ANALYSIS OF A DEDICATED COMMERCIAL TRANSPORTATION CORRIDOR IN THE NEW YORK METROPOLITAN AREA

Final Report [EXCERPTS]

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CHAPTER 1

INTRODUCTION

1.1 Motivation

As the world economy continues to grow, and the law of comparative economic advantage takes on greater significance at both the national and regional level, the importance of having efficient and effective freight transportation systems continues to increase. Local economies are no longer immune, or insensitive to shifts in trading patterns and alliances on the global level. A region that is strategically placed geographically, and well-equipped from a freight transportation system standpoint, will profit significantly from being able to deliver goods and services in a fast, efficient, and effective manner, anywhere in the world, at any time, with the right combination of price and level of service.

Determining how to mold and shape such a transportation network is no small task. It takes careful analysis of the multi-dimensional needs of the system's "customers," the manner in which those needs are expected to change and grow in the future; a vision of how those needs can be met, and a plan for turning that vision into reality. Moreover, the plan must take into account the system's current status; the technological, operational, and institutional options available for improvement; and a perceptive understanding of the financial options available for raising the capital needed to make that vision a reality.

1.2 Purpose and Scope

This document contributes to such a regional-level (freight) network planning effort by presenting a methodology whereby alternative network improvement options can be tested, evaluated, refined, and compared in an effort to identify the best long-run and short-term strategies. The purpose is to provide a tool that metropolitan planning organizations (MPOs), state departments of transportation, and other similar agencies can use for such purposes. The authors believe it to be credible, user-friendly, practical, and adaptable to a wide variety of situations and circumstances.

The focus is on benefits and costs, both in aggregate and as experienced by different constituent groups. It is also on capital investments, operational changes, and Intelligent Vehicle-Highway System/Intelligent Transportation System (IVHS/ITS) technology deployment strategies - actions that can improve system operation by making more, and better information available to the system's users about system status and future conditions. Moreover, there is an emphasis on modeling the effects of these improvements, both how vehicles alter their flow patterns across the network in response to these changes and the impacts they cause by those changes, especially air pollution, pavement damage, and truck operating costs.

As is probably clear from this last reference, the focus is primarily on highway networks. The methodology is intended for the large-scale highway networks that typify major, urbanized areas, where congestion problems are common, capacity investment options are quite limited, and non-recurring incident-related congestion is a significant source of delay, both in an absolute and relative sense.

The focus on air quality impacts is especially aimed at trucks: estimating pollutant output rates and total levels. There is an interest in reducing the freight-related emissions, particularly nitrous oxides (NO_x) and particulates (PM_{10}) from diesel trucks. Lower travel times, achieved through higher average speeds and less delay, translate into smaller quantities of fuel consumed and lower emissions, even without changing the distribution of trips among truck classes, or among modes.

The types of questions for which the methodology is intended include the following. If commercial vans are allowed to use auto-only parkways during off-peak hours, what would be the impact? How would trips be diverted? If a major expressway is taken out of service, in whole or in part, for reconstruction and rehabilitation, what changes in truck flow patterns will result? Will certain businesses be forced to close? Will their transport costs increase dramatically? How will the overall network flow patterns be affected? If better information on traffic incidents and delays could be provided to truck drivers, what would be the effects? How would flow patterns change? If physical or operational improvements were made at a major facility, what would be the local effects? What would be the regional effects?

The tools and methods developed in this project are applicable to truck flow issues in any large urban area. However, this report has a particular focus on the New York metropolitan area. This specific focus has allowed us to test the methods on real data arising from a very complex environment. It has also allowed illustration of the application of the tools and methods in two case studies of particular interest to the sponsoring agencies.

1.3 Tools and Lineage

Actually, one could argue, two modelling tools are presented, both of which follow the same basic analysis methodology. One is micro in focus, the other one, macro. Both are intended to help planners evaluate the benefits and costs of goods movement mobility-enhancing actions. The microscopic tool focuses on congested links, especially toll booth areas, and provides a means to discern the benefits of access strategies, HOV lane use plans, and truck-oriented ATIS (Advanced Traffic Information System) services. The macroscopic-level analysis methodology focuses on network-level improvements including facility construction, dedicated use lanes, and ATIS services.

Both tools are extensions to the method for estimating truck trips in urban areas developed in a previous project sponsored by NYSDOT and USDOT (see List and Turnquist, 1993). The emphasis here has been to take the truck trip estimates which that methodology provides, and evaluate the benefits and costs from various network improvement options. These three tools, in combination, provide a means both to discern the travel patterns that currently exist in a network and to determine what actions, short and long term, might provide the most significant improvements in goods movement mobility for an urban area, especially insofar as trucks are concerned.

The microscopic analysis tool is important because mobility problems are fundamentally caused by congestion - on specific links and in specific locations. Following the perspective taken by many of the traffic analysis tools available today, we have developed a simulation model, based on NETSIM, that allows analysis of toll facilities. One can use it to see if various design options improve the performance of a major toll collection facility. Not that this is the only type of congestion problem that can arise, or that the tool can be applied to any and all bottleneck situations, but rather, the analysis technique, and its application, illustrate the kind of analysis that can be performed, the types of performance metrics that can be examined, and the various conclusions that might be reached.

The macroscopic analysis tool, sitting above the microscopic one, provides a means to evaluate the system-level impacts of various mobility-enhancing actions. Again, the emphasis in what is presented is on the structure of the methodology employed, the performance measures examined, the impact models used to evaluate those measures, and the kinds of findings that result.

1.4 Document Overview

Chapter 2 presents a description of the methodology - the impact-incidence evaluation methodology employed, the vision of the system which undergirds it, the steps followed in assessing the benefits and costs, and the individual impact assessment models developed to quantify such effects as air pollution outputs, pavement damage, etc.

Chapter 3 reports the results of the microscopic tool development effort, focused on a case study involving the western (eastbound) approach to the George Washington Bridge, in which the main objective is to compare and contrast various ways in which delays during peak periods could be reduced. The impacts of IVHS/ITS information deployment strategies are examined, as well as capacity investments and changes in the rules for special facility use by time of day.

Chapter 4 describes the macroscopic tool development effort, focused on a case study involving the New York metropolitan area. The objective in this instance is to see what types of network-wide investments might produce payoffs in travel time reductions and other performance measures. Again IVHS/ITS-type strategies prove to have significant value as do rearrangements of the flow patterns.

Chapter 5 provides a summary of these efforts and points to further enhancements, in both methodological development and in ways the existing methodology could be extended to make it more valuable and robust in its capabilities. One of these is attention to rail. Currently, the network modeling routines are not equipped to deal with intermodal issues or shifts in traffic flow between truck and rail. Yet rail is a significant option for highway congestion, for reducing pavement damage, and for reducing air pollution emissions. Consequently there is a focus on how the model would have to be expanded, extended, and enhanced to allow such considerations to take place.

CHAPTER 2

IMPACT ASSESSMENT METHODOLOGY

2.1 Introduction

This chapter presents the impact assessment methodology used in Chapters 3 and 4. It begins by describing the system definition considered, followed by the steps in the analysis process. Sections 2.5 through 2.8 describe individual impact models for pollutant outputs, pavement damage, pavement costs, and truck operating costs respectively. Additional methodological details, specific to the analyses in Chapters 3 and 4, can be found in sections 3.4 and 4.3.

2.2 Theoretical Underpinnings for the Process

All rational public decision making needs a process whereby scare resources are directed toward actions that maximize societal objectives. For example, each transportation agency has responsibility for selecting from among alternative activities, in a given program area, those that maximize the agency's contribution to achieving societal goals. The best activities need to have highest priority, those that contribute less, or not at all, need to be ranked at lower levels, and those that contribute negatively need to be discarded. Evaluation methodologies, therefore, must assist policy makers in achieving well defined objectives when resource constraints require the ranking of alternative courses of action, because all proposals for improvement cannot be implemented.

2.2.1 Costs, Benefits, Risks and Cost-Effectiveness

Cost-benefit analysis is a technique for evaluating alternative courses of action when inputs (e.g., costs) and outputs (e.g., benefits) can be compared using the same metrics, such as monetary values (Prest and Turvey [1966]; Good [1971]; Lave and Gruenspecht [1991]; and Krupnick and Portney [1991]). Cost-benefit analysis is a generalized set of procedures for assessing the balance of relative costs and benefits, and their incidence, within a matrix or tableau format. The tableau provides a structure for listing systematically the various costs and benefits.

Risk-benefit analysis is a similar approach, differing only in that the costs and benefits are subject to uncertainty. They are expressed in terms of distributions of possible outcomes, rather than fixed or expected values.

Cost-effectiveness analysis is a technique which can be applied when the outputs cannot be evaluated in dollar terms. Thus, the benefits of alternative courses of action can be compared with each other (e.g., vehicle-hours of delay saved) within a given program area, but comparisons across program areas are difficult or impossible (e.g., within transportation but not transportation versus education).

2.2.2 Ranking Alternative Actions

Regardless of which evaluation methodology is employed, the ranking of alternatives can proceed in the same manner. Three main options are available. The first holds the level of output fixed among all comparative actions and orders the actions based on cost (i.e., it results in selecting the activity which achieves a specified level of output with least cost). The second ranks alternatives in decreasing order of greatest benefit or effectiveness given a fixed level of input, such as a budget constraint (i.e., maximize benefits subject to a specific level of cost). The third ranks the various alternatives based on the ratio or the difference (whichever is more appropriate in the specific program area) between benefits and costs, allowing both outputs (benefits) and inputs (costs) to vary. The greater the ratio or difference between benefits and costs, the higher the ranking.

2.2.3 Impact-Incidence Analysis

A variation on cost-benefit and cost-effectiveness analysis is impact-incidence assessment in which the incidence of both costs and benefits is explicitly tabulated (see Table 2-1).

