigh station operation with weight violation rates has been published. Wyatt and Hassan (*5*) investigated the relationship between enforcement effort and weight compliance at permanent and mobile weigh stations in Saskatchewan. They report that, at permanent weigh stations, zero enforcement results in violation rates that exceed 15 percent for all types of loaded trucks. The violation rate is reduced to about 3 percent when the probability of apprehension exceeds 10 percent. For mobile weigh cars, zero enforcement corresponds to violation rates of about 30 percent, with the violation rate reducing to 9 percent as inspections increase. In both situations, once low violation rates are achieved, additional enforcement effort results in little improvement. These results are expressed as a percentage of loaded trucks and were obtained from violation rate records (static weighing), number of loaded trucks checked, and average percent time the scale is open.

Similar data were taken for short-haul trucks, using WIM equipment. Under normal enforcement (approximately 20 hr/week in the case cited), 31.2 percent of 3S2 trucks (26 percent of all trucks) exceeded legal gross vehicle weights (GVWs). Under zero enforcement 34.5 percent of 3S2 trucks (33.2 percent of all trucks) exceeded legal limits. These violation rates are expressed as a percentage of loaded trucks.

In the past few years, WIM equipment has been used in the state of Idaho. This equipment uses stress-strain relationships to weigh trucks without requiring them to stop. Data from WIM sites are considered here. Shannon and Stanley (*6*) investigated the accuracy of the PAT WIM systems used by the Idaho Transportation Department (ITD). Although the WIM method was not accurate enough to replace static axle weighing for enforcement purposes, good agreement was found between WIM total gross weight and static weights. With the exception of the front axle, the R^2 coefficient of determination between WIM axle weights and static axle weights ranged from 0.7 to 0.95. Shannon and Stanley's results indicate that WIM is acceptable for planning purposes, if its limitations are kept in mind.

Users of WIM data are cautioned that a truck of legal static weight may register as an illegal truck on WIM equipment because of normal weight redistribution at speed and normal truck vibrations (J. L. Hamrick, unpublished data).

The state of Idaho uses a number of criteria to determine if a truck is legally loaded. Following are the maximum legal weights:

- Single axle—20,000 lb.
- Tandem axle—34,000 lb (federal Interstate system); 37,800 lb (if total gross weight does not exceed 79,000 lb allowed on non-Interstate system).
- Total weight—80,000 lb (without permit on Interstate highways).

For this study, a legal truck is defined as one with a gross weight of 80,000 lb or less.

METHODS

The calculation procedure includes several steps. First, after the port has been identified, the road segments under its influence (its influence zone) are identified. Because some trucks on each segment do not route through the port, the percentage of trucks influenced by the port is estimated for each segment.

Second, for each road segment, the percent reduction in pavement life resulting from overloaded trucks is calculated from the percentage of overloaded trucks, axle equivalents and net weights of legal and overloaded trucks, and the percentage of trucks influenced by the port. This calculation is performed for port open and port closed conditions. The percentage of overloaded trucks and their equivalent ratios are estimated from 1989 WIM data.

Third, the cost of building and repairing the road system under decreased lifetimes is calculated for port open and port closed conditions. The difference between these values is the economic benefit that results from operation of the POE. This calculation assumes that the port is either always open or always closed. For this study, the port open condition assumes that the POE is open 24 hr/day, 365 days/year. The port closed condition assumes that the POE is closed 365 days/year. In reality, ITD does not normally operate the ports 24 hr/day.

Selecting Road Segments Influenced by the POE

The preferable method for selecting road segments would consist of an origin-destination study of trucks coming to and going away from the POE being analyzed. An origin-destination study would have the benefit of providing an estimate of the number of trucks on each road segment that are influenced by the POE, as well as the range that the road segment system should extend outward from the port.

Because an origin-destination study was not available for the port being analyzed (Bliss), a geographic zone of influence was identified. That is, road segments were divided between the Bliss POE and neighboring POEs. Figure 1 shows the road system used in the Bliss analysis. As long as the zone of influence is not too extensive, and because every road in the state would not be assigned to a POE, the results of the analysis should be conservative; the POE's influence likely extends past the selected road system.

