TransLink

Current and Projected Costs of Congestion in Metro Vancouver

FINAL REPORT

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PREFACE

This report is based on the findings from HDR's larger study of transportation costs and benefits in Metro Vancouver. That larger study estimated the total costs of transportation, and included estimates of congestion costs for today and for various alternative conditions in 2045. This report makes numerous references to that larger study.

EXECUTIVE SUMMARY

Traffic congestion is commonly understood as a large number of vehicles on the road, reduced speeds and longer travel times compared to free-flow speeds and travel times. Congestion occurs because as more and more vehicles travel on a roadway, average speeds decrease affecting all motorists. At a certain point, speeds become slow enough that the roadway is considered congested.

Some degree of traffic congestion can be considered beneficial as traffic brings people and businesses to workplaces, clients, and other destinations of interest. However, a large volume of traffic and resulting reductions in speeds for all road users lead to various costs and inefficiencies in an economy including long travel times and increased vehicle operating costs for commuting, business trips, and goods movement.

Various stakeholders, including TransLink, expressed interest in assessing the effect of congestion on the economy and residents of the affected area in addition to measuring the extent of congestion in terms of traffic, speed, or other indicators. HDR was retained to estimate these costs for Metro Vancouver currently and in 2045 under various strategic transportation alternatives considered for the Metro Vancouver Region.

APPROACH

There are various approaches to measuring congestion and estimating its costs. An "engineering approach" defines congestion as travel occurring at speeds slower than a certain threshold considered as acceptable, for example 60% of free-flow speed. The costs of congestion include then the loss of time, increase in fuel consumption, increase in vehicle operating costs, and related social costs such as air pollution and GHG emissions due to slower average speeds.

An economic approach does not rely on a pre-defined speed. Instead it recognizes that there is an "optimal" volume of traffic and economically efficient level of congestion. This "optimum" corresponds to the traffic volume at which the benefit of the last marginal trip is equal to the cost of that trip. Additional trips beyond that optimum are considered *excess* (or excess traffic), as they generate more costs than benefits. The extent of net costs related to those additional trips – vehicle operating and time costs of driving and related social costs – constitute then the costs of congestion.

This study adopts the economic approach to measuring congestion and its costs. Excess traffic is calculated based on the costs of driving (assumed to consist of a cash component and a time cost component), average actual speed, average posted speed, speed-flow relationship, and travel demand function. The methodology involves in its essence deriving the average cost function and the marginal cost function for the given travel demand function and travel costs, and finding such volume of travel at which marginal cost is equal to price (i.e. travel cost) that travellers pay. This is the "optimal" volume of travel. In congested road conditions, the optimal volume of travel is usually lower than the actual travel; the difference is the *excess traffic* that results in *excess congestion*. The costs related to the excess traffic, net of benefits, are then considered as congestion costs.

The amount by which the benefits of trips that are excess traffic fall below their travel costs (time and cash costs) is referred to in economics as *deadweight loss*. This cost is then further expanded in this study to include the emission and accident costs corresponding to excess traffic as well as time lost by transit passengers.

In addition to the impacts of recurrent congestion (that is congestion that occurs regularly as a result of normal travel levels), estimates of non-recurrent costs of congestion costs – congestion due to random events that occur due traffic incidents such as stalled vehicles, spills, construction, or inclement weather – were adapted for this study from a Transport Canada study[1].

Congestion also has broader economic implications that go beyond the extra time and vehicle costs that people and businesses incur due to slow traffic. As an example, congestion with its long and unpredictable travel times erodes business productivity by impairing supply and distribution chains and inhibiting adoption and efficacy of modern productivity-enhancing management tools and approaches (known as just-in-time management and logistics systems). Longer and less predictable travel times also reduce the range of destinations that workers, firms and shippers can reach within an acceptable cost and time. In other words, in conditions of high congestion certain business operating costs may increase and certain economic activity may not be taking place because it is not economical or not practical.

This study develops a framework for quantification of the broader macro-economic costs of congestion. The estimation framework for these costs represents a "bottom-up" approach built from "structure and logic models", which represent a graphical illustration of the causal relationships among the relevant factors.

The congestion costs estimation framework was populated with input data on traffic in Metro Vancouver, average speeds, economic activity in the region, driving costs, value of time, and other assumptions. While the Regional Transportation Model for Metro Vancouver and other regional metrics were used to guide the analysis, it should be noted that certain input assumptions in this analysis such as the parameters of the cost and travel demand functions, or the industrial cost functions, represent reasoned assumptions guided by insights from economic literature, rather, than empirical estimates specific for Metro Vancouver. Therefore, the resulting estimates of travel delays and congestion costs should be interpreted as high-level or "order-of-magnitude" estimates.

RESULTS

The congestion costs estimated in this study for current conditions (as represented by the 2009 benchmark year), 2045 Base Case strategic transportation alternative and 2045 Mayors' Plan for

[1] See "Costs of Non-Recurrent Congestion in Canada", 11 December 2006, Transport Canada, Economic Analysis, TP14664E. This cost amounted to $579 million in 2015 dollars (Table 24, page 55, 60% threshold, inflated to 2015 dollars). The total costs of congestion in Vancouver (recurrent and non-recurrent) were estimated in the range of $737 million (50% threshold) to $1.1 billion (70% threshold) in 2000 dollars. See Table 25, page 56.

Transit and Transportation are presented in Summary Table 1.[2] The congestion costs quantified in this study were grouped under two broad cost categories that represent various manifestations of congestion costs, or various perspectives on congestion impacts:[3]

1. Delay, vehicle operating, and related costs. In particular, these costs entail longer travel times, wasted fuel, other additional vehicle maintenance and operating costs, more greenhouse gas emissions, and more air pollution.
2. Business inefficiency costs. These costs encompass increased business operating costs, loss in competitiveness in product markets, impaired access to labour pools and other production inputs, reduced business revenue, GDP, and employment.

Summary Table 1: Current and Projected 2045 Recurrent Congestion Costs in Metro Vancouver for Key Metrics, by Strategic Transportation Alternative (all dollar values in 2015$)

Congestion Cost Metric	Current Cost (2009 Benchmark)	2045 Base Case	2045 Mayors' Plan	2045 Base Case vs Mayors' Plan	
				Difference, $	% Change
Delay, Vehicle Operating and Related Costs					
Total Cost of Road Congestion, $ Million (Recurrent + Non-Recurrent)	**$487**	**$1,087**	**$722**	**$365**	**33.6%**
Business Inefficiency Costs and Reduction in Economic Activity					
Reduction in Business Revenue, $ Million	$591.8	$1,761.0	$1,042.9	$718	40.8%
Reduction In Regional GDP, $ Million	$340.1	$1,007.6	$591.6	$416	41.3%

Note: All dollar figures are in 2015 dollars.

Summary Table 1 shows that currently congestion costs are estimated at about $487 million in delay, vehicle operating, and related costs, $592 million in lost business revenue, $340 million in lost regional GDP.

Over time, these impacts are projected to increase substantially as population and traffic in the region grow. By 2045, under the Base Case transportation alternative the various congestion costs are forecasted as follows:

- Delay, Vehicle Operating, and Related Costs: over $1billion, or more than double of current cost;
- Reduction in Business Revenue: more than $1.7 billion, or three times of current cost; and

[2] Most costs in this report were estimated in 2011 dollars. However, for presentation purposes, the final results were adjusted to 2015 dollars.

[3] It is noted that while many of the specified congestion impacts and costs are measured in dollars, they are in general not additive because they measure different aspects of congestion and because of potential overlaps. Therefore, they are reported separately.

- Reduction in GDP: over $1 billion, or nearly triple of the current loss in GDP.

Implementing the Mayor's Plan for Transit and Transportation will temper these increases reducing the various cost measures by about one third to 40 percent compared to the Base Case.

Although congestion costs are often presented (including this report) as costs that characterize and affect regional economies by creating economic inefficiency costs, or various business costs, it should be emphasized that congestion imposes social costs and impacts that affect all local residents and households. For example, more time spent in traffic when commuting to/from work mean less time available for family and personal pursuits. Similarly, accident costs mean additional delays, and possibly lost personal productivity, pain and suffering. Business inefficiency cost can translate into reduced employment opportunities and consequently household income.

1. INTRODUCTION

Traffic congestion is commonly understood as a large number of vehicles on the road that result in an overall reduction in average speeds and longer travel times. It should be pointed out that some degree of traffic congestion is desirable as traffic brings people and businesses to certain destination points. However, excessive traffic is a problem in that lower average speeds slow down everyone. This results in excessive travel times and vehicle operating costs for commuting, business trips, and freight transportation.

