ASSESSMENT OF IMPACT OF ENERGY DEVELOPMENT PROJECTS ON LOCAL ROADS

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ABSTRACT

Oil and gas development has been an important part of the economy of western Canada and the United States for decades. Recently there has been resurgence in the development of natural gas and other alternative energy sources, including wind farms, throughout North America. The development of wind farms require movement of very heavy equipment over low volume, rural roads that were often not designed for such loading. The development of natural gas wells, especially those utilizing hydro-fracturing, requires movement of large volumes of moderately heavy trucks over similar rural roads. Many local municipalities and provincial highway departments are concerned about the impact of this truck loading on the life of their roadway infrastructure.

This paper summarizes the impact of energy development projects on local road networks. A method to estimate the cost impact of various types of trucking on pavements is presented. Additionally, methodologies are presented to: quantify pavement conditions before and after wind farm/oil and gas well development traffic; determine the need for pre-development upgrades, and determine the repairs developers should make or the financial contribution they should pay at the end of the development period for the pavement life that has been consumed. Alternative technical approaches, ranging from simplified, conventional pavement testing to more sophisticated methods involving non-destructive testing that have been used recently are presented. Finally, the paper presents administrative issues to be considered in road use agreements.

INTRODUCTION

Industrial development, in a conventional sense, has often been associated with manufacturing. In such developments there is significant movement of raw materials into and shipment of a manufactured product out of a production plant. For this reason industrial developments are strategically located to take advantage of robust transportation systems (ports, railroads and roads). The roads providing access to these plants are designed to carry the volume and weight of the loads anticipated. In some cases the existing road system may be supplemented by widening the road and/or building an access road from the main highway into the plant.

Many energy development projects differ from other industrial operations in that they are often located in rural areas that are accessed by farm to market roads that were not designed to carry significant heavy vehicle traffic.

Wind farm developments require delivery of very large, heavy components including turbines and blades that are transported to the sites by trucks carrying loads up to 125 tonnes.

Additionally, concrete, gravel and other construction materials and equipment must be delivered to the sites. Oil and gas developments typically do not have such high loads but wells that utilize the high volume hydraulic fracturing (hydro-fracking) process must have several hundred truck loads of water, sand and other materials hauled to the well site. Many local roads with thin pavement sections may fail within weeks of such heavy hauling.

ESTIMATION OF OVERALL COST IMPACT

For government agencies that own road networks that are expected to be affected by significant energy development projects that will occur over many years or decades, it may be useful to estimate the overall impact of such developments on the road network in advance. If the impact in terms of additional road maintenance and reconstruction are known, it can be helpful to the agency in planning long term capital and maintenance budgets and/or assessment of some type of impact fee to help compensate for the expected road impacts.

One of the first challenges in assessing the road impacts from energy development activities is to determine the heavy vehicle traffic associated with the development. There are two primary steps involved in this process; first projecting the extent and location of developments; and second estimating the heavy vehicle loading associated with the development. Short term, the number of wells or wind farms may be estimated based on land leases and/or environmental permit applications that are available through public records. Longer term, the extent and geographic locations of future development is often estimated based on industry projections. For example, exploration by oil and gas companies may have produced good estimates of the location and volume of deposits present in economically viable reservoirs. Based on this information, the number of wells and general locations may be projected. In the second step, the volume, weight, and axle configuration of heavy vehicles associated with each development is estimated; this is unique to each industry.

In the construction of large-scale wind farms, a significant number of heavy vehicle loads are required for each turbine, concrete foundation, and access road. Typically, the turbine components will be delivered by several large transport trucks, including a separate truck for each of the three tower sections and the three blades (an example is shown in Figure 1) and a single truck for the nacelle, or head unit (see Figure 2). These trucks carry loads ranging from 50 to 125 tonnes each. Considering the axle loading, these vehicles are roughly equivalent to fifty 18-wheel tractor trailers per delivered turbine. Large cranes also need to be transported to each site for use in erecting turbines.