For each of the road segments considered in the analysis, the average daily truck traffic (ADTT) for 1989 was collected from the ITD MACS/ROSE data base. The ADTT data from ITD was available for road segments much shorter in length

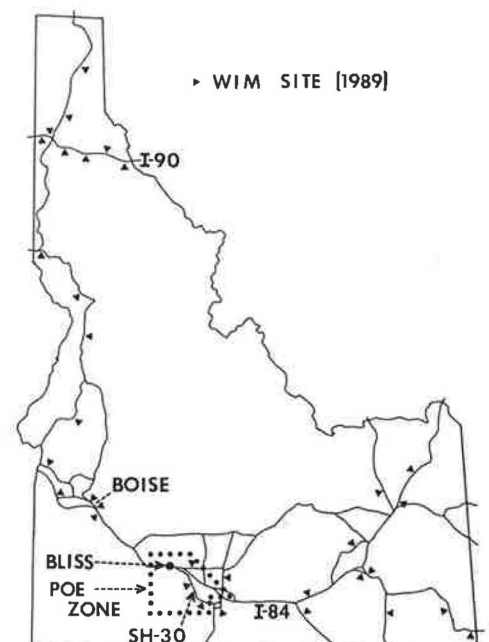


FIGURE 1 Idaho WIM sites and Bliss POE zone.

than the road segments used in this study. The weighted average (by mileage) of the ADTT was calculated for each road segment included in the study area and is used to compute changes in pavement life. Turning volumes are computed using ADTT point data at the intersection rather than the weighted average ADTT of the road segments coming into the intersection.

All of the truck traffic on the POE road segment is assumed to be influenced by the port when it is open, or 100 percent influence (i.e., Segment A in Figure 2). At each branch in the road system leading away from the POE, the influence of the POE on the truck traffic on a given road segment decreases because of the turning traffic. Traffic that travels on road segments influenced by a POE but never passes through the POE is considered uninfluenced traffic.

The number of influenced and uninfluenced trucks on each road segment is estimated using turning movement calculations. In Figure 2, the trucks that follow AC or AB are influenced by the POE, whereas the trucks that follow BC bypass the POE and are uninfluenced by it.

To compute the volume of trucks that follow any of the three possible routes at a three-way intersection, the ADTT for all three segments must be known at the intersection. Equations 1, 2, and 3 are used to compute the turning volumes illustrated in Figure 2:

$$AB = \frac{ADTT_a + ADTT_b - ADTT_c}{2} \quad (1)$$

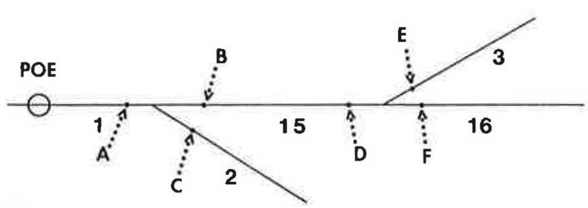
$$AC = \frac{ADTT_a + ADTT_c - ADTT_b}{2} \quad (2)$$

$$BC = \frac{ADTT_b + ADTT_c - ADTT_a}{2} \quad (3)$$

where $ADTT_i$ is the average daily truck traffic on the *i*th segment.

For the situation illustrated in Figure 2, the truck traffic on Segment C consists of AC influenced trucks and BC uninfluenced trucks. Segment B has AB influenced trucks and BC uninfluenced trucks. Segment A has all influenced trucks.

The influenced truck traffic is found for each road segment by computing the turning volume at each intersection, working outward from the POE. The number of influenced trucks



POINT	ADTT
A	2180
B	2180
C	90
D	2180
E	120
F	2180

FIGURE 2 Road diagram to calculate percent influence for multiple branches.

on a road segment is determined by multiplying the number of influenced trucks at the intersection by the percent of trucks that turn onto the road segment being analyzed. The following example illustrates the procedure used to compute the number of influenced trucks on each segment for the POE shown in Figure 2.

Influenced Traffic on Segment 1

No traffic leaves Segment 1 until the intersection; therefore, all trucks on Segment 1 are influenced by the POE. Hence, 2,180 trucks are influenced by the POE on Segment 1.

Influenced Traffic on Segment 2

$$\frac{2{,}180 + 90 - 2{,}180}{2} = 45$$

On Segment 2, 45 trucks are influenced by the POE.