Alternative plans are arrayed against the impacts they have on various affected parties. As Table 2-1 shows, the options being considered are Plan A and Plan B and the affected parties are shippers, carriers and the public. Three types of impacts are presented: 1) monetary, denoted by the $ signs, 2) intangibles, denoted by the i's, and 3) quantifiable but non-monetary impacts, denoted by the M's. (The X's, Y's and Z's denote these three types of benefit categories.) Dashed lines indicate inconsequential or unmeasurable (no significant) impacts.

This evaluation technique makes it possible to track which groups benefit from each of the proposed activities and which ones lose. It makes it possible for policy makers to include distributional or equity criteria in the ranking scheme.

2.2.4 Goals-Achievement Matrix

A widely used operational approach to impact-incident assessment is the goals-achievement matrix developed by Hill [1968]. As Table 2-2 shows, it provides a tableau of information encompassing multiple objectives, multiple program activities to carry out each objective, and weights applied to the incidence of cost and benefits. It is a technique for ranking alternative program activities by measuring costs and benefits relative to specific objectives.

In the table, which shows the goal achievements and group-specific impacts *for one plan*, α through δ are the goal descriptions with relative weights 2,3,5, and 8. Within goals, relative weights are attached to the incidence of costs and benefits (here both must be monetary) for each affected group (i.e., the incidence). For example, for the first goal, where

Table 2-2. Goals/Achievement Matrix Source: Hill [1968], Table 2

the relative goal weight is 2, the most "important" group is Group b (for whom the relative weight of costs and benefits in this category is 3), whereas for goal β, which has a relative weight 50% greater (3 versus 2), Group a has a higher relative weight (5) than any of the others, and 25% greater (5) than Group b (4). In some instances, the costs (or benefits) are the same across the various groups, and in other instances they are different. For instance, in the case of goal α, the cost incidence for Group b is H, for Group c it is L, and for Group d there is none. Meanwhile, the benefit impact for each of these three groups is J.

In some instances (i.e., where a summation sign appears), summing the benefits and costs is useful and meaningful. The total costs and benefits of that particular goal can then be tabulated and compared against other plans.

Each potential course of action generates a table similar to that shown in Table 2-2. The tables can be arrayed, one against the other, so that the similarities and differences among the courses of action become apparent. Given a selected course of action, the information provided by the tables also provides inputs regarding the rationale or basis by which the decision was reached.

Thus, the goals-achievement approach for ranking alternative courses of action is particularly valuable when the objectives and associated courses of action are numerous. Costs and benefits can be compared and aggregated (where possible), but reported separately for each objective and for each course of action. The objectives can be weighted to reflect their relative importance. Weights can also be applied to the incidence of costs and benefits to represent policy preferences about distributional effects.

The goals-achievement approach provides a framework for unique rankings between and among proposals even if the objectives are manifold. Its main drawback is that the policy maker must identify an appropriate set of weights to employ and is willing to make them explicit in the ranking scheme.

2.3 Methodological Framework for the Case Studies

Bringing this general theory to bear on the truck-oriented analyses in this project requires both definition of the system setting and delineation of the analysis steps involved. Figure 2-1 shows that the "system" of interest is a highway network through which trucks and other vehicles pass, such as autos and buses. These flows create impacts, both positive and negative, that are felt by various interested parties (sometimes called actors or stakeholders) affected by the system and its operation, such as the truck operators, other system users and society as a whole.

The system owner and/or operator (e.g., a State DOT) influences the way in which the system functions by changing the operating rules (e.g., use restrictions), making facility investments (e.g., dedicated use lanes, special on and off ramps), or providing more information about the system's real-time status and performance (i.e., IVHS/ITS-type actions: delays, facility closures, places of congestion).

In response to these influencing actions, changes occur in the way in which benefits and costs accrue to the various interested parties (i.e., the distributional effects). An action that is "ideal" produces improvements in all measures of effectiveness simultaneously: e.g., increases in benefits and reductions in cost *along with* a "Pareto optimal" distribution of benefits and costs among the interested parties, i.e., "everyone gains and no one loses." Actions that are not ideal either produce overall gains with negative distributional side effects (i.e., someone loses and/or the gains and losses are disproportionately shared) or else the distribution is "satisfactory" but not as much overall gain is achieved as might have been possible.

Quantifying these benefits and costs (and their distribution) provides a way to determine the relative (i.e., differential) advantages and disadvantages of one action versus another. The differential (or incremental) benefits and costs of alternative actions can be compared and contrasted, with the outcome that the differences in overall impacts drive the decision making process.

2.4 Analysis Tasks

To ascertain the various benefits and costs, the sequence of tasks shown in Figure 2-2 can be employed, particularly in the context of the analyses presented in Chapters 3 and 4. The process begins by specifying the network and land use characteristics of the area under study and ends with impact assessment.

2.4.1 Network Specification

Network specification involves generating a (computer-based) description of the highway network (i.e., its links and nodes). Connectivity must be delineated (i.e., link from and to nodes) as well as use restrictions (trucks or no trucks), directionality (two way or one way, and, in the latter case, the direction), capacity and impedance (travel time, effective cost including tolls, distance, or some other measure).

2.4.2 Land Use Specification

Land use specification yields a database describing the study area’s pertinent socio-economic features. Most often, the area is divided into zones, with each zone having its "vector of attributes" such as size (e.g., square miles), population, employment, and the number of originating or terminating trips. It is also necessary to specify the relationship between the zones and the network, i.e., for each zone, the network node(s) at which trips begin and end.

2.4.3 Flow Data

Flow data describe the pattern of vehicle trips taking place across the network. In Chapter 3, these are origin-to-destination trip matrices developed from on-the-scene empirical observations; in Chapter 4, they are the synthesized origin-destination matrices, estimated from indirect and partial observations of the flows.

2.4.4 Treatment Options

After the flow data have been developed, the next step is to identify treatment options. From a capital investment standpoint, these might be new freeway ramps, new dedicated use lanes, dedicated use roads, geometric improvements to existing facilities, or new terminal facilities. From an operational standpoint, they could be changes in the use restrictions, such as allowing trucks to use selected parkway facilities (or HOV facilities) at specific times during the day. Other options could be the setting aside of specific lanes on freeways or allowing trucks to have exclusive use of certain streets during specific time periods. Finally, from an information distribution perspective, one can examine IVHS/ITS-type strategies that involve the dissemination of real-time network condition data to truck drivers and dispatchers, or real-time flow management by the network operating agencies themselves.

2.4.5 Traffic Reassignment

This step involves reassigning the vehicle trips to the network given the changes being tested. (The assignment process itself may have changed, the network may have changed, or both). In the case of Chapter 3 this means an equilibrium assignment of both autos and trucks to the George Washington Bridge approaches based on actual, observed delay data from the field. In Chapter 4 it means computing new values for the link utilization factors by origin-destination pair and then recomputing the resulting link volumes. In either instance, the result is a new set of traffic flow volumes, by direction, for each link in the network.

2.4.6 Impact Assessment

The last step in the process is to determine the impacts of each competing treatment option and the differences that exist among the options. As portrayed in Figure 2-1, these include the specific impacts felt by the various constituencies involved as well as society as a whole.

From the data currently available on truck-related impacts, it is possible to develop impact models for the following output measures:

- o emissions: based on truck-miles, and idling times;
- o pavement damage: from ESAL calculations, truck-miles and vehicle mix;
- o pavement damage costs: based on ESAL-miles and pavement life-cycle costs; and
- o operating costs: based on truck-miles.

Sections 2.5 through 2.8 present individual impact models for each of these output measures.

2.5 Truck-Based Emissions

The analyses presented in both Chapters 3 and 4 report changes in truck emissions due to changes in the network or operating policies in effect. This generates a need to construct such rates. (In Chapter 3, there is also a focus on changes in auto emissions, due to reassignment of the auto flows to the bridge approach network. NETSIM has a built-in procedure for estimating auto-related emissions and that is employed. NETSIM does not include any emission rates for heavy trucks.)

The common practice is to estimate emission rates in grams/mile for three major pollutants: carbon monoxide (CO), nitrogen oxides (NO_x) and unburned hydrocarbons (usually denoted as HC, but also sometimes referred to as volatile organic compounds, VOC; or as reduced organic gases, ROG). There is also growing attention on emissions of particulate matter less than 10 microns in diameter (PM_{10}), since diesel engines are a particularly noticeable source of particulate emissions, emission rates have been developed for this pollutant as well.

The rates being developed here apply to all truck classes (2-axle, 6-tire and larger). In EPA's MOBILE 4.1 model (Environmental Protection Agency, [1991a]), truck emission rates are specified using a Base Emission Rate (BER) and a Speed Correction Factor (SCF). The resulting effective emission rate for a link is then:

$$r = BER * SCF$$

The base emission rate depends on both the age and odometer reading of the truck, as shown in Table 2-3. Note that there are no rates given for PM_{10} emissions.

Speed correction factors are used to account for the fact that emission rates are higher at both very low and high speeds. Natural logarithms of SCF values are specified using quadratic functions, leading to SCF functions as shown below (Environmental Protection Agency, [1991b]):

$$CO: \quad SCF = \exp(1.396 - 0.088\, s + 0.00091\, s^2)$$

$$NO_x: \quad SCF = \exp(0.676 - 0.048\, s + 0.00071\, s^2)$$

$$HC: \quad SCF = \exp(0.924 - 0.055\, s + 0.00044\, s^2)$$

where: s = average speed (mph). The net effect of the BER and SCF values is to create an effective emission rate function like the example shown in Figure 2-3.

The most recent version of "MOBILE," MOBILE 5, does not include any diesel truck emission rates (Environmental Protection Agency, [1992]). This apparently reflects some concern over inaccuracy of the MOBILE 4.1 rates, but has the unfortunate effect of leaving model users with no direct guidance on truck emission rates.