There are various approaches to measuring congestion and estimating its costs. An "engineering approach" defines congestion as travel occurring at speeds slower than a certain threshold considered as acceptable average speed (for example 60%, or 50%, of free-flow speed).[4] The costs of congestion include then the loss of productive time and increases in fuel consumption, vehicle operating and related social costs such as air pollution and GHG emissions that result from lower average speeds.

An economic approach does not rely on a pre-defined speed. Instead it recognizes that there is an "optimal" volume of traffic and optimal amount of delay (i.e. an economically efficient level of congestion). This "optimum" is the traffic volume at which the benefit of the last marginal trip is equal to the cost of that trip. Additional trips beyond that optimum level are considered *excess* (or excess traffic), as they would generate more costs than benefits. The extent of net costs related to those additional trips – vehicle operating and time costs of driving and related social costs – constitute then the costs of congestion. From an economic point of view, it is thus the *excess* congestion, not the *total* congestion, which should concern policy makers and transportation planners. If congestion is above the efficient level, the efficiency of the transportation system and total economic welfare are reduced.

This study adopts the latter of the two approaches to measuring congestion and its costs and develops a methodology for their quantification.

Excess traffic is calculated based on the costs of driving (assumed to consist of a cash component and a time cost component), average actual speed, average posted speed, speed-flow relationship, and travel demand function. The methodology involves in its essence deriving the average cost function and the marginal cost function for the given travel demand function and travel costs, and finding such volume of travel at which marginal cost is equal to price (i.e. travel cost) that travellers pay. In congested conditions, the volume of travel at which marginal cost is equal to price is usually lower than the actual travel with the difference being the *excess traffic* that results in *excess congestion*. The costs related to the excess traffic over and above the benefits that they generate are then considered as congestion costs.

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[4] This is the approach adopted in a 2006 Transport Canada study. See: "The Cost of Urban Congestion in Canada", Transport Canada, Environmental Affairs, April 2006.

Congestion also has broader economic implications that go beyond the extra time and vehicle costs that people and businesses incur due to slow traffic. As an example, congestion erodes business productivity by impairing supply and distribution chains and increasing logistics costs. This is because congestion, by increasing both average travel times as well as travel time variability and unpredictability, inhibits the adoption and functioning of productivity-enhancing logistics and inventory management techniques. Collectively known as just-in-time (JIT) management systems, they permit a reduction in inventories and thus operating costs. By eroding the business case for investing in such systems, congestion can inhibit the adoption and efficacy of a whole category of modern productivity-enhancing management tools approaches.[5]

Longer and less predictable travel times also reduce the range of destinations that workers, firms and shippers can reach within an acceptable cost and an acceptable risk of being late. For workers, this limits the range of destinations available for job search and work. For shippers, congestion reduces the range of destinations for one-day return truck trips that can be made in compliance with trucking safety and time-out regulations. For firms, high commuting costs reduce their competitiveness in the labour market where the high commuting costs increase an employee's salary expectation above a level that a business can afford or is willing to pay. This is turn reduces the demand for labour and the number of available jobs.

In other words, in conditions of high congestion some commuting and commercial trips and some underlying economic activity may not be taking place because they are not economical or not practical.

This study develops a framework for quantification of these macro-economic costs of congestion in the form of business costs and lost business activity. This is in addition to quantification of excess traffic congestion in its economic sense and costs that could be attributed to it in the form of vehicle operating cost, time costs, and related social costs. The estimation framework of the macro-economic costs is built up from "structure and logic models", which represent in a flowchart or graph the causal relationships and underlying logic among the relevant factors. The models are grounded in economic theory, coded in a series of equations, and populated with input assumptions based on statistical data, and relevant published studies.

In addition to estimating the costs of "recurrent" congestion (that is, congestion that occurs predictably due to regular levels of traffic), estimates of "non-recurrent" congestion are provided here. These estimates are adapted from a 2006 study by Transport Canada[6].

While the Regional Transportation Model for Metro Vancouver and other regional metrics were used to guide the analysis, it should be noted that certain input assumptions in this analysis such as for the parameters of the cost and travel demand functions, or the industrial cost functions, represent reasoned assumptions guided by insights from economic literature, rather, than

[5] ICF Consulting and HLB (now HDR) Decision Economics, "Economic Effects of Transportation: The Freight Story", January 2002, page 4.

[6] See "Costs of Non-Recurrent Congestion in Canada", 11 December 2006, Transport Canada, Economic Analysis, TP14664E.

empirical estimates specific for Metro Vancouver. Therefore, the resulting estimates of travel delays and congestion costs should be interpreted as high-level or “order-of-magnitude” estimates.

The sections that follow present the conceptual framework for analyzing congestion costs, its implementation, data, and results for the current benchmark year of 2009 and for conditions forecasted to prevail in 2045 under the Base Case and under the Mayors’ Plan.[7]

The remainder of this report is organized as follows. Section 2 presents the traditional modeling of travel demand and travel costs under conditions of high traffic congestion, the concept of optimal traffic, excess congestion, and congestion cost referred to as the deadweight loss. Section 3 outlines the specific framework with functions and type of calculations that need to be preformed. Section 4 documents and discusses the data that was used in modeling and presents results for the benchmark year of 2009. Section 5 outlines the approach to extrapolation of current congestion costs into the future and presents the results. Finally, Section 6 provides an overall summary and interpretation of results.

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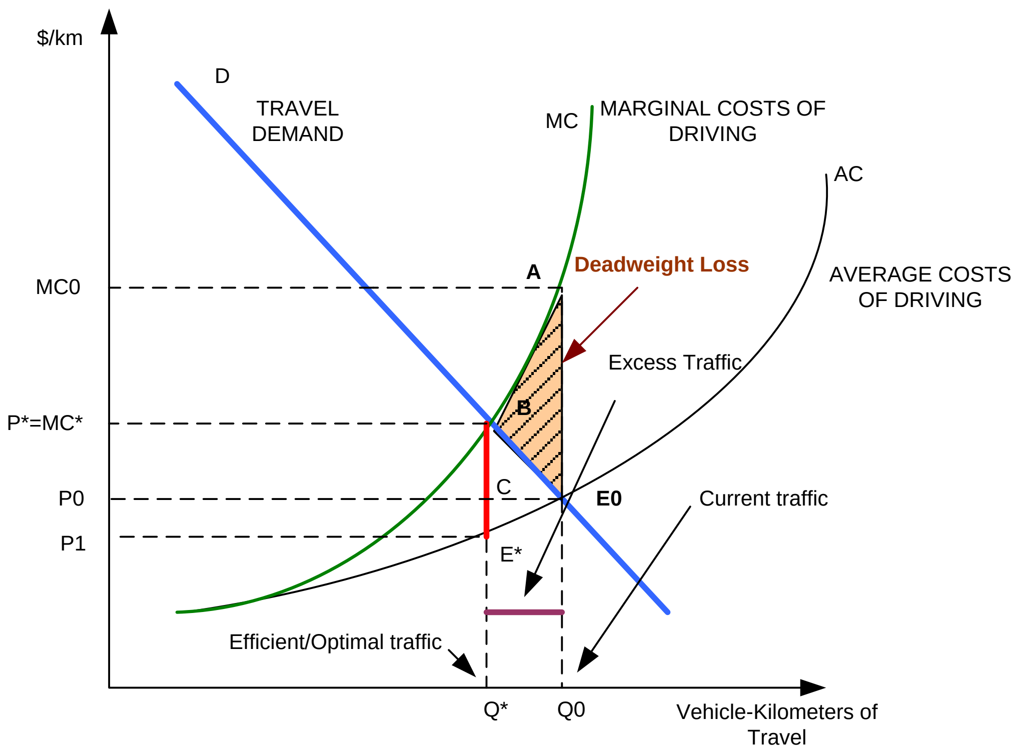
[7] Note that most costs in this report were estimated in 2011 dollars. However, for presentation purposes, the final results were adjusted to 2015 dollars by the Consumer Price Index inflation, about 6.1%.

2. ECONOMICS OF EXCESS CONGESTION

Figure 1 below presents the traditional modeling of travel demand and travel costs under conditions of high traffic congestion.

Figure 1: Approach to Estimation of Efficient Traffic Volume (VKT)



The figure shows the demand for travel (in terms of vehicle-kilometres travelled), as a function of the costs of driving. Drivers face a certain cost of driving which includes both car operating costs (gasoline, oil, maintenance, etc.) as well as time cost of driving. This cost increases as traffic on the road increases because more heavy traffic reduces the overall travel speed and thus increases the time cost of driving. The average private cost function is illustrated in Figure 1 by the curve labelled AC.