Influenced Traffic on Segment 15

$$2{,}180 - 45 = 2{,}135$$

On Segment 15, 2,135 trucks are influenced by the POE, or 97.94 percent of the total.

Influenced Traffic on Segment 3

$$\frac{2{,}180 + 120 - 2{,}180}{2} = 60$$

There are 60 trucks on Segment 3 from Segment 15. That is,

$$\frac{60}{2{,}180} \times 100\% = 2.75\%$$

Thus, 2.75 percent of all trucks on Segment 15 turn onto Segment 3.

$$0.0275 * 0.9749 * 2{,}180 = 59$$

On Segment 3, 59 trucks are influenced by the POE.

Influenced Traffic on Segment 16

$$2{,}135 - 59 = 2{,}076$$

On Segment 16, 2,076 trucks are influenced by the POE, or 95.2 percent of the trucks.

This method does not account for the possibility of trucks leaving and entering the system between intersections, which would decrease the percentage of influenced trucks. However, the method also ignores many trucks that go through the subject POE's influence zone and subsequently travel in other POE zones without encountering another POE. This category of truck movement should be counted as a benefit of the subject POE. In this sense, this method can be considered a pessimistic estimate of both the influenced road system and the benefit of the subject POE.

One way of dealing with this underaccounting is to credit any truck traveling in the Bliss influence zone (that routes through only one POE) as being influenced by the Bliss POE, regardless of which POE it came through. Obviously, this procedure misapplies benefits among POEs. However, if done consistently over the state, the correct statewide benefit would be calculated. This additional benefit is determined for the Bliss POE and included separately.

Calculating Percent Loss of Life

The percent loss of pavement life is calculated from the axle equivalents of legal (LEE) and overloaded (OE) trucks, the fraction of overweight trucks in the traffic stream (OL), and the net (freight) weight of legal (LNW) and overweight (ONW) trucks. The difference in net weights must be included so that equal amounts of freight are carried regardless of the percent of overloaded trucks.

The number of legally loaded (3S2) trucks per year (LTPY) assumed during design is

$$LTPY = \frac{TDE}{LIFE \times LEE}$$

where TDE is the total design life equivalents of the pavement, and $LIFE$ is the design lifetime of the pavement.

The total freight carried per year (TFPY) is

$$TFPY = LTPY \times LNW$$

$$= \frac{TDE \times LNW}{LIFE \times LEE}$$

To account for the fewer number of trips made by overloaded trucks, it is assumed that the highway carries a constant amount of freight. This total amount of freight is actually carried in legal as well as overloaded trucks.

The equivalents per pound (EQP) of freight when both legal and overloaded trucks are used are

$$EQP = \frac{\text{weighted average equivalents per truck}}{\text{weighted average net freight weight per truck}}$$

$$EQP = \frac{(1 - OL) \times LEE + OL \times OE}{(1 - OL) \times LNW + OL \times ONW}$$

The equivalents per year (EQY) experienced by the pavement are

$$EQY = TFPY \times EQP$$

The total pavement life (TPL) under conditions of overloading is

$$TPL = \frac{TDE}{EQY}$$

$$TPL = \frac{TDE}{TFPY \times EQP}$$

The percent reduction in pavement life is

% years lost

$$= \frac{LIFE - TPL}{LIFE} \times 100\%$$

$$= \left(1 - \frac{TPL}{LIFE}\right) \times 100\%$$

$$= \left(1 - \frac{TDE}{TFPY \times EQP \times LIFE}\right) \times 100\%$$

$$= \left[1 - \frac{TDE}{\left(\frac{TDE \times LNW}{LIFE \times LEE}\right) \times EQP \times LIFE}\right] \times 100\%$$

$$= \left(1 - \frac{LEE}{LNW \times EQP}\right) \times 100\%$$

$$= \left\{1 - \frac{LEE}{LNW \times \left[\frac{(1 - OL) \times LEE + OL \times OE}{(1 - OL) \times LNW + OL \times ONW}\right]}\right\} \times 100\%$$

The percent loss of pavement life is given by

$$\% \text{ years lost} = \left\{1 - \frac{LEE}{LNW} \times \left[\frac{(1 - OL) \times LNW + OL \times ONW}{(1 - OL) \times LEE + OL \times OE}\right]\right\} \times 100\% \quad (4)$$

Equivalents and Percent Overloads

Equivalents are a measure of pavement fatigue from truck axle loads. The OL is the percent of total trucks with a gross weight greater than 80,000 lb. Only axle weights of trucks with that weight are used to calculate OE.