Figure 1. Turbine blade transport

Figure 2. Turbine nacelle transport

Massive concrete foundations are required to support each turbine. Each foundation typically requires about 400 to over 600 cubic metres of concrete, which equates to 60 or more fully loaded trucks that deliver the concrete to each site.

To transport the turbine components and concrete to their specified location, the developer must construct access roads between the existing roads and the turbine locations. The construction of these roads is often the greatest source of loading over the pavement network. Depending on the length of access road to be built, several hundred to several thousand truck loads of gravel may be hauled over the local infrastructure.

For gas well development, the vehicle fleet contains a variety of tractor trailer and tri-axle trucks that transport equipment and materials such as sand, gravel, concrete. The most substantial part of the truck fleet consists of approximately 350 to 1,500 trips of 20,000 liter water trucks each weighing about (40,000 kgs) to support the hydro-fracking processs. This water requirement often results in large concentrations of water trucks traversing a single road each day (see Figure 3).

Figure 3. Water trucks to support hydro- fracturing of oil and gas wells

After completing the two steps outlined to estimate the number of wells or wind farms to be developed and the vehicle fleet associated with each development, the impact on the road network in terms of damage or the maintenance and repair needed to compensate for this damage may be estimated. The method proposed in this paper is based on the American Association of State Highway and Transportation Officials (AASHTO) empirical models that relate pavement life to truck axle loads.

The AASHTO road test [1] showed that the relative damage to pavements depends on the weight of vehicles loading the pavement and on the number and spacing of axles over which the load is distributed. A method was developed to convert various truck axle configurations to one standard; an equivalent 80 kN single axle load (ESAL). Design procedures were developed to determine the pavement structure needed to support the projected traffic, in terms of ESALs. This design has been widely used by many agencies throughout North America.

The method essentially consists of comparing the projected truck traffic to the expected pavement life (both expressed in terms of ESALs), determining the percentage of pavement life consumed by the development traffic, and estimating the cost of this consumed pavement life. It should be noted that this procedure is intended for broad, planning level estimating of cost impacts. The details of this approach are provided in the seven steps described below:

Step 1. Convert Truck Fleet into ESALs

In order to determine the damage from a fleet of trucks with various weights and axle configurations, it is customary to determine the equivalent single axle loads (ESALs) for each truck type and add them together to determine the total ESALs anticipated to use the pavement. ESAL factors for each truck's axle type (example- single, tandem or triple) and axle weight are provided in Appendix D of the AASHTO Pavement Design Guide [2]. Alternatively, if weights are not known, average ESAL factors for each truck class may be used. Many agencies have developed average ESAL factors based on field measurements from Weigh-in-Motion (WIM) sites throughout their jurisdiction. A study funded by the Canadian Strategic Highway Research Program (C-SHRP) in 2001 developed generic truck factors (number of ESALs per truck) for five representative types of commercial vehicles used in Canada. [3]

Step 2. Determine Representative Pavement Section for the Roads Expected to be Impacted by the Development

There may be several hundred kilometers of road expected to be used to develop the anticipated energy projects, and the pavement section is likely to vary significantly over this network of roads. In some cases it may be useful to divide the road network into classes and estimate an average or representative pavement section for each class. If an agency's pavement management system has good data on pavement composition it may be possible to extract pavement layer thickness for the network, or for each road class, and calculate an average thickness for each layer.

Step 3. Determine the Structural Number for each Pavement Section

A commonly accepted term used to quantify the overall strength and load carrying capacity of a pavement is the Structural Number (SN) as defined in the AASHTO Guide for Pavement Design [2]. The SN is determined by multiplying the structural layer coefficient (or contributing strength from each layer) by the thickness of each layer, then summing them together. Typical layer coefficients have been published widely; some transportation agencies have developed coefficients for their specific pavement materials. Applying the appropriate layer coefficients to the typical pavement sections identified in step 2, the SN is determined for the road network or for each road class if the analysis is done for separate classes.