The curve labelled MC represents the marginal costs of driving, or the incremental costs of driving imposed by each additional vehicle entering the road. A key property of this relationship is that at higher levels of traffic, the same increment in traffic produces a greater cost increase for existing traffic. (In other words, the marginal cost increases at greater rates at higher levels of traffic). This is somewhat analogous to what happens when a person jumps to the front of a queue. The longer the line, the larger the number of people in the line behind the queue-jumper is who are delayed.

The market equilibrium, or the observed equilibrium, occurs at the traffic level that corresponds to the point where the average private cost of driving curve intersects the travel demand curve.

This equilibrium is represented by point E_0 and the corresponding private cost of driving P_0, and vehicle kilometres travelled Q_0.

The efficient traffic volume occurs at the traffic level that corresponds to the point where the marginal cost curve intersects the travel demand curve, Q*. This economically efficient level of congestion would result under the conditions of efficient congestions tolls (that induce some motorists to reduce their travel), or if motorists altruistically took the "external cost" they impose on other road users into account when making their travel decisions and reduced their travel accordingly. Any congestion above that level is excess congestion. In Figure 1, excess congestion is represented graphically by the distance Q^*Q_0.

The loss in economic welfare is referred to as the "*deadweight loss*". Technically, the deadweight loss is the amount by which the benefits of additional trips fall below their costs. This loss is a net loss of society's resources due to excess traffic. In Figure 1, the deadweight loss is represented by the triangular orange-shaded area ABE0, the difference between the benefits from the excess traffic area $Q^*BE_0Q_0$ and their costs captured by area Q^*BAQ_0.

The principles described above relate to recurrent congestion. Estimates of non-recurrent congestion presented in this report were adapted from Transport Canada's 2006 study, *Costs of Non-Recurrent Congestion in Canada*.

The next section discusses the specific framework adopted to quantify the congestion costs, inputs assumptions and results.

3. EXCESS CONGESTION COSTS FRAMEWORK FOR IMPLEMENTATION

The previous section outlined the general conceptual framework for analyzing congestion and identifying excess congestion. This section discusses the implementation. The specific manifestations of excess congestion quantified in this study include the following:

(1) Deadweight loss due to excess travel time and operating costs;
(2) Excess travel time to transit users;
(3) Excess emissions costs;
(4) Excess collision costs;
(5) Business inefficiency costs and reduction in regional economic activity, including:
   a. Reduction in regional GDP due to negative impacts of congestion on industrial costs and competitiveness, and
   b. Reduction in regional demand for labour due to increase in labour costs (due to higher employee expectations regarding their remuneration to compensate them for increased commuting costs).

Item (1), the deadweight loss, represents the most common exposition of excess congestion costs as illustrated in Figure 1. Items (2), (3) and (4) are not included in the deadweight loss but can be thought of as a consequence and extension of excess traffic. If a portion of traffic is considered wasteful and excess, so must be the emissions costs (air pollution and GHG emissions) and accident costs related to it as well as travel time of transit passengers caught in road traffic.

Item (5) represents another manifestation of congestion costs stemming from the observations that high congestion inhibits operations of industries that depend on the efficient and reliable transportation systems such as manufacturing and trade. Also, high congestion increases workers' salary expectations raising it above a level that some employers can afford, or are willing to pay. This leads to a reduction in demand for labour further reducing regional activity and GDP.

It should be noted that while Item (1), (2), (3) and (4), are additive to form the *total congestion costs/excess traffic effects*, Item (5) in general is not additive to those costs because of potential overlaps and because it measures different manifestations of congestion cost burden. The details of implementation are discussed below.

3.1. DEADWEIGHT LOSS

The quantitative magnitude of excess traffic as represented by distance Q*Q0 and the triangular area of deadweight loss ABE0 in Figure 1 can be derived using assumptions with respect to the average cost curve, marginal cost curve, and elasticity of travel demand and an iterative procedure outlined below.

- **Average costs of driving and average cost curve**

The average cost of driving per VKT is assumed to be equal to the cash costs of driving (variable costs that include fuel and maintenance) and time cost of driving. This cost can be expressed as:

$AC = c + b/v$,

where c is the cash cost of driving per VKT, b/v is the time cost of driving per VKT (b is the value of time, and v is the average speed). The cash cost of driving is assumed constant. However, the time cost of driving increases as the average speed falls.

The average actual speed is modeled using the speed-flow relationship commonly referred to as the BPR curve.[8] A speed flow relationship calculates the actual speed as a function of road congestion and speed in conditions of no congestion and no travel delays (referred to as "free-flow speed"). The speed-flow relationship used in this study is of the following form:

$v = v_0/[1 + 0.05(Q/CAP)^{10}]$, where

v = actual (congested) speed;
v_0 = free-flow speed;
Q = volume of travel, and
CAP = road capacity.

Note that volume of travel divided by road capacity is equal to the volume-to capacity (VC) ratio:

$Q/CAP = VC\_Ratio$

- **Marginal social cost curve**

The marginal cost curve is derived from the total cost curve as follows:

$TC = AC * Q$, where

TC = total social costs;
Q = volume of travel, and
AC = average private cost of driving shown earlier.

Then, using the definition of marginal costs as the differential of total costs and the expressions derived earlier we have:

$MC = \partial TC/\partial Q = AC + Q \cdot \partial AC/\partial Q$, and

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[8] Speed-flow relationship developed by the US Bureau of Public Roads (i.e. the BPR). The BPR curve is frequently used by economists in similar high-level traffic modelling.

$MC = c + b/v_0 \cdot [1+ 0.6 (Q/CAP)^{10}]$, where MC is the marginal cost.

- **Iterative procedure to estimate excess congestion**

The iterative procedure involves finding the intersection point between the marginal cost curve and the demand curve. Assuming a certain travel demand function, such as a constant elasticity demand function (with an assumed elasticity of travel volume with respect to travel costs)[9] and calibrating it so that it is consistent with the average cost curve, one can experiment with various levels of travel Q by plugging them in the demand curve and in the marginal cost curve to calculate the corresponding cost of driving shown on the vertical axis in Figure 1. When the results from the two calculations converge, equilibrium is achieved. The traffic level for which equilibrium is achieved represents the optimal traffic volume. The difference between the current market traffic volume and the optimal volume represents excess traffic.[10] The speed-flow relationship discussed above can then be used again to calculate the vehicle speeds corresponding to the optimal volume.

- **Calculation of Deadweight Loss**

The deadweight loss to the economy due to inefficient or excessive traffic volume (triangular area ABE_0) is equal to the difference between the area under the marginal cost curve and the demand curve between the optimal and the market traffic volume (Q^* and Q_0, respectively, based on notation used in Figure 1). Using the notation of that figure, the deadweight loss (DWL) can be derived as follows:

$$DWL = \int_{Q^*}^{Q0} MC\ dQ - \int_{Q^*}^{Q0} DEMANDdQ$$

Since marginal costs are defined as the differential of total costs with respect to quantity produced/consumed, it follows that the integral of marginal costs is equal to total costs at those particular quantities. Therefore, the first equation above can be continued as follows:

$$DWL = [TC(Q_0) - TC(Q^*)] - Q^* BE_0 Q_0 = [P_0 E_0 Q_0 0 - P_1 E * Q * 0] - (CBE_0 + CE_0 Q_0 Q^*) .$$

Comparing the areas listed in the above equation (and as illustrated in Figure 1), and carrying out the subtractions as indicated we obtain the following:

$$DWL = P_0 CE * P_1 - CBE_0$$

where

[9] Constant demand elasticity functions are frequently used by economists in similar modeling applications. Constant elasticity travel demand function expresses the idea that the volume of traffic changes by a certain constant percentage as the costs of driving change by 1%.

[10] This procedure can be easily adopted in MS Excel using the “Solve for” optimizer that are available with the standard version of Excel.

P_0CE*P_1 is the travel time savings to road users that remain on the road under efficient traffic conditions;

and

CBE_0 is the consumer surplus to road users who are using the roads under usual market conditions (i.e. unconstrained market conditions) but who would not be a part of the efficient traffic volume (i.e. who drop off).

- **Travel delays to existing traffic**

The optimal speed (at the optimal traffic level, Q*) calculated from the speed-flow function can also be used to calculate the delays to current traffic, or excess travel time at current speed as compared to the optimal speed. This can be interpreted as the value of travel time lost because current traffic moves at a speed that is slower than the economically efficient speed. This measure can be presented in addition to other measures of congestion although it should be noted that it is not additive with the other measures.