AASHTO ESAL tables are used here to calculate equivalents, requiring knowledge of the truck axle weights, the terminal serviceability index (P_t), and the structural number (SN) for asphalt concrete or the thickness for portland cement concrete.

The predominant pavement material throughout the study area is asphalt concrete. A 3S2 design truck (five-axle tractor/

TABLE 1 OL and E for Open and Closed POEs

	Location	Total # of Trucks Weighed	Percent Overload	Weighted EQ
Interstate POE Open	Buhl-Hollister	267	9.0	3.26
	Cotteral	903	19.9	3.75
	Lewiston	630	6.8	4.42
	Average		11.9	3.81
Interstate POE Closed	Buhl-Hollister	28	17.9	3.50
	Cotteral	1499	46.5	4.26
	Average		32.2	3.88
Secondary POE Open	Samuels	104	26.7	3.66
Secondary POE Closed	Samuels	387	20.4	4.13
	Ashton	176	38.1	3.76
	Council	172	17.4	3.91
	Payette	278	24.8	3.65
	Cottonwood	151	33.8	3.64
	Average		26.9	3.82

single-trailer truck, one steering axle, and two tandem axles) is used to compute the legal equivalents because the majority of trucks on Idaho highways are of this type. The legal equivalent is computed from the AASHTO tables as follows:

Steering Axle (12 kip) = 1 axle $*$ 0.19 equiv. = 0.19 equiv.

Tandem Axles (34 kip) = 2 axles $*$ 1.09 equiv. = 2.18 equiv.

Total Equivalents = 0.19 + 2.18 = 2.37 equiv. (legal)

It is preferable to conduct a long-term, site-specific survey to obtain the percent of overloaded trucks and equivalents. Because this information is not available, axle weights are obtained from WIM data at locations throughout the state for port open and closed conditions. OL and equivalents were calculated at selected Interstate and secondary WIM sites, both for port open and port closed conditions. The OL and equivalent values applied to Bliss (see Table 1) are based on averages from these WIM sites. If OL and equivalent values are available for a specific site, they should be used instead of these statewide values.

Table 2 presents the calculation procedure used to estimate average equivalents (E) for a group of tandem axles. Adding the average equivalents for the front axle and other tandem axles results in an average equivalent for the group of trucks.

The axle load data available at each WIM site indicate that the average overload equivalent on Interstate and secondary highways for influenced and uninfluenced trucks is approximately 3.80 and is only weakly related to the percent of overloaded trucks. Figure 3 shows the relationship between percent overload and equivalents.

WIM data from 1989 are used to estimate the percent overloads on Interstate and secondary highways for influenced and uninfluenced truck traffic. Again, a long-term survey at each site would be preferable. The OL values used in the benefit calculation are presented in Table 3. The percentages given in the table are rounded averages of the WIM data from Table 1. For convenience, the data reported by Wyatt and Hassan (5) for all truck types is shown next to the values used in the benefit calculation. Unlike the values from this study, the Saskatchewan data are expressed as a percentage of loaded trucks and use static weighing.

TABLE 2 Example Calculation of Average Equivalent for One Tandem Axle

Tandem 1

Axle Load	# of Tandems	Equiv. / Axle, SN=5	Sum of Equiv.
20000	0	0.121	0
24000	0	0.180	0
28000	0	0.364	0
32000	0	0.658	0
36000	2	1.090	2
40000	32	1.700	54
44000	25	2.510	63
48000	8	3.550	28
52000	0	4.860	0
56000	0	6.470	0
60000	0	8.400	0
Sum =	67		148

Average Equivalent = 148 / 67 = 2.2

Note: P_t = 2.5; SN = 5. 1989 WIM data for 352 trucks with GVW ≥ 80,000 lb. All trucks, asphalt concrete.