Step 4. Determine the Pavement Life for each Pavement Section

The AASHTO design method calculates the required pavement structural strength based on the following input parameters:

- W_{18} – projected traffic, in terms of ESALs
- R- reliability (a factor used to account for chance variations in traffic data and the performance prediction; therefore it provides a level of assurance that the pavement will perform as designed)
- S_O – standard deviation (another factor used to account for chance variations in traffic data and the performance predication)
- Δ PSI- change in pavement serviceability index from time of new construction until the end of its service life.
- M_R – subgrade soil resilient modulus

The same design principles may be applied in reverse to determine the pavement design life (in terms of ESALs carried) for a known pavement strength (i.e. - structural number, SN). Suggested values for R, $S_{O,}$ and Δ PSI are provided in pages II-9 to II-11 of the AASHTO Pavement Design Guide [2]. Additionally, suggested values for M_R are provided for various categories of subgrade quality on page II-71 of the AASHTO Guide [2]. The values for M_R vary considerably, therefore it is recommended that local knowledge of soil conditions be used to select appropriate values.

Step 5. Estimate Pavement Life Consumed by Heavy Vehicle Traffic

The portion of pavement life consumed by projected traffic associated with energy development projects is determined by dividing the projected ESALs applied (from step 1) by the ESAL life of typical pavements (from step 4).

Step 6. Determine Unit Cost for Pavement Replacement

The replacement cost is estimated for the typical pavement section referenced in step 2.

Step 7. Determine Pavement Replacement Cost due to Projected Traffic

The cost to replace pavements consumed by the projected traffic is determined by multiplying the portion of pavement life consumed by the replacement cost.

The cost impact projected using this method may be used as the basis for a development impact fee or for maintenance and capital planning.

COMPENSATION FROM DEVELOPERS

An alternative to assessing a development impact fee is to charge a user fee based on damage incurred on specific roads used by developers. Such an approach has been adopted by several agencies where developers are required to obtain a permit to haul heavy loads on low volume roads and to enter into a Road Use Agreement (RUA) as part of the process. The RUA typically requires the permit holder to make some type of improvement to roads they will use. Such improvements may be required in advance and/or at the end of development. One approach used by several agencies is to perform a visual condition survey before and after development and to require that the developer repair visible damage (example- seal cracks, patch areas of base failure, and possibly resurface with a thin overlay). Alternatively, a more rigorous approach may be used that is based on the same principles as the Overall Cost Impact (OCI) method presented above, using more project specific data. Some agencies have found that in addition to estimating the pavement damage caused by development traffic, it is necessary to determine when pavement improvements should be made: before the start or after heavy hauling by the industry is complete. The procedures described below address both of these issues.

Procedures for determination of the need and financial responsibility for pre-development and post-development upgrades are outlined in five basic steps:

1. Projection of Truck Traffic
2. Pre-Development Assessment
3. Determination of Need for Pre-Development Upgrades
4. Post-Development Assessment
5. Assignment of Financial Responsibility

Step 1. Projection of Truck Traffic

a. Request that the developer provide a list of heavy vehicle types, volumes and axle configurations anticipated to use the permitted road(s) over the period of the permit. If the permit covers more than one year, the permittee should provide an annual projection of heavy vehicle volume and axle configurations.

b. Convert the truck fleet projected above to equivalent single axle loads (ESALs) using the axle equivalency factors provided in Appendix D of the AASHTO Guide [2]. The determination of axle equivalency factors requires the axle weight; if this is not known assumptions will need to be made. For example, it may be reasonable to assume that half of the projected trips are made with trucks loaded to the legal limit and half of the trips are made by an empty truck. Alternatively, the process may be simplified by multiplying the volume of trucks by an ESAL factor that converts truck trips to ESALs based on the axle configuration as discussed previously.