The New York City Department of Environmental Protection has created the set of rates shown in Table 2-4 for use in City air quality analyses (Nudelman, [1993]). There are separate rates for arterial streets and expressways, constructed assuming an average speed of 10 mph for arterials and 30 mph for expressways. These rates are based on the estimated fleet age distribution in 1995.

Table 2-4. Emission Rates (grams/mile)

Pollutant	Arterials	Expressways
CO	21.08	7.51
HC	3.49	1.65
NO_x	15.54	10.5
PM-10	2.14	2.14

The NYCDEP rates for CO, HC and NO_x are consistent with MOBILE 4.1 estimates if we assume the BER's are as follows:

Pollutant	BER(grams/mile)
CO	11.5
HC	2.3
NO_x	11.9

The NYCDEP rates can be used for all links where queuing is not an issue. For those where it is (e.g., due to delay), an alternate approach is needed for estimating the pollutants. The average speed of the vehicles involved is less than 10 mph, the end of the range for which the MOBILE model is intended.

If one examines the queuing at the George Washington Bridge toll plazas, where significant slow-speed vehicle flow data are available (and for which we need to have a "while standing" pollution generation rate), the average speed while in queue is about 2 mph. If we use the BER's from the preceding page plus the MOBILE 4.1 SCF formulae for s=2 mph, which may be somewhat inaccurate, one obtains the effective emission rates shown in Table 2-5. (Note that the NYCDEP rates for PM-10 show no dependence on average speed, so the same rate has been assumed for the queue links.)

Table 2-5. Approximate Idling Pollutant Generation Rates

Pollutant	BER (gm/mile)	SCF (2 mph)	Effective Emission Rate (gm/mile)
CO	11.5	3.4	39.1
HC	2.3	2.26	5.2
NO_x	11.9	1.79	21.3
PM-10	2.14	N/A	2.14

An alternative approach is to use the idling emission rates from MOBILE 4.1. This approach calls for use of the following formula:

$$IER = ZML + DR*M$$

where IER is the idle emission rate, ZML is the zero mile level in grams/hour, DR is the deterioration rate in grams/hour/10k miles and M is the cumulative mileage (in tens of thousands of miles). Table 2-6 shows the resulting heavy duty diesel idle rate estimates, in grams/hour. These rates would likely yield different overall emission estimates, but they can be implemented, and are sensitive to changes in delay time.

Table 2-6. Idling Emission Rates based on Mobile 4

Pollutant	Model Years	Zero Mile Emission Level	Deterioration Rate
HC	Pre-1985 1985+	21.6 16.2	0.0 0.0
CO	All	16.20	0.60
NO_x	Pre-1985 1985+	55.2 13.2	0.0 0.0

On balance, the best approach seems to be to use the MOBILE 4.1-based idling rates for the time spent in queue (i.e., Table 2-6), and add those projected emissions to the estimates derived from Table 2-4 for all other links. For CO, which has a deterioration rate, we have assumed an average vehicle age of 4 years and an accumulated mileage of 135,000, so the effective CO rate for idling time is 48.3 grams/hour.

2.6 Pavement Damage

Pavement damage is the second type of impact for which predictive models have been developed. Generally speaking, pavement damage is due to a combined effect of vehicle loads and climatic conditions. It is also true that it is not easy to distinguish between damage due to vehicle loads and that due to weather since the two occur concurrently and cumulatively. However, given a particular climate, it is evident that higher loads produce faster deterioration. A comparison of the destructive effects of different axle loads, with due regard to climatic effects, leads to the concept of load equivalence.

2.6.1 Equivalent Single Axle Loads

The Equivalent Single Axle Load (ESAL) is central to the determination of pavement damage. One ESAL is defined as the impact equivalent of an 18,000 lb. single axle load. It is a measure of the rate at which damage is occurring, much as horsepower is a measure of work output per unit time. Thus, a truck with an "ESAL factor" equal to 1.0 causes the same rate of damage as would an 18,000 lb. single axle. Put another way, the ESAL factor also represents the number of repetitions of a given axle load (single axle, axle combination, or a truck taken as a whole) that will cause a reduction in pavement serviceability index (PSI) equivalent to that due to one ESAL loading. (The method of estimating ESALs, which is based on the AASHTO road test, is further discussed in Appendix A.) The ESAL ratings for trucks that typically operate in the New York City area have been estimated using that method.

Not only are ESALs used to measure damage rates, they also provide a measure of expected pavement life. For example, a 10" concrete (rigid) pavement is expected to have a lifetime between 25 and 30 million ESALs. This means that it should be able to withstand 25-30 million 18,000 lb. equivalent axle loadings before reaching the end of its design life. The total life cycle cost of such a pavement (including initial investment, preventive and corrective maintenance cost, and minor rehabilitation cost) is defined as the cost of keeping the pavement serviceable for its design load (ESALs) across its lifetime. Therefore, given a pavement's ESAL rating, we can estimate the average cost per mile per unit of pavement damage (ESAL loading).

Further, given the average number of ESALs per vehicle (vehicle type), the average damage cost per ESAL, and the number of vehicle-miles accruing on a given facility it is possible to evaluate the cost and pavement damage implications of various traffic flow situations.

2.6.2 Average ESALs per Truck

To estimate the number of ESALs for a given vehicle, one needs the axle configuration and loadings. The types of trucks being considered in this project are two-axle-six-tire trucks or larger, so ESAL ratings are needed for these truck categories. A study recently conducted by Harrison *et al.* [1991] in Pennsylvania produced ESAL ratings by truck type based on weigh-in-motion (WIM) data. Table 2-7 summarizes these findings.

For Chapter 4's metropolitan area network analysis, the truck flows are not broken down by class. Hence, a composite or average ESALs per truck is required. We have used the Pennsylvania-wide average ESAL ratings by truck class (as shown in the last column of Table 2-7), combined with the breakdown of truck types by axle count from the PANYNJ 1991 Truck Commodity Survey, to compute an overall weighted value. This process and its results are shown in Table 2-8.

2.7 Pavement Damage Cost

To estimate the pavement damage cost in dollar terms per ESAL-mile or per truck-mile of truck traffic we need to know: i) the life cycle cost (LCC) per mile of pavement, ii) the total number of ESALs the pavement can carry during its lifetime, and iii) the proportion of total damage caused by trucks.

Harrison, *et al.* [1991] estimate that the LCC per mile of pavement due to trucks is \$6.64 million (see Table 2-9). This includes the initial construction cost, maintenance cost and rehabilitation cost. The figure of \$6.64 million is derived by considering that truck damage accounts for 70% of most of the major costs while other traffic and climatic conditions account for the remaining 30%. The "30/70" cost allocation was chosen based on experience from several states.

Given typical pavement cross-sections, the most likely lifetime ESALs are between 20 and 30 million. However, during a pavement's typical lifetime (LCC analysis period), it also receives rehabilitation work (overlays) and routine maintenance. This additional pavement thickness tends to increase the facility's ESAL rating. Thus, it is estimated that the life cycle carrying capacity of these sections is about 42 million ESALs. Therefore, we can estimate the average damage cost to be 6.64 / 42 = $ 0.1593 per ESAL-mile. This figure is consistent with the damage cost estimated by Harrison *et al.*

This leads to the damage cost estimates ($ per truck-mile) shown in Table 2-10. They vary from $ 0.04 per mile for a 2-axle truck to about $ 0.30 per mile for trucks with 4+ axles.

2.8 Truck Operating Costs

The operating costs presented here are economic (pure resource) costs only. An economic cost is the operating cost that excludes all social transfers such as taxes, subsidies, etc. Accounting costs, on the other hand, are costs that include these social transfers and are referred to as financial costs. The distinction between economic and financial costs is important when assessing the total system cost of truck operations in order to avoid double counting of these social transfers.

The costs discussed in this section are based on the results of the study by Harrison, *et al.* [1991]. However, these costs (mainly the truck operating costs) compare very well with those obtained in (or based on) other studies (Watanatada *et al.* [1987]; Bein [1989]; Mbwana [1993]; and Archondo-Callao and Faiz [1994]).

Truck operating costs are divided into groups. The first group consists of fixed costs which are independent of truck utilization, such as depreciation, driver salary, insurance, interest, and overhead costs. The second group consists of variable costs which vary directly with truck utilization, such as fuel, oil, tire wear, repair and maintenance. Table 2-11 shows the economic costs (fixed + variable) obtained from Harrison *et al.* [1991].

As can be seen, truck operating costs are estimated to vary from $0.58/truck-mile for a 2-axle single-unit truck to $0.93/truck-mile for a 5-axle semi-trailer. These costs compare well with those obtained by Mbwana [1993] which were based on previous work by Bein [1989], using the World Bank models (Watanatada *et al.* [1987] and Archondo-Callao *et al.* [1994]).

A summary of operating cost figures is shown in Table 2-12. Using the operating costs for four truck types (see Table 2-11) and the percentage of truck-miles by vehicle class (see Table 2-7), we can estimate an overall average operating cost per truck-mile. In Table 2-12, the operating cost for 6+ -axle trucks (7-axle to be precise) was taken from Mbwana [1993]. The cost for a 3-axle semi-trailer and a 4-axle single unit truck were assumed to be the same as the cost for 4-axle semi-trailer, and cost for a 5-axle semi-trailer was assumed to also apply to a 5-axle twin-trailer. The results show that truck operating cost (less emissions and congestion costs) is about $0.58 per mile for a 2-axle truck, $ 0.81 per mile for a 3-axle truck, and $0.93 per mile for trucks with 4+ axles.

CHAPTER 4

DIFFERENTIAL IMPACT ASSESSMENTS AT THE NETWORK LEVEL

4.1 Introduction

This chapter describes the tools and techniques created to facilitate network-level differential impact assessments. It begins by putting the effort into context, relative to other facets of the current effort and other projects with which it is related. Section 4.2 puts this effort into context vis a vis prior research efforts and the case study presented in Chapter 3. Section 4.3 supplements the discussion of Chapter 2 by presenting methodological elements specifically germane to this particular Chapter, from flow estimation through impact assessment and shows how they tie together. Section 4.4 then describes a case study analysis, focused on the New York metropolitan area, that demonstrates how the methodology can be employed. Section 4.5 summarizes the resulting findings and presents recommendations for further work.