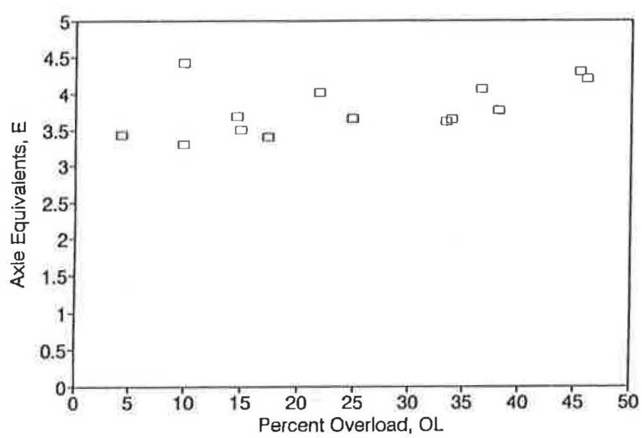


FIGURE 3 Average percent overload versus average axle equivalents for selected WIM sites.

TABLE 3 OL Values

	POE	Used[a] % OL	Saskatchewan[b] % OL
Interstate Roads	Open	10	3
	Closed	30	18.6
Secondary Roads	Open	10	9
	Closed	30	30

a percent of all trucks, WIM
b percent of loaded trucks, static weights

Because of the small size of the secondary open data set, and because secondary ports are frequently closed, it is assumed that 10 percent is a reasonable figure if the port was normally open. The Saskatchewan data indicate a 3-to-1 ratio of percent of overloaded trucks for closed and open ports.

The 1989 WIM data used to estimate E and OL were taken during periods of approximately 1 week or less for each WIM site. Data collected during a relatively short time span may be influenced by short-term local or seasonal events. A more accurate estimate would be possible from a larger data set collected over a longer time span, preferably several times throughout the year. The Wyatt and Hassan data (*5*) were collected over longer periods.

Percent Loss of Life for Continuous POE Operation

If the port was operating continuously, truck traffic on road segments within the study area would consist both of influenced and uninfluenced trucks because of turning traffic not influenced by the port. To account for the difference in percent overloads of influenced and uninfluenced trucks, the percent loss of service life is computed both for port open and port closed conditions for each road segment using Equation 4. Then, a weighted average percent loss of service life is found using the number of influenced and uninfluenced trucks on each road segment. The weighted average percent loss of service life is used to compute a reduced life for the condition of continuous POE operation. The following example illustrates the procedure used to compute the weighted average loss of life.

The following conditions are assumed:

- Influenced traffic, loss of pavement life = 4.06 percent;
- Uninfluenced traffic, loss of pavement life = 11.27 percent;
- POE influenced ADTT = 1,530; and
- POE uninfluenced ADTT = 710.

Then,

Weighted average loss of life

$$= \frac{4.06\% \times 1{,}530 + 11.27\% \times 710}{1{,}530 + 710} = 6.35\%$$

Percent Loss of Life When No POE Is Operating

If the port did not exist or is not operating, it is assumed that all truck traffic in the study area would be uninfluenced. The percent loss of life would then be 11.27 percent.

Reduced Life

ITD uses a pavement design life of 20 years but maintains roads on a 36-year replacement schedule, with maintenance and repairs scheduled at 12 and 24 years after initial construction. It is assumed here that a reduction in pavement service life would reduce the 36-year scheduled lifetime, as well as the 12- and 24-year maintenance schedule.

The reduced service life was computed as follows:

$$\text{Reduced life} = 36 - 36 \times \text{percent years lost} \quad (5)$$

Calculating Present Cost per Mile of Pavement with Reduced Life

ITD uses the following cost estimate for a four-lane highway. The initial cost per mile is $868,600. The 12- and 24-year maintenance costs are $168,200 and $401,100, respectively. The costs of a two-lane road are half these costs. ITD uses a 4 percent interest rate to evaluate its projects.

It is assumed that truck traffic on Interstate and four-lane highways travels in the outside lanes. That is, the inside lanes do not experience any loss of pavement life resulting from overloaded trucks. Therefore, all road segments, Interstate or secondary, are considered to be two lanes wide for allocating costs attributable to pavement damage from overloaded trucks. A cash flow diagram for a 1-mi length of two-lane road would include the following: (a) an initial cost of $434,000, (b) a maintenance cost of $84,000 after a third of its life, and (c) a maintenance cost of $220,550 after another third of its life. The next replacement cycle would begin after the final third of the pavement's life.