- **Disaggregating Deadweight Loss into Vehicle Costs and Delay Costs**

Deadweight loss is composed of two components that drive the cost of driving and consequently the deadweight loss: (1) excess vehicle costs, and (2) excess delay (or excess travel time). The two components of the deadweight loss can be approximated on the basis of share of time costs and vehicle costs in total costs in the equilibrium.

3.2. Excess Travel Time to Transit Users

The transit mode that can be expected to be affected by the general road congestion is primarily bus. The time cost of congestion to transit riders can thus be estimated on the basis of bus VKT, the actual speed and the optimal speed. The idea behind this approach is that the difference in implied vehicle hours that result under actual speed and the optimal speed represent the excess delay to transit users. This is then multiplied by the value of time and bus occupancy rate to obtain total value of excess delay to transit riders.

3.3. Excess Emissions Costs

Excess emissions costs can be estimated on the basis of unit emissions costs derived from the main model of transportation costs multiplied by excess traffic estimated at earlier steps. This estimate represents the emissions corresponding to traffic that is considered excess.

3.4. Excess Accident Costs

Excess accident costs can be estimated in a similar way as excess emissions costs on the basis of unit accident costs derived from the main model of transportation costs multiplied by excess traffic estimated at earlier steps. This estimate represents the accident costs corresponding to traffic that is considered excess.

3.5. Business Inefficiency Costs and Reduction in Economic Activity

This section develops a methodology for the assessment of industry-level macro-economic congestion impacts. We consider industries that appear particularly sensitive to congestion problems, including the following:

- Retail trade;
- Wholesale trade;
- Agriculture industry;
- Manufacturing industry;
- Construction; and
- Tourism-related industries.

The impacts measured are changes in industry revenue, operating costs, and employment, though not all of these impacts are estimated or considered for each industry.

The estimation framework is built up from "structure and logic models", which represent in a flowchart or graph the causal relationships among the relevant factors as well as the underlying logic. The models are grounded in economic theory and coded in a series of equations; values for parameter and variables in these equations are obtained from related published studies, statistical data series, local data, and other data sources. The graphical representation facilitates client and stakeholder evaluation of the model logic.

The models frequently utilize the concept of elasticity. As explained earlier in the context of elasticity of travel demand with respect to cost of driving, elasticity measures the sensitivity of response when one of the underlying driving factors changes. The response is measured in terms of percent change of the variable in interest when the driving factor of this variable changes by 1 percent. For example, elasticity of vehicle kilometres traveled with respect to cost of driving equal to -0.8 indicates that vehicle-kilometres of travel increase by 0.8 percent when the cost of driving goes down by 1 percent.

It should be noted that chronic traffic congestion induces certain adaptive responses that evolve only gradually over the long-run. Since these tend to be especially hard to model with much confidence, our analysis is largely limited to congestion's short-to medium-term impacts. For example, we do not estimate the inhibiting effects of congestion on the consolidation of wholesale operations with the resulting change in cost or employment structure.

The industry impacts are estimated for the entire Metro Vancouver region using the congestion impacts estimates. In order to account for possible mitigation of congestion costs impacts that are already taking place by using less congested links or shifting sensitive transportation trips to off-peak hours, all industry level costs calculated using average speed and delay on congested links are divided by two (or reduced by half).[11]

As in the case of travel delays and related impacts, all industry-level impacts are estimated for the current 2009 baseline.

- **Retail Trade Industry**

The impact of congestion on the retail industry could manifest itself in two types of effects, which are discussed in turn:

1. Effect on shopping habits, or behaviour, and number of shopping trips; and,
2. Effect on the costs of logistics and inventory held by shop owners.

Effect of congestion on shopping habits

The literature on the effects of travel times and traffic congestion in particular on shopping behaviour and retail sales in a geographic region is very limited, if not non-existent. Casual observations suggest that traffic congestion can affect at least the distribution of shopping and retail sales across a geographic region.

However, it seems that high traffic congestion can also impact the net number of shopping trips and retail sales. For example, in conditions of high congestion some individuals may be discouraged to go shopping for some discretionary purposes or items as they want to avoid aggravation and loss of time. The sales lost from that trip may not necessarily be recovered when the individuals go on their next shopping trip. A related marketing study found that consumers do combine multiple shopping purposes and destinations on one trip but the scope for this behaviour is considerably smaller than could be expected if shopping trips were planned based purely on travel cost minimization.[12]

We acknowledge here this possibility. However, in view of lacking general evidence on the issue, or insights from local data or a local transportation model on trip patterns under various travel costs and travel conditions, we treat this type of impact as somewhat speculative. Although retail shops in some congested areas in the region could be negatively affected by the current traffic situation, shops in other parts of the region may actually be benefiting in the form of a larger number of shoppers and revenues. The net effect on the industry in the entire region may well be close to zero. This issue would require more complex research that was not possible within the scope of this study. As a result, this effect is not estimated here.

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[11] It should be pointed out that the congestion impacts estimated here are based on industry level research on the role of logistics costs and their sensitivity to transit times. Given this role and sensitivities, businesses faced with high congestion and increased transit times may be expected to make some adjustments that mitigate costs.

[12] See Dellaert, Benedict, Theo Arentze, Michael Bierlaire, Aloys Borgers, and Harry Timmermans ((1998), "Investigating Consumers' Tendency to Combine Multiple Shopping Purposes and Destinations"; also published in *Journal of Marketing Research*, Vol. 35, No. 2 (May 1998), pp. 177-1888.

Effect of congestion on the costs of logistics and inventory in the retail industry
Congestion also can add to the logistics costs of local retailers by reducing travel speeds and the reliability of delivery times for merchandise and supplies. The literature indicates that in a wide range of industries these types of effects add to operation costs directly, and also indirectly, by inhibiting businesses from adopting inventory-saving strategies such as just-in-time inventory systems.[13]

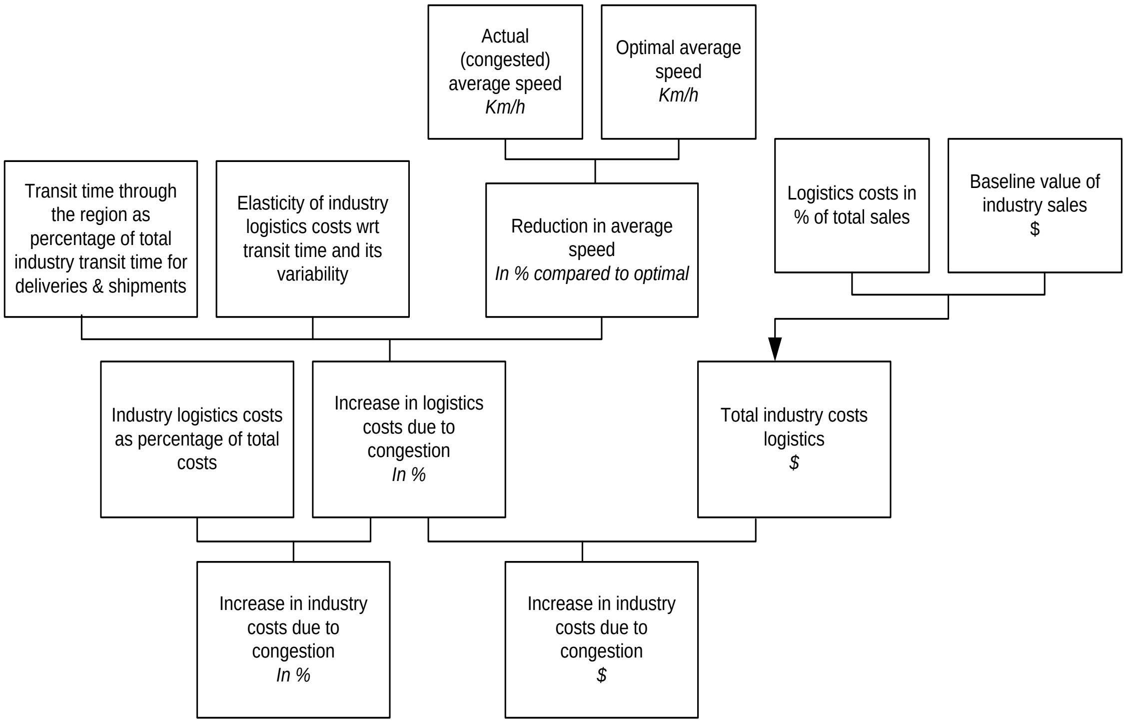
The overall increase in logistics costs can be estimated using information on the ratio of logistics costs to total sales of the sector, existing elasticity estimates of this cost item, and estimates of the increase in average delivery time resulting from congestion.