Step 2 Pre-Development Assessment

The condition of the existing pavement before the start of hauling by developers should be assessed in terms of its structural carrying capacity. This may be determined using non-destructive testing of the pavement structure and mechanistic pavement analyses. Alternatively, a simpler but more subjective procedure may be used based on pavement cores, visual assessment of pavement conditions and empirical methods contained in the AASHTO Guide [2].

The mechanistic approach consists of nominal pavement coring or ground penetrating radar testing to obtain pavement layer thicknesses, and non-destructive testing using a falling weight deflectometer (FWD) to determine pavement layer stiffness and subgrade soil strength. FWD testing consists of the application of a series of loads on the pavement surface and measuring the resultant pavement surface deflection with sensors placed on the pavement surface. Using this data, mechanistic analyses [4] are performed using layered elastic theory to predict stresses and strains in the pavement and to compute the number of load applications (expressed in terms of ESALs) the pavement can withstand before failing (ie.- the remaining pavement life).

The simpler empirical approach consists of coring and soil borings to determine pavement layer thicknesses and subgrade strength, combined with a visual assessment of pavement surface conditions. Correlations provided in Table 5.1, page III-102 of the AASHTO Guide [2] may be used to estimate the structural coefficient for each pavement layer based on the pavement's surface condition. As described above, the layer thicknesses and structural layer coefficients may be used to calculate the effective structural number (SN) for the pavement. This information combined with the subgrade strength determined from soil borings may be used in the AASHTO empirical design procedure to estimate the remaining pavement life in terms of ESALs.

A similar procedure described in the Asphalt Institute Manual MS-17 [5] may be used to estimate an equivalent thickness for each pavement layer based on the thickness determined from cores and a factor from table 8-1, page 8-8 of Manual MS-17. The equivalent layer thicknesses and structural layer coefficients may then be used to calculate the effective structural number (SN) for the pavement and its remaining life in terms of ESALs.

Step 3 Determination of Need for Pre-Development Upgrades

Compare the projected truck traffic, in terms of ESALs, to the remaining life determined in Step 2. If the projected ESALs provided in the developer's permit is expected to result in a remaining pavement life below some threshold, after a specific agency defined period (example- if remaining life is less than 2,000 ESALs after 6 months of hauling), it is recommended that the pavement be upgraded prior to the start of hauling. The upgrade should include a repair of any base failures and an overlay designed to carry the projected ESALs. The purpose of this evaluation is to prevent premature, severe failures that have been known to occur that render the road unsafe for the traveling public.

Step 4 Post-Development Assessment

a. Conduct FWD testing, or pavement cores and a visual condition survey, as described in Step 2.

b. Determine the structural number, SN as described in Step 2.

c. Determine the pavement life consumed during the period of developer's hauling (remaining pavement life pre-development minus post-development, in terms of ESALs). Note- the developer could be provided an option to obtain background truck traffic, at their own expense prior to development, and have the portion of pavement life consumed by background truck traffic deducted from the pavement life consumed, if they so choose.

d. Determine the cost per ESAL for the pavement within the limits of the permitted road. The cost is computed as follows: Unit Cost = (cost to construct a new pavement with the layers identified in the cores in Step 2 / ESAL life for new pavement).

Step 5 Assignment of Financial Responsibility

Determine cost impact which can be calculated as the unit cost per ESAL multiplied by the pavement life consumed, in terms of ESALs. Developer/permittee may pay the highway agency an amount equal to this cost impact or construct an upgrade that will consist of patching areas of base failure and a hot mix asphaltic concrete (HMA) overlay, full depth reclamation, or reconstruction that restores the SN to the effective SN at the pre-development stage.