4.2 Context of the Effort

The direct predecessor of this effort is the flow estimation methodology developed by List and Turnquist [1994] (See also List and Turnquist [1993]). That methodology estimates truck trip matrices for urban networks based on partial observations of the flows. An archimedean goal programming problem is solved in which the choice variables are the flows (origin to destination broken down by truck class) and the goals are observed values of link volumes, partial observations of origin-to-destination volumes and zonal trip productions and attractions.

Here that methodology is used to provide the trip matrices upon which the differential impact assessments are based. Those flows are translated into link volumes, through an assignment process, so that estimates of air pollution impacts, pavement damage and truck-related costs can be developed. The result is a flow-based differential benefit/cost analysis. The traffic assignment capability makes it possible to assign trips to new and altered networks, different from the one used to estimate the flows, and assess the changes in benefits and costs that ensue. It is also possible to tie to the microscopic (link-specific) differential impact assessment technique described in Chapter 3 directly into this process so that more detailed analyses of specific network links can be conducted.

The capabilities taken in totality make it possible to evaluate and compare the benefits and costs of alternative actions intended to improve the flow of trucks through a given network. The differential impacts can be assessed and the "best" choice of action identified.

Comparisons between auto and truck-related impacts might also be possible in the future, given these techniques if a multi-commodity (auto and truck) traffic assignment model were available. Moreover, the analysis of diversions of freight traffic between and among modes (e.g., rail and truck) could also be conducted if a similar rail-based analysis tool were adopted or developed for use with the existing methodology.

4.3 Methodological Issues

The methodology presented here is a macroscopic-level realization of the process set forth in Chapter 2. It adopts the problem conceptualization presented in Figure 2-1 and the tasks outlined in Figure 2-2, starting with network and land use specification and ending with impact assessment. Features of the specific realization of that methodology employed here are described in this section.

4.3.1 Inputs for Estimating the Truck Flows

As described in Chapter 2, flow estimation involves assembling information about the truck movements across the network. For a region-wide analysis such as the one presented here, those flows must be estimated (imputed) based on incomplete observations.

If one uses the trip estimation methodology developed by List and Turnquist [1993], three types of data can be employed: 1) link volume (LV) observations, 2) direct origin-destination (OD) flow observations, and 3) originating/terminating (OT) data. A brief description of these data types is given below and a more thorough discussion can be found in List and Turnquist [1993].

4.3.1.1 Link Volume (LV) Data

LV data are observations of link flows for the network. A good example is the number of heavy trucks moving in a particular direction on a given link during a specific time period. Classification counts are a good example, as are turning counts.

4.3.1.2 OD Data

OD data provide direct estimates of specific flows in the trip matrices. Typically, only selective information is available, say for specific origin-destination pairs, or combinations of pairs, such as might be available from a county-to-county survey of flows, or partial observations of OD flows derived from a mailback questionnaire, a roadside survey, or a set of place-of-business interviews.

4.3.1.3 OT Data

OT data are observations of trip productions or attractions for specific zones or clusters of zones. They provide estimates of either row or column totals in the OD matrices. Screenline counts exemplify such data, particularly when the count is taken at a gateway node (e.g., at a bridge or toll plaza). Another good example is a place-of-business survey that identifies trip production or attraction rates for specific zones or clusters of zones.

4.3.2 New Technique for Developing OT Observations

In previous applications of the trip estimation methodology (List and Turnquist, [1993]), direct observations of trip productions and attractions were available, developed as a result of prior survey work, etc. In the instance of the current work, however, such data were not available and needed to be estimated.

Two previous research efforts were identified that provide a basis for estimating trip productions and attractions. Schlappi, Marshal and Itamura [1993] developed a trip estimation methodology for the San Francisco Bay area and Ruiter [1992] developed a similar methodology as part of the Phoenix Commercial Vehicle Survey and Travel Model project.

The San Francisco model consists of land use-based trip rates. Three truck types (2-axle, 3-axle, and 4+ axle) and three trip types (internal-internal, internal-external (or external-internal), and external-external) were used in estimating the rates. "External" refers to an origin or destination outside the study area. Internal-external trips have either an external origin or destination. The internal-internal trips are further subdivided into garage-based and linked trips. Schlappi *et al.* explain these trip categories in detail. However, for the purpose of the metropolitan network analysis, these definitions were not used since the "internal" and "external" categorizations were specific to the Bay Area. The socioeconomic data considered in developing the rates included total employment, retail employment, manufacturing employment, service employment, other employment, population, households, and average household income. However, it is reported that the most meaningful correspondence between socioeconomic categories and trip ends was achieved by using either total employment or other employment, Therefore the rates employed here for estimating truck productions and attractions is based on these trip production rate coefficients (See the last row of Table 4-1).

The Phoenix truck trip generation models are also land use-based trip rate models, The socioeconomic data considered in developing these models include total households, retail employment, industrial (manufacturing and warehousing) employment, public (medical and government) employment, office (office and service) employment, other (transportation, utilities, communication, other) employment, resident households, group quarter households, total area, and vehicles. Both regression and land use-based models were estimated and tested for accuracy in replicating the district-level survey results. It was found that the land use trip rate models were preferable to linear regression models. Table 4-2 summarize summarizes these trip rate results.

When one computes trip production/attraction estimates from these two models based on the employment data available for the New York Metropolitan region, the Phoenix model produces consistently higher estimates, and the estimates seem to be at odds with the values available from other sources, such as the cordon counts and the trip generation estimates prepared for the Route 9A study. Also, to use that model would imply developing variables for which no current observations exist. Either those values would have to be assumed, or more data would have to be collected to make the model useable. Hence, the San Francisco model was selected for use.

4.3.3 Trip Matrix Estimation

Collectively, the LV, OD, and OT observations are used to constrain or direct the choice of values for the trip flow matrix values. For example, if k represents the index on such observations and b_k is an individual observation, and x_{ijc} is the flow matrix value for trips from i to j by trucks of class c; then, if we know α_{ijc}, the percent of observation b_k that should be attributable to (or caused or created by) flow x_{ijc}, then we can write the following: which says that the observed value b_k must match the estimate of that same value derived from the current estimates of trip matrix flow variables ($\alpha_{ijc}\ x_{ijc}$) or else allow for a deviation to exist, either on the high side ($e_k^+ + d_k^+$) or the low side ($e_k^- + d_k^-$). Variables e_k^- and e_k^+ are intended to represent small deviations, and variables d_k^- and d_k^+, deviations beyond those values. So, if there are limits on the magnitudes of e_k^- and e_k^+, say E_k^- and E_k^+, and the penalty for the large deviations, say w_k^d, is higher than for the smaller ones, w_k^e, then a piecewise linear archimedean goal programming problem can be formulated in which the objective is to minimize the weighted sum of the deviations from the observed values b_k and the choice variables are the trip matrix flows (i.e., the x_{ijc}'s). The resulting formulation is as follows:

$$\sum_{m \varepsilon M_k} \alpha_{mk}\ x_m + e_k^- - e_k^+ + d_k^- - d_k^+ = b_k \forall\ k \qquad \mathbf{1}$$

<u>Minimize</u>:

$$\sum_k w_k^d \left(d_k^- + d_k^+ \right) + w_k^e \left(e_k^- + e_k^+ \right) \qquad \mathbf{2}$$

Subject to:

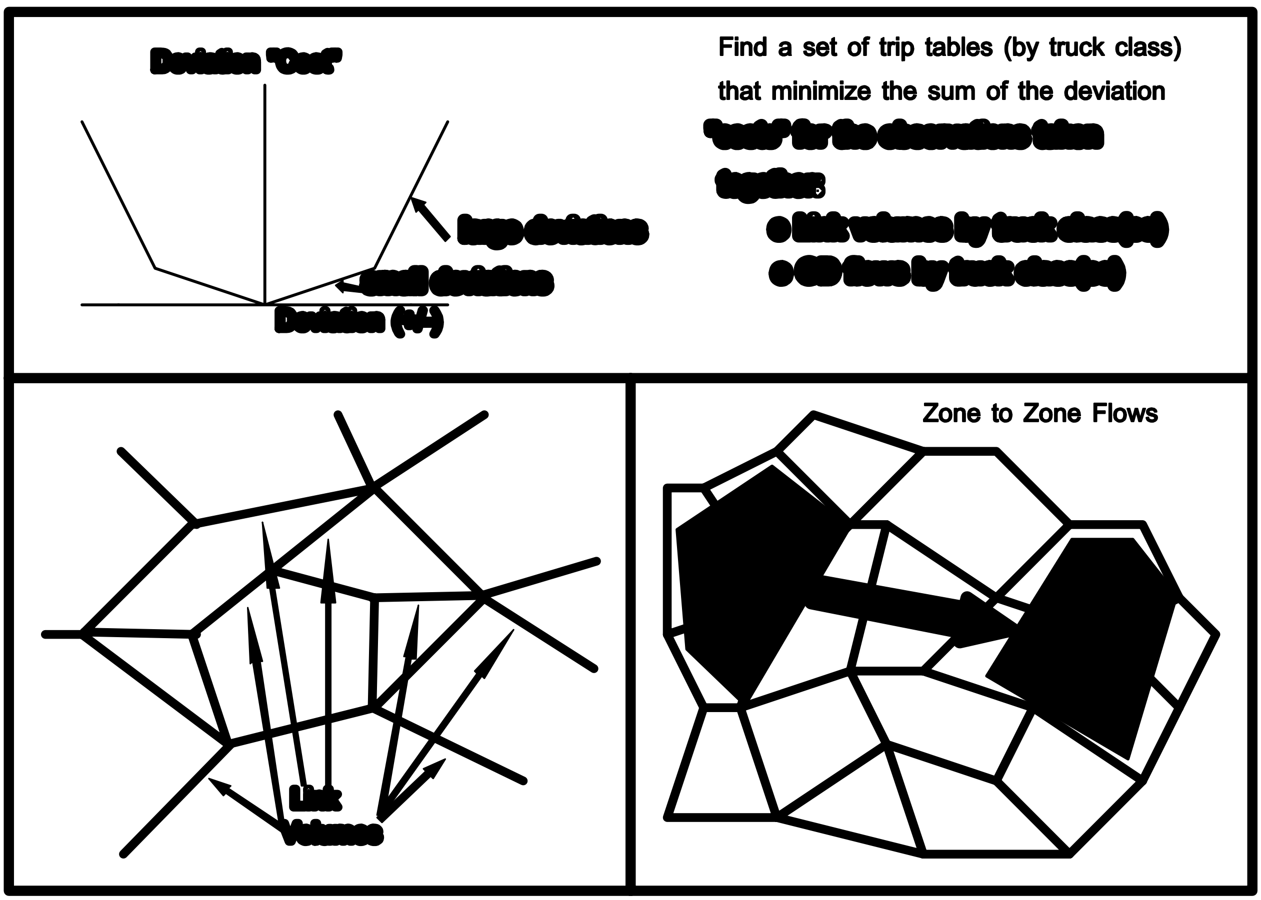
$$\sum_{m \varepsilon M_k} \alpha_{mk}\, x_m + e_k^- - e_k^+ + d_k^- - d_k^+ = b_k \,\forall\, k \qquad \mathbf{3}$$