Figure 2 shows a general structure and logic of these costs. The difference between the actual congested speed and economically optimal speed is transformed into a percent reduction in actual speed compared to the economically optimal speed. This is combined with the industry's elasticity of logistics costs with respect to transit time to give an estimate of the increase in industry logistics costs. This calculation is adjusted by the percentage of the industry transit time for deliveries and shipments that take place in the region in order to capture the idea that transit through heavily congested road network within the region may account for only a fraction of total transportation distance and time.

The increase in industry logistics costs is, in turn, combined with estimates of industry logistics costs as percentage of total industry costs to give an estimate of the increase in industry costs.

[13] See for example: Freight Benefit-Cost Study, a report for Federal Highway Administration, Office of Freight Management and Operations, by ICF Consulting, HLB Decision Economics, and Louis Berger Group, July 2002.

Figure 2: Effects of Congestion on Industry Logistics Costs



- **Manufacturing Industry**

Traffic congestion impairs the operations of manufacturing businesses by adding to delays and reducing the reliability of deliveries of materials and components as well as shipments of finished products to markets. These effects tend to increase inventory and logistics costs by an amount than can be estimated in our model framework according to a similar approach as that illustrated in Figure 2.

In addition, the literature indicates that high congestion may reduce the market area for a firm's output, leading to a reduction in sales.[14] To illustrate this point, let's assume that congestion leads to an increase in production costs because a firm may have to purchase more expensive inputs and supplies from another location, increase its inventories, etc. An increase in production costs may require a firm to increase the price of its product, or make changes in the terms of delivery of a product. This in turn may reduce sales as buyers will be looking for less expensive alternatives. In some industries where final products are highly homogeneous, even a small price differential may induce switching to another supplier who offers a lower price. The reduction in sales (and possibly a reduction in economies of scale in production) results in a loss of output and business revenue.

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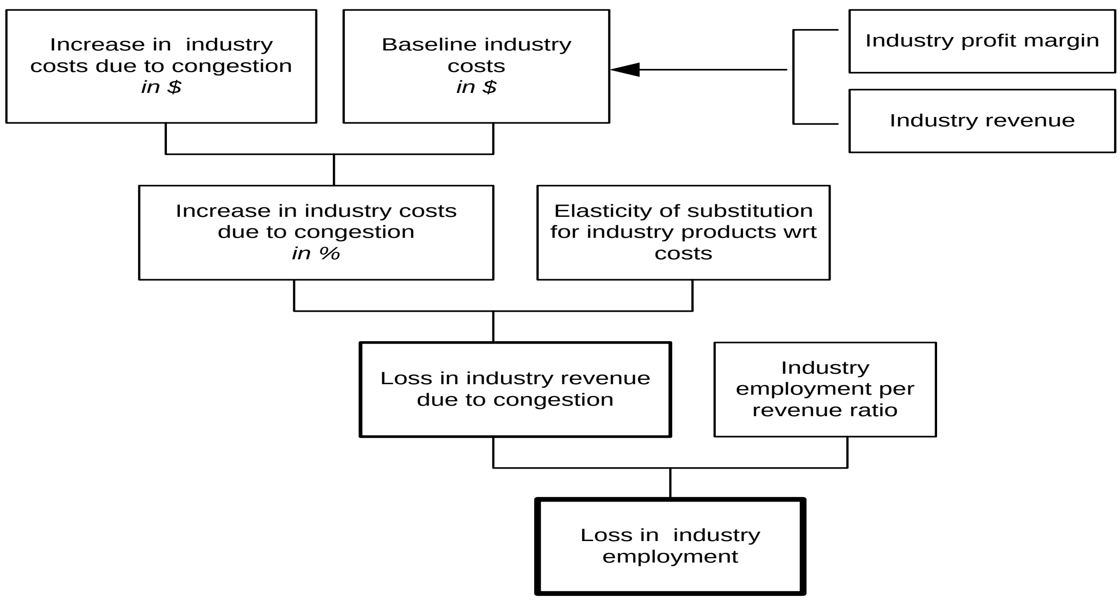
[14] See Weisberg G., D. Vary, and G. Treyz (2001) "Economic Implications of Congestion", NCHRP Report 463, Transportation Research Board, National Cooperative Highway Research Program.

In Metro Vancouver, transportation efficiency and reliability is also likely to play an extremely important role in the development and success of manufacturing.

The structure and logic diagram for the revenue loss is shown below in Figure 3. The increase in industry costs due to congestion estimated in earlier steps is transformed into a percentage increase based on the industry cost structure and is combined with the elasticity of substitution for that industry's products with respect to costs, to obtain an estimate of revenue loss due to congestion. The lost revenue is then combined with statistical industry employment per $1 million of revenue to estimate the resulting loss in employment.

Figure 3: Effect of Congestion on Revenues and Employment in the Manufacturing Industry



- **Construction**

Traffic congestion impairs the operations of construction businesses by adding to delays in deliveries and reducing reliability of the transportation network. Again, these effects add to inventory and logistics costs by an amount than can be estimated in our model framework and using similar approach as that laid out in Figure 2. Note that revenue impacts are not estimated for the construction industry. This is because of two reasons. First, construction may be expected to be affected much less by buyers' decisions not to buy when its costs increase than is the case for the manufacturing industry. While the manufacturing industry in a location may be competing intensively with manufacturing industries in other locations due to a high degree of substitution of many manufactured goods, construction activities and their products in one location are not substitutable in the same way with construction activities and products from another location. Second, the data for this industry that would allow to populate similar functional relationships was not available.

- **Wholesale Industry**

For the wholesale industry, congestion, reduced average speeds, and less reliable delivery times will push up inventory levels and logistics costs. This effect can be estimated using an approach similar to that shown in Figure 2.

In addition, the industry may also suffer from congestion indirectly, through the adverse effects on sales in retail trade, manufacturing, and other industries from which the wholesale industry draws business. The wholesale trade can be seen, however, as further down the production/supply chain and a buyer of manufactured and other products, which means that including these indirect impacts on the industry's revenues would involve some double-counting. In addition, the empirical evidence for the industry that would allow to populate the functional relationships was not identified. Therefore, this indirect effect of congestion on wholesale trade revenue is omitted here.

- **Agriculture Industry**

Traffic congestion impairs the operations of agricultural businesses by adding to delays, adding to delivery times, and reducing the reliability of deliveries of production inputs and final products to consumer markets. This may lead to a direct increase in industry logistics, warehousing, and transportation cost by inhibiting cost-saving innovations in storage and transportation management.

In addition, as in the case of the manufacturing industry, higher logistics costs and longer delivery times may induce some buyers to switch to an alternative supplier who can provide the product at a lower cost and deliver it within a shorter period of time. The NCHRP report cited earlier found that the scope for product switching in the agriculture business is particularly high due to the highly homogenous nature of these products.[15]

Both the logistics cost and the output effect of excess congestion discussed above can be estimated using similar approaches and logic models as those for the manufacturing industry.