The current cost of two-lane road segments per mile is determined using the following equation both for port operating and port not operating conditions:

$$PC = \$434{,}300 + \$84{,}100 \times \left(P/F, 4\%, \frac{\text{reduced life}}{3}\right) + \$200{,}550 \times \left(P/F, 4\%, \frac{\text{reduced life}}{3} \times 2\right) \quad (6)$$

The annual cost (AC) of each two-lane road segment per mile in the study area is found using the following equation both for port operating and port not operating conditions:

$$AC = PC \text{ of segment} \times (A/P, 4\%, \text{reduced life}) \quad (7)$$

The total annual cost of all road segments in the study area is determined by multiplying the annual cost per mile of each road segment by its length (in miles) and then summing the costs of each road segment. The difference between the total annual cost for port operating and port not operating conditions is the benefit derived from operating the port.

RESULTS

An example calculation for the Bliss POE is presented in Table 4, which shows the spreadsheet and procedure used to calculate the annual benefit. The following truck-related val-

TABLE 4 Pavement Life Economic Analysis for Road System Near Bliss POE

SEGMENT CODE	SEGMENT LENGTH	ADT TOTAL	ADT INFL.	ADT UNINFL.	% INFL.	100% POE OPERATION WTD AVE LOSS OF LIFE %	100% POE OPERATION REDUCE LIFE	100% POE OPERATION TOTAL A.C.	NO POE OPERATION REDUCED LIFE	NO POE OPERATION TOTAL A.C.	NO POE OPERATION DIFFERENCE OF A.C.
1010	3.16	2180	2180	0	100.0	5.69	34.0	$98,035	30.5	$105,322	$7,287
2040	42.65	140	45	95	32.1	12.23	31.6	$1,387,299	30.5	$1,421,415	$34,116
2240	8.40	120	60	60	50.0	10.51	32.2	$269,730	30.5	$279,970	$10,240
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
1040	1.41	70	30	40	42.9	11.20	32.0	$45,445	30.5	$46,928	$1,483
1050	0.59	70	40	30	57.1	9.82	32.5	$18,849	30.5	$19,665	$815
TOTALS	159.2 MILES							$5,063,012		$5,304,567	$241,554

ues were used in the Bliss analysis: LEE of 2.37, OE of 3.8, LNW of 51,400 lb, and ONW of 58,400 lb.

In Table 4 the difference between net weights of legal and overloaded trucks is ignored. The percent loss of life as calculated by Equation 4 is 5.69 percent for influenced trucks and 15.33 percent for uninfluenced trucks. Under these conditions, and with the POE open continuously, the net benefit of the POE is $5,304,567 − $5,063,012 = $241,555.

If the difference in net freight weights is included, and the percent of overloaded trucks is 10 percent for influenced trucks and 30 percent for uninfluenced trucks, the percent loss of life is 4.41 and 11.87 percent for influenced and uninfluenced trucks, respectively. With the POE open continuously, and if the difference in net weights is considered, the annual cost is $4,987,627. With no port, the annual cost is $5,163,017. Under the assumptions employed, this second calculation indicates that full-time operation of the port results in an annual benefit of $5,163,017 − $4,987,625 = $175,390. The length of the road system included in the Bliss example is 159.2 mi. The annual benefit of full-time operation of the port is $1,102/mi. This amount represents the minimum benefit of the Bliss POE under the given assumptions; the calculation does not include benefits of the Bliss POE that occur outside of the Bliss zone, which are not included in the benefits of other POEs.

The annual cost of building and repairing the roadways in the Bliss area would be $4,756,300 with no overloaded trucks. The benefit if all overloading could be stopped is $5,163,017 − $4,756,300 = $406,717. This amount represents the maximum benefit possible.

If the Bliss POE reduces the fraction of overloaded trucks to a uniform 10 percent, then the annual benefit is $366,850. Table 5 presents the annual benefit that results from the Bliss POE.

If it is assumed that 90 percent of the trucks on Highway 30 (Segment 2040) are influenced by the Bliss POE (instead of 32 percent), the percent influence on each segment remains as originally calculated in Table 4, and the OL is 10 percent, then the annual benefit is $296,797. Although the port influence calculations show that most (68 percent) of the trucks on Highway 30 are not influenced by the Bliss POE, these trucks have a very high probability of routing through adjacent POEs. Because the adjacent POEs would not have their beneficial influence on Highway 30 attributed to their zone (it is outside of their influence zone), it is reasonable to apply this benefit to the Bliss POE. Consistency requires that any benefits from the Bliss POE that are felt in other zones (and the truck only travels through one POE) should be credited to those POEs, not the Bliss POE. This method would be a consistent way to apply this otherwise ignored benefit. It also results in the correct total statewide benefit.