$$e_k^- \leq E_k^- \,\forall\, k \qquad \mathbf{4}$$

$$e_k^+ \leq E_k^+ \,\forall\, k \qquad \mathbf{5}$$

$$e_k^-, e_k^+, d_k^-, d_k^+ \geq 0 \,\forall\, k \qquad \mathbf{6}$$

MODEL OVERVIEW



In the context of the LV observations, the b_k is the observed link flow volume and α_{ijc} is the percentage of b_k being caused by flow from i to j passing over the subject link (estimated through a traffic assignment model). The bottom left hand portion of Figure 4-1 illustrates this point. For OD observations, the b_k is the observed origin-to-destination flow value and the α_{ijc} is either a 0 or a 1 depending upon whether flow x_{ijc} contributes to generating the observed value (e.g., its origin and destination zone locations overlap the county boundaries) or not. The bottom right hand portion of Figure 4-1 illustrates this point. For OT observations, b_k is the observed trip attraction or production value and the α_{ijc} is either a 0 or a 1 depending upon whether flow x_{ijc} contributes to generating that observed value (e.g., its origin or destination coincides with the zone or network node to which the observed value is linked) or not.

4.3.4 Traffic Reassignment

In the context of this particular analysis, new values for the α_{ijc} are estimated using a traffic assignment algorithm (the probabilistic assignment methodology due to Dial [1971] has been used in the work presented here). The result is a new set of traffic flow volumes by link and direction that can be used to develop estimates of pollution impacts, pavement damage, cost, etc..

4.4 Case Study

This section presents the New York metropolitan area case study used as an implementation test of the methodology described above.

4.4.1 Network Specification

The network for the case study was extracted from the master New York metropolitan area highway network maintained by the New York Metropolitan Transportation Council (NYMTC), the designated Metropolitan Planning Organization for the New York State portion of the region. For each link the dataset contains an extensive collection of attributes including functional class, length, travel time (peak flow conditions), a trucks permitted flag, state, county, from and to node, etc.

From this network, we extracted all of the freeway links and all of the principal arterial links. These were supplemented by a few minor arterial links extracted to close gaps between nodes and to provide practical paths around truck-use-restricted links.

To this NYMTC-derived network we added a handful of links, particularly within Pennsylvania. These extend the network far enough to the west so that logical path choice decision points existed for important facilities such as I-76 (Harrisburg) and I-80 (Scranton). We did not want the network to be "so narrowly defined" in geographic scope that these path choices were artificially constrained by the fact that the path choices did not exist.

The resulting baseline network is shown in Figure 4-2. It contains 3410 links and 3074 nodes. It extends from Harrisburg on the west to Providence on the east, and from Albany on the north to Wilmington on the south. The density of links is high in the vicinity of the metropolitan region proper and sparser elsewhere. For each link we make use of the from node, to node, truck use flag, length, travel time, state identification and county identification.

4.4.2 Zones and Land Use

Zonal definitions maintained by the Port Authority of New York and New Jersey (PA zones) were selected as the basis for the zonal structure used in the case study. At the 5-digit level, these PA zones are either parts of counties or entire counties. For example, Manhattan County is divided into 4 PA zones while Passaic county is just one.

Fifty zones were identified on this basis. They are listed in Table 4-3 along with their codes, names and centroids (i.e., a description of the place to and from which trips originate/terminate and from the network node number that corresponds to that location.

4.4.3 Link Volume Data

Link volume datasets for the AM (6-10AM, midday (10AM-3PM) and PM (3-8PM) time periods were developed. They each contain about 200 observations. The data were derived from the following list of sources:

- o 1992 PANYNJ Regional Truck Cordon Survey;
- o 1991 PANYNJ Truck Commodity Survey;
- o NYCDOT classification counts at bridges;
- o Route 9A Study in Manhattan

- Gowanus Expressway project;
- NYSDOT Van Wyck classification counts

- o I-684 Survey conducted for the Westchester Goods Movement Project
- o TBTA toll data;
- o 1991 TBTA survey;
- o NYCDCP East River Truck Crossing Survey;
- o Brooklyn Truck Route Study;
- o LIE 4th Lane Study;
- o NYSTA toll plaza data; and
- o NYSDOT S1 data.

A listing of the records from the AM LV dataset can be found in Appendix B along with a description of how to interpret the fields.

4.4.4 Origin-Destination (OD) Flow Observations

Datasets containing between 400 and 450 OD observations were developed for each of the three analysis time periods. These data were derived from the following sources:

- o 1992 PANYNJ Regional Truck Cordon Survey;
- o 1991 PANYNJ Truck Commodity Survey;
- o Route 9A Study in Manhattan
- o I-684 Survey conducted for the Westchester Goods Movement Project
- o 1991 TBTA survey; and
- o NYCDCP East River Truck Crossing Survey.

The data from these various sources were combined to form a comprehensive, composite set of OD flow observations. The data were first scrutinized to see if any (significant) double counting would result if the observations were combined, and no evidence of that potentiality was found. Then observations across the datasets of flows between specific OD pairs were combined (summed) to create a more complete (higher estimate) of what the lower bound on the true OD flow might be.

4.4.5 Originating/Terminating (OT) Observation Data

Truck trip production and attraction on a daily basis were estimated using the methodology described in Section 4.3.2 The employment dataset used as the basis for generating the estimates was derived from two sources. In New Jersey, the data came from the New Jersey Department of Labor and represent employment data on a municipality level. In New York, zipcode-level data from the 1987 Economic Census data were employed. Both of these data sources were aggregated to the zonal level used for the study, by hand using maps.

Total truck trips per day, by number of axles, were then estimated using the model developed for San Francisco by Schalappi *et al.* This model uses daily trip rates per 1,000 employees as follows:

2-axle truck trips:	60
3-axle truck trips:	6
4 or more axle truck trips:	19

To apportion these trips among periods of the day, several sources of hour-by-hour traffic counts were consulted. NYSDOT publishes time-of-day factors for apportioning AADT volumes, but the factors pertain to all flows, not just trucks. True 24-hour classification counts were available for the New Rochelle toll plaza (eastbound) on the Thruway, and for the truck ramps leading into and out of the air cargo area at JFK. Neither of these is the most representative of locations. Elsewhere the truck data exist from 6AM to 8PM or 7AM to 7PM. Indirectly, it is possible to reconstruct some 24-hour counts (in one direction) from the PA Truck Commodity Survey, because in most locations the survey covered a 24-hour period. The results, however, are highly variable across facilities.

A 1972 report on "Urban Area Travel by Time of Day" provides truck-specific hour-by-hour flow estimates for St. Louis and Boston. These distributions are very similar, and approximately constant from 7AM to 5PM, which is consistent with the truck counts in Manhattan over that period. Hence, use of these data, while dated and from other cities, seems the most logical option to select. Based on this, the percentage breakdown of trucks by time period are as follows:

6 AM - 10 AM: 26.5 %

10 AM - 3 PM:37.3 %

3 PM - 8 PM: 27.5 %

8 PM - 6 AM: 8.7 %

4.4.6 Truck Trip Matrix Estimation and Baseline Performance Measures

Estimation of the truck trip matrices by time period followed the procedure described in Chapter 2 and Section 4.3.2 above, and more fully documented in List and Turnquist [1993]. The results are shown in Table 4-4, and involve 5-7 million truck-miles per time period and 7-9 million truck-minutes. The average trip length ranges between 40 and 60 miles.

Table 4-4. Performance Measures for the Base Case Condition

Daily Environmental and Economic Impacts				
Impact	AM Peak	Midday	PM Peak	Total
Truck-miles (millions)	7.14	6.68	5.47	19.29
Truck-minutes (millions)	9.23	9.13	7.17	25.53
Truck Cost ($millions)	$7.38	$6.91	$5.66	$19.95
ESAL-miles (millions)	8.20	7.67	6.28	22.14
Carbon-Monoxide (tonnes)	279	261	214	754
Hydrocarbons (tonnes)	37.1	34.7	28.4	100.3
Nitrous Oxides (tonnes)	152	142	117	411
Particulates (tonnes)	15.3	14.3	11.7	41.3
Number of Trips (000)	116	146	118	380
Average trip length (mi)	62	46	46	51

For the other performance measures computed, the ESAL-miles ranges between 6-8 million. Carbon monoxide outputs are about 250 tonnes (1000 kg) per time period; hydrocarbons are between 20 and 30 tonnes, and nitrous oxides are about 140 tonnes. The total truck-related cost per day, following the models presented in Chapter 2, is about $20 million per day, broken down into $3.5 million in pavement damage-related costs and $16.5 million in operating and insurance costs. (This translates into $4.0 billion per year.)