- **Tourism and Tourist Expenditures Impacts**

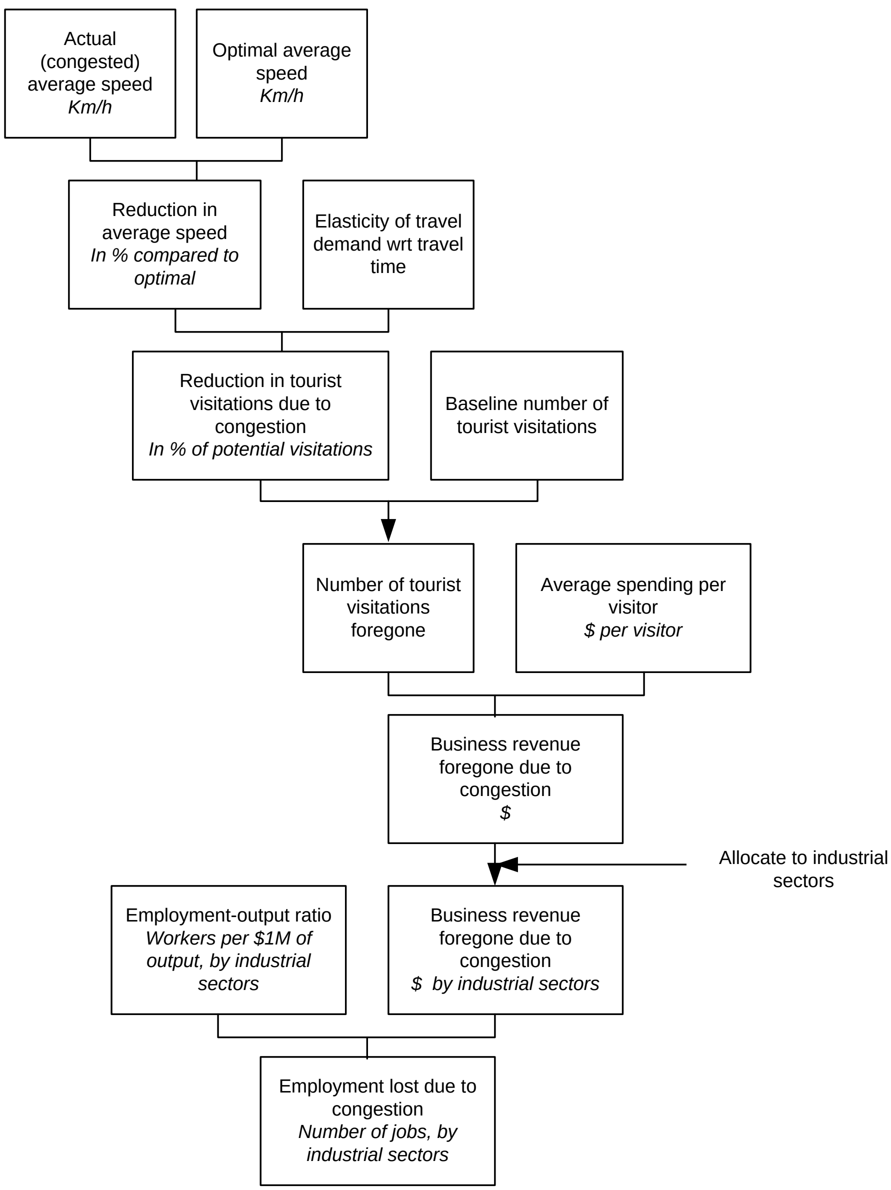
Traffic congestion also increases travel times and stress for tourists. It seems intuitive that they would not want to spend excessive time in traffic and thus that they may be discouraged from coming to a congested geographic area. Although congestion in a particular geographic area may account only for a small portion of the entire trip, there is evidence that delays in some key congestion points or bottlenecks may discourage travel. For example, studies report that delays and waiting times at border crossings reduces the number of cross-border trips.[16] Although direct evidence for Vancouver is not available, it seems reasonable to anticipate similar mechanisms for Vancouver as well.

[15] See Weisberg G., D. Vary, and G. Treyz (2001) “Economic Implications of Congestion”, NCHRP Report 463, Transportation Research Board, National Cooperative Highway Research Program

[16] See for example *Economic Impacts of Wait Times at the San Diego-Baja California Border*, report prepared by HDR|HLB Decision Economics for San Diego Association of Governments and California Department of Transportation (District 11), January 19, 2006 and other studies reported there.

Figure 4 shows the approach to estimation of these effects. The approach is based on the estimate of speed reduction and elasticity of tourist visits to a geographic area with respect to travel time. This gives an estimate of the reduction in tourist visitations. This is then combined with the average spending by tourist on local goods and services to obtain an estimate of revenues, by industry, lost due to congestion. This method was applied to estimate reduction in revenues for the retail, accommodation and food services, arts and entertainment, and transportation sectors.

Figure 4: Effect of Congestion on Tourism



- **Impact on Labour Demand**

Excess congestion increases workers' commuting costs, including the cost of their own time spent in traffic. Since workers factor these costs into their choices of where to work, increased congestion may force employers to remunerate more generously to attract the workers they need. In some cases, the salary that would be sufficient to compensate for a long commute will be more than the employer can afford. In this case, employers may have to scale down their employee expansion plans, or devote more resources to recruitment, or settle on less suitable employees, with a consequent decrease in labour demand, labour productivity, or both. Congestion on a region's roads, particularly unanticipated congestion, can also have other consequences for employers, such as when an employee misses a meeting because of a traffic jam while en route to work. There is some empirical evidence (although limited and with some qualifications) indicating that employers are sensitive to these delays and costs.

After reviewing the limited evidence on the relationship between pay and commuting costs, NCHRP Report 463 assumed for a modeling exercise similar to this one that in the long run, higher pay offsets half of any increase in commuting costs in a metropolitan region.[17] Using this assumption and the excess commuting delay cost per employee calculated in earlier steps, one can estimate the average commuting cost per employee absorbed by local employers in the form of higher salaries. This can then be compared with the average labour costs (salaries plus benefits) in the region to calculate the percentage increase in average labour costs due to congestion. This can then be combined with the elasticity of demand for labour with respect to labour costs to calculate the percentage reduction in labour demand. Applying this percentage to the current employment data, one can estimate the reduction in employment due to congestion in absolute terms. These effects are illustrated graphically in Figure 5.

As mentioned earlier, excess commuting costs can, in addition to forcing up the cost per worker, reduce worker productivity, but evidence on the magnitude of this effect is lacking. NCHRP Report 463 simulated region-wide reductions in commuting travel time for the Chicago and Philadelphia metropolitan areas and found the effect on labour productivity to be very small relative to the straight change in labour cost (though this may partly have stemmed from the limitations of their model). Therefore, this effect – as somewhat speculative – is not estimated here.

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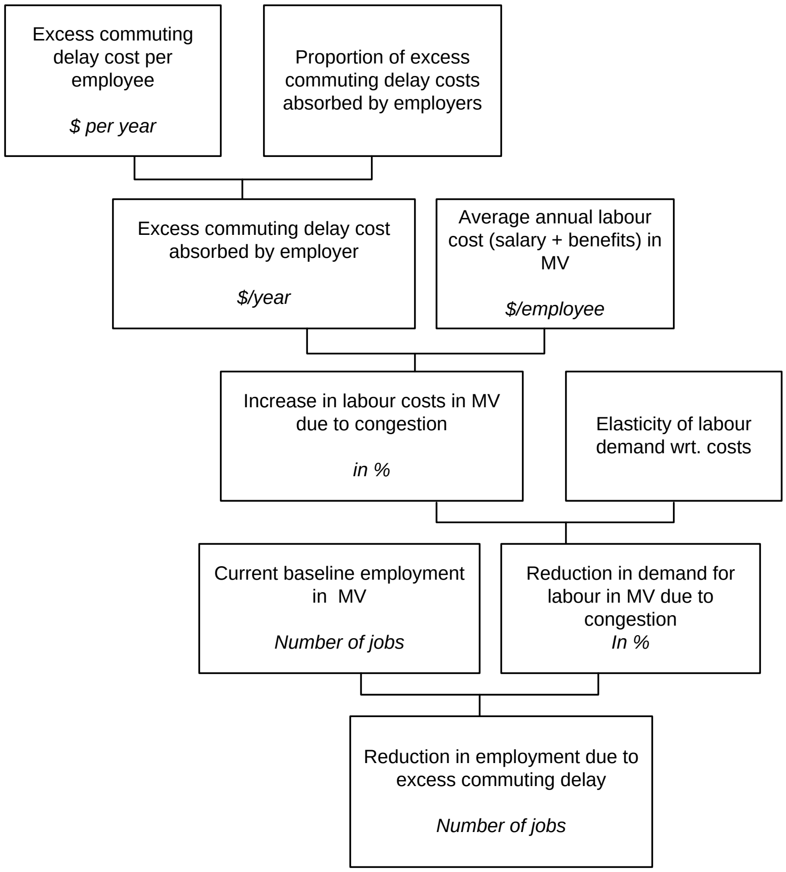
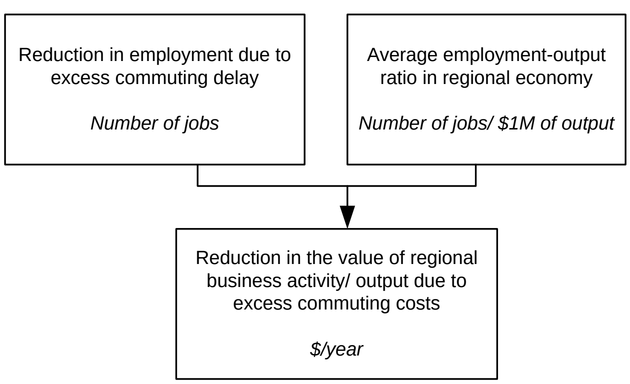
[17] Weissbrod, G., Vary, D. and Treyz, G. 2001. *Economic Implications of Congestion*, National Cooperative Highway Research Program Report 463, National Academy Press, Wash., D.C., 2001, esp. pp. 16, 26 (also available at: gulliver.trb.org/publications/nchrp/nchrp_rpt_463-a.pdf).