It should be noted that in most cases, this method will result in a greater cost impact than the method currently being used by some highway agencies that requires the developer to repair only significant distress visible at the pavement surface. If FWD testing is used, any fatigue cracking that may be present in the bottom portion of the pavement that has not yet manifest itself at the road surface will result in lower pavement stiffness and less remaining pavement life. Although the more subjective empirical methods do not account for any fatigue cracking that may be present below the pavement surface, it does downgrade the effectiveness of the current pavement structure even if surface distress is below a threshold where crack filling or patching may normally be recommended. This downgraded pavement effectiveness will result in a lower remaining pavement life.

If the permittee constructed a pre-development pavement upgrade and the effective SN after development is greater than or equal to the effective SN pre-development, it will not be necessary to make any payment to the highway agency or to construct any additional upgrades.

ISSUES TO CONSIDER WITH MULTIPLE USERS OF PERMITTED ROADS

When applying the procedures discussed above, or similar procedures that require compensation from developers hauling heavy loads over low volume roads, there are special considerations that may come into play if there are multiple developers using the same road segments. For example, in Pennsylvania it is common for roads under permit to be used by many different companies from three or more different industries and road repair costs need to be allocated to each of these permitted haulers or road users. Companies from some industries such as logging and mining have been entering into permit agreements with Pennsylvania Department of Transportation (PennDOT) for many years and paying for road damage, but they are now sharing some of their haul routes with gas well development companies that use a different fleet of heavy trucks. Some industries operate throughout the year while other industries tend to suspend their hauling during the critical spring thaw period when road damage is more severe due to saturated pavement sections.

Two issues to be considered in assessing road damage costs to multiple users of permitted roads are the relative damage caused by different types of trucks and the relative damage inflicted to roads during different times of year. Procedures to account for these two issues are presented below.

Accounting for Different Truck Types

Many different truck types with different weights and axle configurations are used in the development of oil and gas wells and wind farms. As discussed earlier, the AASHTO pavement design procedure converts all projected truck traffic to a common standard, the ESAL, to reflect the relative contribution of various truck types to pavement damage. For this reason, a fair and defensible method to allocate responsibility amongst multiple users of permitted roads is to apportion damage costs in relation to the number of ESALs applied to the road by each user. Specifically, the percentage of total ESALs applied to the road by each user would be multiplied by the cost to restore the road to its pre-development condition to determine each user's share of the damage cost.

This procedure is considered to be technically sound, however there is at least one practical issue to be handled if this method is used. In order to apply this procedure the number of ESALs applied to the road by each user must be determined. One method, as is used in the state of Pennsylvania, is to require permittees to self-report their truck loads. In order to determine the number of ESALs associated with each load, either the axle loads and configuration need to be known and the ESAL factor determined from Appendix D of the AASHTO Guide [2] or average ESAL factors published by the highway agency may be used if the truck type (axle configuration) is reported.

Accounting for Relative Damage by Season

Many highway agencies have recognized that road damage from truck traffic is accelerated during the period of spring thaw. Water from thawing ice near the surface becomes trapped because it is unable to percolate downward through the soils that remain frozen. Subgrade soils directly below the pavement structure become saturated and weakened. The decreased subgrade support leads to increased deflection of the pavement layers which leads to fatigue cracking and/or rutting. Many Canadian provinces [7] and many northern U.S. state departments of transportation place load restrictions on some vulnerable roads during spring thaw to address this issue. Conversely, the damage to pavements during winter is much less severe when the roadbed is frozen. For this reason, some provinces (for example, Saskatchewan, Ontario and New Brunswick) allow loads greater than the normal legal limit to use these roads in winter.

In areas with substantial energy development activity the highway agency may be reluctant to post spring load restrictions due its negative impact on the local economy. An alternative approach for roads with multiple haulers operating under a permit with the agency is to allow hauling during spring thaw but to seek additional compensation for the relatively greater road damage caused by those permitees that choose to continue hauling during spring thaw.