The AM peak flow pattern for the closer-in portion of the metropolitan area is shown in Figure 4-3. There are heavy flows along the New Jersey Turnpike, across the George Washington Bridge, along I-80 and I-287, and along the LIE. Smaller flows can be seen across the Verrazano Narrows bridge, the Throgs Neck and Whitestone Bridges, I-95 near

New Rochelle, and along NJ Route 17. The midday and PM peak flow patterns are similar and are not reproduced here for sake of brevity.

4.4.7 Exploring Small Changes in Network Use Rules

At times in the past, changes in facility use by trucks have been proposed, to reduce the conflicts between autos and trucks, and to make the overall network function more efficiently. Based on inputs received from the Port Authority, several of these were explored to see what differential impacts would result:

- closure of the Throgs Neck and Whitestone bridges to trucks;
- opening the Grand Central Parkway for truck use
    - with the Throgs Neck and Whitestone bridges closed;
    - with the bridges open; and
- creation of a "Circumferential Corridor" around the metropolitan area for truck use and prohibitions on truck use of other bridges.

Table 4-5 and Figures 4-4 through 4-7 present the comparative results of these analyses. Closing the Throgs Neck and Whitestone bridges produces a relatively small impact in terms of the overall statistics. The increase in truck-miles in the AM peak is 6,973/day (less than one percent) and the cost implication is $7,226/day. Assuming there are about 200 typical truck traffic days per year (corresponding to the number of work-weekdays), this means the annual cost implication of such a change is about $1.4 million. While this is a considerable amount of money, it is relatively small compared to the $1.5 billion/year involved in the AM peak period truck traffic taken as a whole. Opening the Grand Central Parkway, with the Throgs Neck and Whitestone Bridges closed diminishes the negative impacts from closing the bridges by and opening the Grand Central Parkway with the Throgs Neck and Whitestone Bridges open produces further decreases.

Table 4-5. Impacts from Bridge Closures and Parkway Openings

AM Peak Environmental and Economic Impacts				
Impact	Bridges Closed	GCP Open	Bridges & Parkway	Circum. Corridor
Truck-miles (millions)	7.15	7.30	7.29	7.32
Truck-minutes (millions)	9.25	9.49	9.46	9.53
Truck Cost ($millions)	$7.39	$7.55	$7.54	$7.57
ESAL-miles (millions)	6.08	8.38	8.37	8.41
Carbon-Monoxide (tonnes)	279	285	285	286
Hydrocarbons (tonnes)	37.2	38.0	37.9	38.1
Nitrous Oxides (tonnes)	152	155	155	156
Particulates (tonnes)	15.3	15.6	15.6	15.7
Number of Trips (000)	116	116	116	116
Average trip length (mi)	62	63	63	63

The last map (Figure 4-7) shows the impacts from establishing a circumferential ring road around New York City. Included are the New Jersey Turnpike, the George Washington Bridge, the Brooklyn-Queens Expressway, the Gowanus Expressway, and the Verrazano Narrows bridge on the south. The assumption is that concentrating traffic in such a corridor facilitiates improvements in truck mobility. In the corridor, special attention would be given to truck traffic-related needs: traveler information systems, road condition reports, dedicated use lanes, special on and off ramps, etc.

However, concentrating this traffic could also produce negative impacts. The question is: how significant would those changes be? Are such changes worthwhile or "tolerable"? Table 4-5 shows that our model predicts across-the-board increases in the impact categories considered. However, the increases are not large. One can argue therefore that a finer-grained analysis would be justified to see if the benefits from specialized treatment (e.g., travel time reductions due to special treatment in the corridor) would offset the investment costs involved (i.e., in building, operating and maintaining the truck-oriented services and facilities). Our sense is that they would.

4.4.8 Implicit Value of the George Washington Bridge and ITS Actions

While it is not anticipated that the George Washington Bridge will ever be closed to truck traffic on purpose, incidents do occur, and congestion and delays ensue. As the case study in Chapter 3 amply demonstrates, the bridge operates very near capacity significant portions of the day, and the volumes it carries are very large.

Hence it was decided to examine the impacts that would result from having to reroute traffic away from the bridge. We also decided to explore the benefits that would result from being able to use radio communications, or some other IVHS/ITS/ATIS-type enhancement so that truck traffic could either be directed to or away from the bridge in real-time in response to changing conditions as incidents and their recovery unfold.

Table 4-6. Impacts from Closure of the George Washington Bridge

GWB Closure Environmental and Economic Impacts				
Impact	AM Peak	Midday	PM Peak	Total
Truck-miles (millions)	7.18	6.72	5.50	19.40
Truck-minutes (millions)	9.32	9.20	7.23	25.75
Truck Cost ($millions)	$7.42	$6.95	$5.68	$20.05
ESAL-miles (millions)	8.24	7.72	6.31	22.27
Carbon-Monoxide (tonnes)	281	263	215	758
Hydrocarbons (tonnes)	37.3	34.9	28.6	100.9
Nitrous Oxides (tonnes)	153	143	117	413
Particulates (tonnes)	15.4	14.4	11.8	41.5
Number of Trips (000)	116	146	118	380
Average trip length (mi)	62	46	47	51

As Table 4-6 shows, loss of the bridge causes significant impacts. The increase in truck-miles in the AM peak alone is 38,600. The change across an entire day is 105,096 truck-miles. The cost implications are an additional $39,906 for the AM peak period, and $108,645 for the three time periods combined. Thus, were the bridge not present in the system, the annual incremental trucking cost of that loss would be $21.7 million.

Other incremental impacts are also significant. Carbon monoxide emissions would increase by 4.11 tonnes; hydrocarbons by 550 kg, and particulates by 225 kg. Of the $108,645 in truck cost increase, $19,000 would be in pavement "damage" costs, or $3.8 million per year.

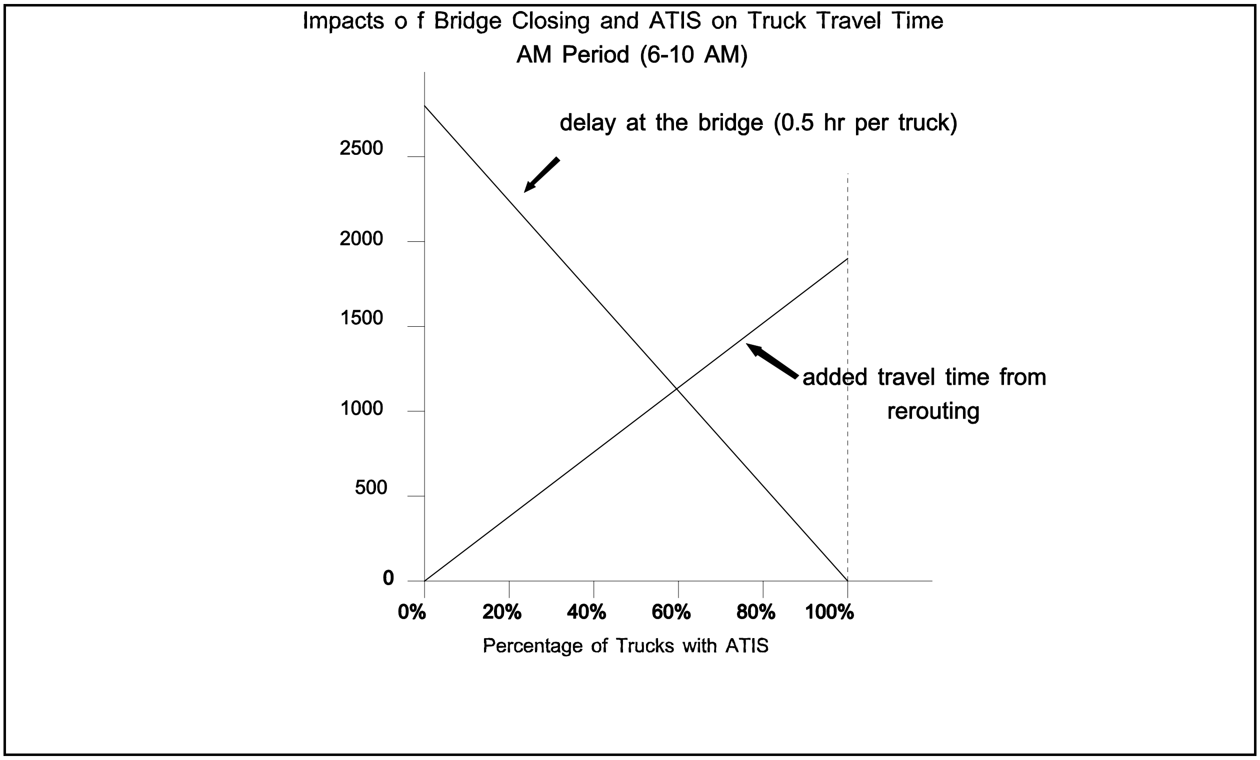


Figure 4-8. Tradeoffs in Vehicle Hours due to Bridge Closure

The significance of these impacts is also underscored by considering the benefits that would also come from letting the truck drivers know when and if the bridge is closed. Figure 4-8 shows that if the bridge is closed, and 100% of the trucks are diverted away to other paths, the incremental change in vehicle-hours is 1,528. However, the figure also shows that if each of the 5,677 trucks that we estimate cross the bridge during the AM peak period in both directions were delayed a half-hour each, the resulting increase in vehicle-hours due to the bridge being closed would be 2,838 hours, 1.86 times as much. So, even though the penalty for diverting the trucks to other paths is a substantial number of truck-hours, letting them sit in traffic waiting for the incident to be cleared is even more significant. In fact, the average delay per truck would have to be 16 minutes or less for the two incremental truck-hour "penalties" to be equal. Put another way, if the incident were to cause a one-hour delay to one hour's worth of trucks (1419) the incremental truck-hour penalties would also be equal.