Figure 5: Estimation of the Impact of Congestion on Labour Demand



One could, however, continue the logic illustrated in Figure 5 and argue that reduced employment also results in lost business activity and lost business output or revenues. This effect is illustrated graphically in Figure 6.

Figure 6: Estimation of Business Output Lost due to Congestion



3.6. NON-RECURRENT CONGESTION COSTS

In addition to recurrent congestion costs described above in section 3.1, travelers typically budget extra travel time to allow for delays caused by random events that occur due to traffic incidents such as stalled vehicles, spills, construction, inclement weather, etc. A 2006 Transport Canada study estimated these costs for Vancouver at between $354 million and $488 million in 2000 dollars.[18] Inflating these figures to 2015 dollars gives a cost between $470 million and $650 million. These results were adapted for inclusion in this study. In order to account for methodological differences between this study and Transport Canada study, only a portion of these costs was assumed to represent *excess* non-recurrent congestion. That portion, or fraction, was assumed equal to the share of excess traffic in total peak traffic (about 9% currently; 11% and 9% in 2045 under the No Investment and Mayors' Plan scenarios, respectively).[19]

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[18] "Costs of Non-Recurrent Congestion in Canada", 11 December 2006, Transport Canada, Economic Analysis, TP14664E, Table 24, page 55. The ranges of estimated costs correspond to the threshold of reduction in average speed below which traffic is considered to be congested. The thresholds were defined in terms of 50%, 60% and 70% reduction in average speed relative to free flow speed.

[19] For this calculation, the mid-range non-recurrent congestion cost was used. This cost amounted to $435 million in 2000 dollars, or $579 million in 2015 dollars.

4. DATA, INPUT ASSUMPTIONS AND ESTIMATED CURRENT CONGESTION COSTS

4.1. DEADWEIGHT LOSS, EXCESS ACCIDENT COSTS, EXCESS EMISSIONS COSTS, AND EXCESS TRANSIT DELAY COSTS

The method of estimating congestion costs described above was applied independently to three types of roadways in the region: Low, Medium and High Volume + Capacity. Table 1 describes the inputs to the calculations for each of the facility types.

The travel demand function was assumed to be represented by a constant elasticity function. The key parameter of this function, the elasticity of traffic volume with respect to total generalized travel costs (including cash costs and time costs of driving) was assumed equal to -0.5. [20]

The cash costs of driving assumed to affect the driving decisions were assumed to include fuel costs (with tax) and maintenance cost. These costs were estimated under the Auto Operating Costs and Truck Operating Costs components of the cost model. For autos, this cost amounted to $0.17 per km. For trucks, data on vehicle maintenance costs was available only combined with other vehicle costs, including depreciation and financing, as “other vehicle operating cost”. Vehicle maintenance was assumed at one third of those costs. Together with fuel costs, truck costs of driving amounted then to $0.76 per km. The weighted average of the two figures (with weights based on the share of trucks and autos in their combined traffic volume) assumed for the analysis amounted to $0.21 per km.

Value of time and average speed were the same as discussed earlier in this report. Value of time for trucks was assumed at the same value as that for autos. In addition, value of time for autos was adjusted for (or multiplied by) the average vehicle occupancy to reflect the idea that vehicle passengers also suffer the consequences of congestion. The weighted average of value of time for autos and trucks (with the same weights as for vehicle costs) amounted to $16.69 per hour.

The table shows that deadweight loss is estimated at $220.79 million. In addition, excess accident costs amount to $121.96 million, excess emissions costs amount to $15.78 million, and excess transit travel time amounts to $48.49 million. Total costs of congestion are thus estimated at $407.02 million.

[20] Travel demand is known to be rather inelastic, i.e. when travel costs increase by 1% (decrease by 1%), the volume of travel is reduced but by less than 1% (increased by less than 1%). The demand elasticity for travel of -0.5 means that when travel costs increase by 1%, VKT are reduced by 0.5%. This represents a relatively responsive (or relatively elastic) travel demand function assumed here due to availability of a good public transit system

Table 1: Summary of Key Input Data for Calculation of Deadweight Loss and Results

	Facility Type (Volume and Capacity)			
Data Item	**Low**	**Medium**	**High**	**Source and Comments**
Key Inputs				
Peak period VKT, millions	1,325	2,116	3,716	Based on the Regional Transportation Model (INRO's EMME/3 model)
Baseline congested speed - V (km/h)	35.3	42.2	64.1	2011 EMME output; average speed.
Average free-flow speed	50	56	67	Based on data provided by Translink. Reflects average posted speed on major arterials and highways.
Value of time, weighted average truck and autos ($/h)r	$16.69			Calculated by HDR based on the value of time of $13.02 per person per hour, average auto occupancy of 1.46 and truck traffic share of 9.8%.
Cash cost of driving ($/km)	$0.21			Calculated by HDR from cost model inputs (fuel and maintenance); weighted average of auto and truck costs.
Coefficient in BPR curve	0.05			From 'Updated BPR Curve' (www.mtc.ca.gov/maps_and_data/datamart/research/boston1.htm) Congested Speed = (Free-Flow Speed)/(1+0.05[volume/capacity]^10)
Exponent in BPR curve	10			
Implied volume-to-capacity (VC) ratio, baseline - VC_0	1.24	1.21	0.99	Calculated from the BPR curve. Based on observed speed under congestion in relation to BPR curve
Elasticity of travel demand	-0.5			Reasoned assumption.
Average cost of driving (AC) under initial conditions, $/km	$0.683	$0.605	$0.470	Calculated from cost model inputs.
Average cost of driving (AC) under optimal traffic conditions, $/km	$0.57	$0.53	$0.46	Calculated from cost model inputs.
Accident costs, $/VKT	$0.179			Calculated by HDR from cost model inputs; weighted average of auto and truck costs.
Air pollution costs, $/VKT	$0.023			Calculated by HDR from cost model inputs; weighted average of auto and truck costs.
Intermediate Results				
Excess travel time of current traffic, $ M (2011 Dollars)	$142.69	$154.83	$19.61	Calculated from cost model inputs.
Excess traffic, VKT Millions	183	275	224	Calculated from cost model inputs.
Optimal traffic, millions of VKT	1,141	1,841	3,492	Calculated from cost model inputs.
Proportion of Peak VKT that is excess	14%	13%	6%	Calculated from cost model inputs and results. Used to estimated non-recurrent congestion.
Final Results				
Deadweight loss, $ M (2011 Dollars)	**$101.2**	**$108.1**	**$11.5**	
Excess accident costs, $ M (2011 Dollars)	**$32.8**	**$49.1**	**$40.0**	

Excess emission costs; $ M (2011 Dollars)	**$4.2**	**$6.4**	**$5.2**	
Transit excess travel time, $ M (2011 Dollars)	**$21.8**	**$23.7**	**$3.0**	
Total Costs of Congestion, $ M (2011 Dollars)	**$160.06**	**$187.29**	**$59.67**	Sum of the cost components above.
	$407.02			

4.2. Business Inefficiency and Reduction in Economic Activity

- **Impact on Industrial Costs and Competitiveness**

Estimation of the impact on industrial competitiveness is based on the estimates of regional business activity and congestion measured by the ratio of actual speed to free flow speed. The regional business activity is estimated on the basis of labour force statistics by industry (from 2011 National Household Survey) combined with employment-output ratios from Statistics Canada Input-Output Model. An employment-output ratio gives the number of employees required for $1 million of output (or gross revenues). Therefore, dividing total employment in an industry by the corresponding input-output ratio gives an estimate of business output in a region.

Business output can also be multiplied by other input-output ratios to obtain other measures of economic activity. For example, GDP per $1 million of output ratio can be used to estimate the regional GDP. Table 2 shows the selected multipliers by industry. The bottom row in the table shows the weighted average metrics which are used in further analysis.