One method to account for the relative damage during spring thaw is to apportion road repair costs to multiple users based on each user's share of "equivalent ESALs" applied. The equivalent ESALs take into account the relative damage that is expected to occur to the pavement during the spring thaw and outside the spring thaw period. During the critical period of spring thaw, when the subgrade is weakened, the applied ESALs are multiplied by a factor that accounts for the additional damage expected. In order to apply this procedure, two issues need to be addressed. First, a reasonable factor needs to be derived for the relative spring thaw damage. Second, a method to estimate the period of spring thaw for each posted road, for a specific year needs to be developed. Each of these issues is discussed below.

The spring thaw damage factor may be defined as the ratio of damage predicted, per ESAL, during the spring thaw period compared to the average damage throughout the remainder of the year. Mechanistic pavement analyses developed by the U.S Corps of Engineers, applied through the WINJULEA software [6] may be used to determine the stresses and strains in each pavement layer resulting from the application of a standard ESAL on the pavement surface. The Asphalt Institute has developed a failure criterion, as referenced in Huang [8], based on these stresses and strains to predict the number of load applications before failure occurs from either fatigue cracking in the asphaltic concrete layer or rutting in the subgrade soils beneath the pavement. Using representative pavement layer thickness and properties for the roads expected to be used, these analyses may be completed and the number of applications to failure determined based on typical subgrade strength (resilient modulus) during the spring and based on average subgrade strength throughout the remainder of the year. Since the number of ESAL applications to failure is the inverse of damage created, a spring thaw damage factor may be derived as follows:

Spring Thaw Damage Factor (SF) = N_{OST} / N_{ST}

where N_{ST} = number of load applications to failure during spring thaw period

N_{OST} = number of load applications to failure outside spring thaw period

Determination of Spring Thaw Period

As stated above, the intent is to apply the spring thaw damage factor (SF) to each ESAL load, by each permitted hauler, during the period of spring thaw. There are several methods that could be used to estimate the spring thaw period; a few suggested methods are noted below.

- Highway agency staff could estimate the beginning and end of the spring thaw period based on field observations each year.

- Temperature sensors could be installed in a few representative locations throughout each District and monitored for subgrade temperature to help in determining the spring thaw period. This method has been used by many highway agencies (for example, British Columbia [7]).

- Falling Weight Deflectometer (FWD) testing could be performed to determine the spring thaw period. This method has been used by many roadway agencies.

- A defined period could be used that represents a typical spring thaw period; this could be one set of dates for all geographic areas (districts), or could be unique to each district. Although this method would be the simplest it would also be the least accurate.

- The start and end of spring thaw could be calculated using temperature data and a method developed by Washington State DOT (WSDOT). Based on significant research [9,10,11], WSDOT developed a method to determine when spring load restrictions should be implemented and when they should be lifted. As a result of their studies, they determined that load restrictions should be applied after a thawing index, TI, of about 25^{o} F-days (14^{o} C-days) has been accumulated (this is based on the observation that significant weakening begins after some degree of thawing has occurred). The duration of load restrictions is estimated to be the period after which a TI = 0.3 (FI) has been accumulated, where FI is the freezing index. It has been observed that beyond this degree of thawing the subgrade strength has recovered to the point where the load restriction may be removed.

Methods to calculate a freezing index and thawing index based on average daily air temperatures are widely accepted [9,10,11]. The freezing or thawing index is given by the summation of the degree-days for a freezing or thawing season as shown below:

Freezing Index (FI) or Thawing Index (TI)= $\sum(\bar{T} - 32^0 F)$

where: T = mean daily temperature

= $0.5(T_1 + T_2)$

T_1 = maximum daily air temperature

T_2 = minimum daily air temperature

One modification proposed by WSDOT is to use 29 ^oF (-2^o C) as the reference temperature in lieu of 32^o F (0^o C) when calculating the thawing index to account for solar warming of the dark surface of bituminous pavement.

Winter Hauling

A procedure similar to that described for spring thaw could be used to account for the relatively lower level of damage that occurs during the winter when the subgrade soils are frozen. This effort may be warranted if the roads in the highway agency's jurisdiction are typically frozen a significantly long period of time.