This suggests that the value in providing real-time information to truck drivers about the status of the bridge is very high. For example, if a partial closure of the bridge were to result in half-hour delays per truck across the duration of our study period (6 AM to 8 PM), the truck-hour penalty from that delay would be 8,239 hours. By comparison, the incremental "penalty" from routing those trucks away from the bridge, onto other paths would be 3,800 truck-hours, assuming no other significant congestion problems were created as a result (which is questionable).

Hence, not only is it important to deflect truck traffic from the bridge when it is blocked, but the converse is also true. It is important to redirect truck traffic back to the bridge when it is open. In the former case, the penalties for delay while waiting for the bridge to reopen are considerable. And in the latter, the penalty for being diverted to some other route is not insignificant.

It is also interesting to examine the differential impacts of such a loss in capacity from the perspective of where the changes in impacts occur. As Figure 4-9 shows, there are significant changes in the truck flow pattern as a result of the bridge's closure. In fact, the figure shows that a significant propensity exists to make extensive use of Manhattan for cross-city traffic. Notice the heavy projected volumes across the Lincoln and Holland Tunnels. Not to suggest that these volumes would actually materialize - likely they would not - but rather *in spite of the slow travel times - 10 MPH or less - across Manattan in the model*, the travel time savings from using cross-Manhattan paths are substantial vis a vis others available. So the model predicts significant flows there. The implication we draw from this is that the need for truck driver-oriented traveller information systems is vital to provide suggested alternate routes *and* the value in creating a circumferential freight corridor around the city is significant. The Verrazano Narrows bridge needs to be an attractive alternative were such a situation to arise. (For example, improvements to the Gowanus Expressway and Brooklyns-Queens Expressway are vital.)

From a different perspective, if the shifts in pavement damage are considered on a county-specific basis, the diagram shown in Figure 4-10 results. One county in particular, Bergen, sees a significant decrease in damage due to diversion of the traffic away from the bridge. Two other counties, Bronx and Passaic, also see decreases in damage because the traffic on the Cross Bronx Expressway and I-80 decreases. Concomitant increases in damage occur in seven other counties. Essex is the most affected, followed by Rockland, Queens, Westchester, Manhattan, Kings and Richmond. The other counties are largely unaffected. While these shifts in impacts are hypothetical, and related to a short-term loss of use of the bridge, such impacts would be of great concern and interest if permanent changes to the flow patterns from some change in network capacity.

4.5 Concluding Remarks

It is clear from the various investigations conducted that the differential impact assessment methodology works and produces results of considerable interest, on both an aggregate and disaggregate basis. Moreover, the impacts from losses in network capacity can be substantial for certain facilities. Similarly, the benefits from investments to improve and protect the quality of the flows are high, and the differential impact results help illustrate where those benefits would occur.

Continued refinement and enhancement of such tools and techniques would make them even more useful to network planners and managers alike. The impact assessment capabilities provided help identify the most beneficial solution strategies to pursue, and help evaluate the short-term impacts from traffic shifts and capacity losses, as well as the implicit value of providing real-time information to the network users so that intelligent path selection choices can be made.

CHAPTER 5
SUMMARY AND CONCLUSIONS

5.1 Introduction

This study has focused on developing a new network-based cost-benefit analysis methodology geared toward exploring truck-related system improvements: investments in new capacity, operational changes, and Intelligent Vehicle-Highway System/Intelligent Transportation System (IVHS/ITS) technology deployment strategies - actions that can improve system operation by making more, and better information available to the system's users about system status and future conditions. The methodology is particularly strong in assessing the way in which trucks might alter their flow patterns across the network in response to these changes and the impacts they would cause as a result, especially air pollution, pavement damage, and increases (or decreases) in truck operating costs.

While the methodology is applicable to urban areas of any scale, it is specifically geared for regions the size of the New York metropolitan area, as is amply illustrated by the case study analyses. These are situations where congestion problems are common, capacity investment options are quite limited, and non-recurring incident-related congestion is a significant source of delay, both in an absolute and relative sense. For dealing with the goods mobility questions that often arise in such settings, the methodology contains a microscopic tool capable of assessing the truck-related benefits of link-specific actions as well as macro-level tools capable of assessing the impacts of network-wide actions.

The intended audience is metropolitan planning organizations (MPOs), state departments of transportation, and other similar agencies. We want them to find this tool useful for performing goods movement-related mobility studies and/or develop transportation investment plans that are comprehensive in nature, as called for in ISTEA, having components that focus on freight as well as passenger flows.

5.2 Methodological Overview

One could argue that the methodology consists of two components that follow the same basic analysis methodology. One is micro in focus, the other one, macro. Both can help planners evaluate the benefits and costs of goods movement mobility-enhancing actions. The macroscopic-level analysis methodology focuses on network-level improvements including facility construction, dedicated use lanes, and ATIS services.

Both components are extensions of the method for estimating truck trips in urban areas developed in a previous project sponsored by NYSDOT and USDOT (see List and Turnquist, [1993]). The emphasis here has been to take the truck trip estimates which that methodology provides, and evaluate the benefits and costs from various network improvement options. These three tools, in combination, provide a means both to discern the travel patterns that currently exist in a network and to determine what actions, short and long term, might provide the most significant improvements in goods movement mobility for an urban area, especially insofar as trucks are concerned.

The microscopic analysis tool is important because mobility problems are fundamentally caused by congestion - on specific links and in specific locations. Following the perspective taken by many of the traffic analysis tools available today, we have developed a simulation model, based on NETSIM, that allows analysis of toll facilities. One can use it to see if various design options improve the performance of a major toll collection facility. Not that this is the only type of congestion problem that can arise, or that the tool can be applied to any and all bottleneck situations, but rather, the analysis technique, and its application, illustrate the kind of analysis that can be performed, the types of performance metrics that can be examined, and the various conclusions that might be reached.

The macroscopic analysis tool, sitting above the microscopic one, provides a means to evaluate the system-level impacts of various mobility-enhancing actions. Again, the emphasis in what is presented is on the structure of the methodology employed, the performance measures examined, the impact models used to evaluate those measures, and the kinds of findings that result.

5.3 Methodological Advances

The types of questions for which the methodology is intended include the following. If commercial vans are allowed to use auto-only parkways during off-peak hours, what would be the impact? How would trips be diverted? If a major expressway is taken out of service, in whole or in part, for reconstruction and rehabilitation, what changes in truck flow patterns will result? Will certain businesses be forced to close? Will their transport costs increase dramatically? How will the overall network flow patterns be affected? If better information on traffic incidents and delays could be provided to truck drivers, what would be the effects? How would flow patterns change? If physical or operational improvements were made at a major facility, what would be the local effects? What would be the regional effects?

To reach a point where these kinds of questions could be answered, several methodological advances were required. First, we needed a capability to analyze a large-scale network. This involved reworking the network analysis tools and techniques developed earlier (see List and Turnquist [1993]) so that they would accommodate larger scale problems: more nodes and arcs, more OD pairs, and longer paths.

Second, a technique was developed for estimating truck trip production/attraction rates for urban area zones. Two previous research efforts were identified that provide a basis for estimating trip productions and attractions. Ruiter [1992] developed a trip estimation methodology as part of the Phoenix Commercial Vehicle Survey and Travel Model project and a similar model was developed by Schlappi, Marshal and Itamura [1993] methodology for the San Francisco Bay area. When we computed trip production/attraction estimates from these two models based on the employment data available for the New York Metropolitan region, the Phoenix model produced consistently higher estimates, and ones that were at odds with the values available from other sources, such as the cordon counts and the trip generation estimates prepared for the Route 9A study. Also, the model required values for variables for which no current observations exist. Either those values would have had to be assumed, or more data would have to have been collected to make the model useable. Hence, the San Francisco model was selected for use.

A third methodological advance involved developing a mechanism for reassigning traffic to the network in response to information provision and/or physical changes. At the microscopic level (see Chapter 3), this meant a process whereby user equilibrium traffic assignments could be made to the network based on observed values of delays. For the macroscopic analysis (see Chapter 4) this meant developing a way to take an OD matrix that had been estimated using one network topology and reassigning those trips to a network whose topology had been altered. To achieve this, a procedure was developed whereby new link utilization coefficients could be developed for a new network situation and then those coefficients could be applied to the estimated flows to develop link-based flow estimates.

A fourth advance was the development of impact assessment models for a variety of important truck-related measures of effectiveness (see Chapter 2). Four of these related to truck pollutant outputs: carbon monoxide, hydrocarbons, nitrous oxides, and particulates less than 10 microns in diameter. The others focused on pavement damage-related costs and truck operating costs. These non-trivial efforts place this work at the forefront of impact model development inasmuch as the fact that the Environmental Protection Agency has removed all references to truck-related pollution rates in MOBILE-5, its current transportation-focused air pollution estimation model.

This focus on air quality impacts was especially important in light of the need to reduce freight-related emissions, particularly nitrous oxides (NO_x) and particulates (PM_{10}) from diesel trucks. Lower travel times, achieved through higher average speeds and less delay, translate into smaller quantities of fuel consumed and lower emissions, even without changing the distribution of trips among truck classes, or among modes.

Last, but not least, a method was developed to simulate the performance of large-scale toll plazas such as those found on the western side of the George Washington Bridge (see Chapter 3). NETSIM was used for this purpose, with significant adaptations of the nominal input data to create a realistic representation of such facilities. Not only were innovative changes made to the way in which the model is typically configured and run, but extensive validation runs were carried out to ensure that the model predictions were faithful to the observed queue dynamics and delays observed in the field under real-life operating conditions. Not only was this important from the standpoint of developing credible estimates of the impacts from changes in information provision and the bridge approach's physical characteristics, but also in that it demonstrated that the highly adapted model was capable of replicating observed traffic dynamics and performance measures.