Because of the uncertainties of OL, OE, and LEE, these factors were allowed to vary to check the sensitivity of the results. ER is the ratio of OE to LEE. Table 6 presents the

TABLE 5 Annual Benefit of Bliss POE

Condition	Annual Benefit Bliss POE Zone
I. All Overloading Prevented	$ 407,000.
II. 10 % of Influenced Trucks are overloaded:	
A. All Trucks Influenced:	$ 367,000.
B. Percentage of Influenced Trucks calculated by Turning Volumes	
1. Constant ADTT	$ 242,000.
2. Constant Net Freight Weight	$ 175,000.

TABLE 6 Sensitivity Analysis for Bliss POE

CONSTANT EQUIVALENT RATIO (ER), COST IN 1000'S OF DOLLARS.

	OL -50%	OL -20%	OL 0%	OL +20%	OL +50%
POE Open	4864	4929	4972	5015	5079
POE Closed	4947	5062	5140	5217	5333
Difference	83	133	168	202	254

CONSTANT FRACTION OF OVERLOADED TRUCKS (OL), COST IN 1000'S OF DOLLARS.

	ER -50%	ER -20%	ER 0%	ER +20%	ER +50%
POE Open	4607	4827	4972	5115	5328
POE Closed	4499	4881	5140	5400	5796
Difference	-108	54	168	285	468

results of the sensitivity analysis for OL and ER. If the assumed percentage of overloaded trucks is reduced by 50 percent, the annual benefit is also reduced by about 50 percent. OL and ER have a strong effect on the results. The results confirm that care should be used when estimating them.

CONCLUSIONS

A calculation procedure has been developed to determine the economic benefit of increased pavement life resulting from operation of a POE. The procedure uses WIM data and the AASHTO ESAL tables to evaluate the percentage of overloaded trucks and their equivalent ratio. These values are used to calculate a reduction of pavement life. The cost of reduced pavement life is based on construction and rehabilitation costs of a typical asphalt highway section and an assumed life of 36 years. The economic benefit per mile of increased pavement life resulting from the Bliss POE ranges from $175,390 to $406,717, depending on the assumed influence of the POE.

ITD can use this method to estimate benefits that result from increased pavement life caused by operation of a POE. Other benefits (such as fee collection, accident reduction because of truck inspections, and agricultural inspections) can be added and the sum compared with the cost of operations (facilities, personnel, and reduced net freight weight per trip) to determine the benefit/cost ratio of each POE. This method will help ITD determine the economic viability of POEs throughout the state.

ACKNOWLEDGMENT

This research was funded by ITD. The authors gratefully acknowledge the support and cooperation.

REFERENCES

1. R. T. Barros. Analysis of Pavement Damage Attributable to Overweight Trucks in New Jersey. In *Transportation Research Record 1038*, TRB, National Research Council, Washington, D.C., 1985, pp. 1–9.
2. J. J. Wyatt and M. U. Hassan. Overweight Trucks: Incidence, Costs to the Highway System, Enforcement and Compliance. *Transportation Forum*, Vol. 1–3, 1984, pp. 70–78.
3. A. D. Nielsen. *Civil Penalties for Overweight Violations: A Concept Prepared for the Idaho Motor Carrier Advisory Committee.* Idaho Transportation Department, Boise, Jan. 1987.
4. A. O. A. Halim and F. F. Saccomanno. Axle Load Limit in Ontario: Long-Term Analysis. In *Transportation Research Record 1038*, TRB, National Research Council, Washington, D.C., 1985, pp. 26–40.
5. J. J. Wyatt and M. U. Hassan. Some Tentative Findings About the Effect of Level of Enforcement on Compliance with Truck Weight Regulations. *Transportation Forum*, Vol. 2–3, 1985, pp. 48–52.
6. P. Shannon and A. F. Stanley. *Field Evaluation of the PAT Weigh-in-Motion System*. Research Project 95. Idaho Transportation Department, Boise, 1983.

Publication of this paper sponsored by Committee on Transportation Economics.