ADMINISTRATIVE CONSIDERATIONS

Many highway agencies have been dealing with heavy hauling, associated with the logging and mining industries, on low volume roads for decades. Many of these agencies have developed regulations, incorporated into their jurisdiction's highway law, that provide a mechanism to obtain compensation from heavy haulers for road damage. With the rapid increase in energy development projects throughout North American in recent years, more agencies are developing such regulations or modifying existing regulations to better address their concerns.

One common technique is to post low volume roads with a relatively low load limit (example- 10 tonnes) and to require companies that wish to haul heavier loads over these roads to enter into a Road Use Agreement (RUA). Typically the RUA address a wide range of issues including safety, hours of operation, noise, environmental restrictions, geometric restrictions on vehicles and others.

A few of the common pavement related issues addressed in RUA's are listed below:

- Performance bond required to help enforce RUA requirements including receipt of compensation for road damage or adequate repairs performed by the developer.
- Pre- and post-development road inspections to determine the extent of damage and/or extent of repairs required. Most RUA's require developer to pay for inspections; some have a maximum cap on the inspection cost.
- Requirement that damage causing an unsafe condition be repaired within 8 hours.
- Provision that allows the highway agency to make emergency repairs if in their opinion the road is not safe for the motoring public and to require the developer to pay for such repairs.
- Developer is required to perform any necessary road repair as a result of damages caused by developer, or developer's repair work that is found to be defective and required additional repair during the three (3) years period after the date of final acceptance.

The inspection of pre- and post-development pavement conditions is a key component of RUA's. As stated above, many agencies require that the developer pay for these inspections. It is recommended that the highway agency perform the inspections with their own staff or that they hire a qualified engineering consultant to perform the inspections to ensure that their interests are protected; this does not preclude the agency from requiring the developer to pay for the inspections.

SUMMARY AND CONCLUSIONS

Roadway agencies that have experienced a significant increase in energy development projects, or other industrial development, applying heavy truck traffic to rural, low volume roads that were not intended for such traffic may wish to consider seeking compensation from developers for road damage incurred. This compensation could be in the form of a development impact fee based on the magnitude of the development (example- wind farm capacity or number of wells for oil and gas fields). Alternatively, the compensation could be in the form of a user fee based on measured damage to specific roads used by the developer.

If a development impact fee is adopted, the basis for fees charged could be determined by the pavement life expected to be consumed by the truck traffic associated with the development. The method proposed in this paper requires an estimate of the truck traffic associated with the development. Ideally, truck axle configurations and weights would be included in the projection in order to convert the truck fleet to total ESALs. Additionally, reasonable assumptions need to be made regarding the typical pavement section and subgrade soil strength for the affected roads. Finally, the cost to construct this pavement section needs to be estimated.

If it is preferable to seek compensation from developers based on actual damage they cause to roads they use, a similar method is proposed. However, if this method is used it will be necessary to measure pavement conditions before and after use by the developer in order to objectively estimate the magnitude of damage associated with the developer's truck traffic. The simplest procedure involves a pre-development and post-development visual pavement surface condition survey and a requirement that the developer make repairs of visible damage beyond that present at the start of development. Such repairs may include crack filling, patching and perhaps resurfacing to restore ride quality. A more comprehensive approach may be taken that more accurately determines the true cost, to the highway agency, for allowing heavy hauling by the developer. The more comprehensive approach is based on an assessment of the cost of pavement life consumed by the developer's truck traffic.

If the highway agency adopts a policy such as that described above, thought should be given to how to handle cases where multiple companies are under permit for use of the same road. In such cases, it is recommended that the repair costs be allocated to each permit holder based on their percentage of the total ESALs applied to the pavement during the permit period. This procedure may be further refined by allocating costs based on equivalent ESALs that account for the relative damage caused by each ESAL in different seasons such as the vulnerable spring thaw period and the more forgiving winter freeze period. A method to account for this is provided in this paper.

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