5.4 George Washington Bridge Case Study

The George Washington Bridge study in Chapter 3 examines four strategies for reducing delays, fuel consumption and emissions at the toll plazas west of the George Washington Bridge. All are intended to illustrate the microscopic analysis methodology:

1) providing better information to drivers regarding delays at the various toll plazas, allowing them to redistribute the load among the plazas more effectively;
2) adding a new ramp (Ramp Z) to connect US 9W northbound with the Palisades Interstate Parkway toll plaza;
3) implementing electronic toll collection for some of the users; and
4) allowing trucks to use the existing HOV lanes during the off-peak hours.

The results of the analyses suggest that both increased information and electronic toll collection can provide substantial benefits. The addition of Ramp Z or the off-peak use of the HOV lane, however, provide almost no benefits.

Clearly these results are useful from the perspective of the Port Authority, which is responsible for the bridge. In addition, though, they illustrate the value in performing such analyses to determine the relative merits of congestion relief strategies. Unproductive capital investments can be avoided; changes in operating rules can be foregone, and the high payoff actions can be emphasized without having to conduct actual experiments in the field.

5.5 Metropolitan Network Case Study Analysis

Chapter 4 presents a network-level case study analysis based on the New York metropolitan area. The baseline network contains 3410 links and 3074 nodes. It extends from Harrisburg on the west to Providence on the east, and from Albany on the north to

Wilmington on the south. The density of links is high in the vicinity of the metropolitan region proper and sparser elsewhere.

Since facility improvements are a significant area of interest, much of the effort focused on exploring the impacts from facility additions and/or deletions. At times in the past, changes in facility use by trucks have been proposed, to reduce the conflicts between autos and trucks, and to make the overall network function more efficiently.

Based on inputs received from the Port Authority, several of these were explored to see what differential impacts would result:

- closure of the Throgs Neck and Whitestone bridges to trucks;
- opening the Grand Central Parkway for truck use
  - with the Throgs Neck and Whitestone bridges closed;
  - with the bridges open;
- creation of a "Circumferential Corridor" around the metropolitan area for truck use and prohibitions on truck use of other bridges; and
- closure of the George Washington Bridge - to assess the implicit value that the facility has to the region.

The results from these analyses showed that changing the availability of facilities such as the Grand Central Parkway, and the Throngs Neck and Whitestone bridges would indeed have impacts on truck circulation patterns. However, the increases are not large. It seems reasonable, in fact, to assume that a finer-grained analysis would find that the benefits from such specialized treatment (e.g., travel time reductions due to special treatment in the corridor) would offset the investment costs involved (i.e., in building, operating and maintaining the truck-oriented services and facilities).

While it is not anticipated that the George Washington Bridge will ever be closed to truck traffic on purpose, incidents do occur, and congestion and delays ensue. Hence it was decided to examine the impacts that would result from having to reroute traffic away from the bridge. We also decided to explore the benefits that would result from being able to use radio communications, or some other IVHS/ITS/ATIS-type enhancement so that truck traffic could either be directed to or away from the bridge in real-time in response to changing conditions as incidents and their recovery unfold.

What was found was that if the bridge were not present in the system, the annual incremental trucking cost of that loss would be substantial (about $21.7 million.) In addition, if the bridge were closed, an 86% increase in vehicle-hours would result. Even though the penalty for diverting the trucks to other paths is a substantial number of truck-hours, letting them sit in traffic waiting for the incident to be cleared is even more significant. In fact, the average delay per truck would have to be 16 minutes or less for the two incremental truck-hour "penalties" to be equal. Put another way, if the incident were to cause a one-hour delay to one hour's worth of trucks, the incremental truck-hour penalties would also be equal.

These results suggested that the value in providing real-time information to truck drivers about the status of the bridge was very high. Not only would it be important to deflect truck traffic from the bridge when it is blocked, but the converse would also be true. It is important to redirect truck traffic back to the bridge when it is open. In the former case, the penalties for delay while waiting for the bridge to reopen are considerable. And in the latter, the penalty for being diverted to some other route is not insignificant.

Both this investigation and the one in Chapter 3 make it clear that the methodology works and produces results of considerable interest, on both an aggregate and disaggregate basis. Moreover, the impacts from losses in network capacity can be substantial for certain facilities. Similarly, the benefits from investments to improve and protect the quality of the flows are high, and the differential impact results help illustrate where those benefits would occur.

5.6 Opportunities for Future Work

Although the accomplishments in this study are significant, there is still room for further advances:

- further refinement of the microscopic link-based analysis tools, especially the customized adaptation of NETSIM to this environment;

- additional work on integrating the network-level tools and techniques into a more unified GIS/DBMS/analysis tool environment so that the analysis process is seamless from the user's perspective;
- more explicit treatment of the multi-commodity equilibrium assignment process that is implicit in reassigning truck flows to a heavily congested network;
- additional experiments in the application of both the micro and macroscopic tools to additional case study environments; and
- development of more refined, and empirically tested, models for predicting the pollutant generation rates of the trucks that typically operate in urban environments.

In addition, there is a need to make all of the tools and techniques more multi-modal in focus and capability, especially insofar as rail-based freight transport is concerned. Currently, the network modeling routines are not equipped to deal with intermodal issues or shifts in traffic flow between truck and rail. Yet rail is a significant option for highway congestion, for reducing pavement damage, and for reducing air pollution emissions. Consequently there is a focus on how the model would have to be expanded, extended, and enhanced to allow such considerations to take place.

Finally, continued refinement and enhancement of such tools and techniques would make them even more useful to network planners and managers alike. The impact assessment capabilities provided help identify the most beneficial solution strategies to pursue, and help evaluate the short-term impacts from traffic shifts and capacity losses, as well as the implicit value of providing real-time information to the network users so that intelligent transportation investment plans can be developed.

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Appendix A

Computation of Equivalent Single Axle Load (ESAL)

One of the most widely used form of ESAL factors for highway analysis are those developed from the AASHO road test. 1, 2, 3, 7 These ESAL factors are expressed in terms of a) pavement strength, b) axle load characteristics and c) terminal level of serviceability selected as the pavement failure point. ESAL factors can also be affected by the vehicle tire pressure especially for thin pavements. Sebaaly6 discusses this interaction between tire pressures, axle loads and axle configuration in pavement damage.

For flexible pavements, strength is expressed by a Structural Number (SN). Structural Number is the sum of the products of layer thickness and layer structural coefficient. Strength for rigid pavements is expressed in terms of pavement thickness (D).

Axle load characteristics are denoted by two factors namely the axle load (L1) and the axle configuration L2 (e.g., single, tandem, or tridem). This categorization is important because different axle configurations have different effects on pavement damage. For example, an 18-kips (18,000 lb) single axle causes the same amount of pavement damage as a 33-kips tandem axle, which in turn causes the same amount of pavement damage as a 48-kips tridem axle. Therefore, according to the above notation a single 18-kips axle will be denoted as (L1 = 18, L2 = 1) while a 48-kips tridem axle will be denoted as (L1 = 48, L2 = 3).

AASHO (now AASHTO) road test used a measure called Pavement Serviceability Index (PSI) to evaluate pavement performance. This is a composite measure of ride quality and pavement structural distress. PSI values lie between 0 and 5 with 5 reflecting an excellent pavement. Depending on the importance of the pavement in question, we may define its failure at a PSI value of 1.5, 2.0, 2.5, or 3.0. These failure PSI values are called terminal serviceability values, (pt). Terminal serviceability denotes an intervention PSI value when a major rehabilitation or reconstruction is scheduled. Common values of pt are 2.0 for local roads and 2.5 or 3.0 for highly trafficked roads, such as interstate highways.

The general equation for ESAL, based on a standard 18-kips single axle is as follows:

$$\text{ESAL} = \frac{N_{f18}}{N_{fi}} = \left[\frac{(L_1 + L_2)^a}{(18 + 1)^a}\right]\left[\frac{10^{G/\beta}}{(10^{G/\beta_i})L_2^{\,b}}\right]$$

For flexible pavements, $a = 4.79$ and $b = 4.33$, while $a = 4.62$ and $b = 3.28$ for rigid pavements.

Where;

$$G_t = \beta(\log W_t - \log \rho)$$

$$\left.\begin{aligned} \beta &= 0.40 + \frac{0.081\ (L_1 + L_2)^{3.23}}{(\overline{\text{SN}} + 1)^{5.19} L_2^{\,3.23}} \\ \log \rho &= 5.93 + 9.36 \log (\overline{\text{SN}} + 1) - 4.79 \log (L_1 + L_2) + 4.33 \log L_2 \end{aligned}\right\} \text{For flexible pavements}$$

$$\left.\begin{aligned} \beta &= 1.0 + \frac{3.63(L_1 + L_2)^{5.20}}{(D + 1)^{8.46} L_2^{\,3.52}} \\ \rho &= \frac{10^{5.85}(D + 1)^{7.35} L_2^{\,3.28}}{(L_1 + L_2)^{4.62}} \end{aligned}\right\} \text{For Rigid Pavements}$$

where G_t = a function (the logarithm) of the ratio of loss in serviceability at time t to the potential loss taken to a point where $p_t = 1.5$

β = a function of design and load variables that influence the shape of the p versus W serviceability curve

ρ = a function of design and load variables that denotes the expected number of axle load applications to a $p = 1.5$

W_t = axle load applications at end of time t

p_t = serviceability at end of time t

L_1 = load on one single axle or on one tandem axle set (kips)

L_2 = axle code ($L_2 = 1$ for single axle and $L_2 = 2$ for tandem axle)

$\overline{\text{SN}}$ = structural number of pavement

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