Table 2: Selected Direct Input-Output Multipliers/Ratios from Statistics Canada's Input-Output Model

Industry (with NAICS Code)	Supplementary Labour Income, Per $1 of Output	GDP; Per $1 of Output	Full-Time Equivalent Jobs, Per $1 M of Output
11 Agriculture, Forestry, Fishing and Hunting	0.03	0.44	6.38
21 Mining and Oil and Gas Extraction	0.01	0.77	0.71
22 Utilities	0.03	0.75	1.78
23 Construction	0.02	0.40	4.91
31-33 Manufacturing	0.05	0.36	3.63
41 Wholesale Trade	0.04	0.63	7.97
44-45 Retail Trade	0.05	0.66	12.15
48-49 Transportation and Warehousing	0.05	0.38	4.62
51 Information and Cultural Industries	0.04	0.63	4.11
52 Finance and Insurance	0.01	0.76	1.29
53 Real Estate and Rental and Leasing	0.01	0.76	1.29
54 Professional, Scientific and Technical Services	0.03	0.62	9.26
55 Management of Companies	0.01	0.76	1.29

56 Administrative, Support, Waste Management Services	0.04	0.65	14.96
61 Educational Services	0.06	0.74	22.82
62 Health Care and Social Assistance	0.04	0.65	11.50
71 Arts, Entertainment and Recreation	0.03	0.52	11.83
72 Accommodation and Food Services	0.03	0.50	12.98
81 Other Services (except Public Administration)	0.03	0.69	17.79
91 Public Administration	0.09	0.60	7.49
Weighted Average (with weights equal to the share of employment)	**0.125**	**0.59**	**5.49**

Source: Statistics Canada, Inter-Provincial Input-Output Model, British Columbia, Small Aggregation, 2008 Estimates

Table 3 shows employment and estimated output in the region.

Table 3: Employment and Output in Metro Vancouver

Industry	Employment, Workers 15 Years+	Direct Employment-Output Ratio, Jobs/$1 Million, Adjusted to 2009	Estimated Industry Output, $ Millions, 2009 Dollars
Total – Industry (NAICS) (3)	**1,167,174**		**$208,011.92**
11 Agriculture, Forestry, Fishing and Hunting	11,641	6.38	$1,824.94
21 Mining and Oil and Gas Extraction	4,643	0.71	$6,507.56
22 Utilities	6,843	1.77	$3,856.60
23 Construction	77,492	4.91	$15,795.59
31-33 Manufacturing	74,838	3.63	$20,641.98
41 Wholesale Trade	55,392	7.97	$6,953.45
44-45 Retail Trade	123,978	12.14	$10,211.94
48-49 Transportation and Warehousing	62,881	4.62	$13,620.20
51 Information and Cultural Industries	41,267	4.10	$10,056.06
52 Finance and Insurance	57,440	1.29	$44,558.60
53 Real Estate and Rental and Leasing	30,395	1.29	$23,578.76
54 Professional, Scientific and Technical Services	110,536	9.25	$11,947.94
55 Management of Companies and Enterprises	1,600	1.29	$1,240.80
56 Administrative and Support, Waste Management and Remediation Services	52,106	14.95	$3,485.75
61 Educational Services	85,792	22.80	$3,762.10
62 Health Care and Social Assistance	115,037	11.49	$10,013.10
71 Arts, Entertainment and Recreation	28,017	11.82	$2,369.51
72 Accommodation and Food Services	88,927	12.97	$6,854.87
81 Other Services (except Public Administration)	56,551	17.77	$3,181.66
91 Public Administration	56,538	7.49	$7,550.48

Source: Employment is estimated from 2011 National Household Survey data on labour force in 2010. Total labour force is reduced by the unemployment rate (assumed equal in all industries) to obtain employment figures for 2010. This is then further reduced by the employment growth rate from 2009 to 2010 from Labour Force Survey to obtain estimates of employment. Employment-Output ratios are taken from the respective input-model and adjusted to 2009 by dividing by the inflation rate between 2008 and 2009.

Estimates of economic activity are then combined with assumptions regarding the magnitude of logistics costs (as percentage of total sales) and elasticities of these costs with respect to transit times. These assumptions were sourced from the related literature. [21] In a further step, elasticity of industry revenues with respect to costs (i.e. the extent to which industry revenue falls when the costs of its products increase[22]) was used together with costs estimates to derive the loss in industry revenue and employment. The key input assumptions are shown in the table below.

Table 4: Key input Assumption for Estimation of Industrial Impacts

Data Item	Value	Source
Logistics costs as percentage of sales		Freight Benefit-Cost Study
Retail Trade	2.5%	
Other Industries	5%	
Elasticity of logistics costs wrt to transit time	0.27	Freight Benefit-Cost Study
Elasticity of industry revenues wrt costs (elasticity of substitution for industry products)		NCHRP Report 463, Table 5.3
Manufacturing	7	
Agriculture	11	

To estimate the impacts on tourist visitations as discussed earlier, the number of tourist visits was calculated as total tourist expenditures divided by the average expenditure per tourist visit. The average expenditure per tourist visit and total expenditures (by category) were taken from statistical data reported on Tourism Vancouver website. Based on that data, in 2009 there were 8,191,398 person visits to Metro Vancouver, and the average expenditure per person visit amounted to $429.63. The elasticity of tourist visits with respect to travel time was sourced from the literature, and the employment-output ratios were taken from input-output data.

Table 5 below shows the estimated impact of congestion on industries across the Metro Vancouver region. Note that not all effects were estimated for all industries. In particular, tourist expenditure impacts do not include increase in industry costs as the essence of this category of impacts is a reduction in expenditures with resulting reduction in revenues of various businesses.

[21] "Freight Benefit-Cost Study", a report for Federal Highway Administration, Office of Freight Management and Operations, by ICF Consulting, HLB Decision Economics, and Louis Berger Group, July 2002.

[22] Glen Weisbrod, Donald Vary, and George Treyz "Economic Implications of Congestion", National Cooperative Highway Research Program (NCHRP) Report 463, 2001.

Under the competitiveness impacts, reduction in revenue was estimated only for the manufacturing and agricultural industries. This is because of lack of empirical evidence for other industries as well as different nature of these industries and likely lower substitution options of their buyers.

The table shows that the impact across all industries considered in this assessment includes an increase in industry costs of $18.58 million, a reduction in revenue of $51.2 million and a loss of 317 jobs.

Table 5: Estimated Industry-Level Impacts of Congestion in Metro Vancouver

Industry	Increase In Industry Costs ($ Millions)	Reduction In Industry Revenues ($ Millions)	Reduction In Industry Employment (FTE Jobs)	Reduction In GDP ($ Millions)
Industry Costs and Competitiveness Impact				
Retail Trade	$3.36			
Construction	$10.38			
Manufacturing	$3.39	$26.72	93	$9.50
Wholesale Trade	$1.14			
Agriculture	$0.30	$3.80	23	$1.66
Tourists Expenditures Impacts				
Retail Trade		$3.62	8	$0.47
Accommodation and Food Services		$12.91	161	$6.51
Arts and Entertainment		$1.90	22	$0.99
Transportation		$2.25	10	$0.86
TOTAL	**$18.58**	**$51.20**	**317**	**$20.00**

- **Impact on Labour Demand**

The average excess delay per car commuter was calculated from the excess delay estimates experienced by the current motorists as shown in Table 6 divided by the number of employees commuting to work by car across the region extracted from the 2011 National Household Survey data. The magnitude of delay per employee estimated in this way amounted to $257 per employee per year. The 2006 Census data was used to extract information on median salary in the region. This data was then adjusted for salary growth until 2009 and inflation until 2011. As mentioned earlier, it is assumed that half of the delay cost per employee is absorbed by the employer (and the other half by the employee), and that the elasticity of demand for labour is equal to 1.

Table 6 shows the estimated impacts which include a reduction in employment of 2,672, reduction in regional business activity in the amount of $507 million, and reduction in regional GDP of $301 million. The impact on GDP is estimated by multiplying the reduction in industry revenues by the average weighted GDP to business output ratio for the region ($0.58 per $1 of business revenue, as shown in Table 2).

Table 6: Labour Demand Impacts of Excessive Congestion in Vancouver

Metric of Impact	Value
Reduction in employment due to excess commuting costs (jobs)	2,672
Reduction in the value of regional business activity, $ millions ($2011)	$506.61
Reduction in regional GDP, $ Millions ($2011)	$300.58

4.3. Summary of Current Congestion Costs

Table 7 below provides a summary of estimated current congestion costs in Metro Vancouver for key congestion cost metrics. The table shows that the costs of delay and related excess traffic effects (excess time, vehicle costs, accidents, and emissions) amount to about $407 million and the lost GDP amounts to nearly $321 million.

Table 7: Summary of Current Congestion Costs in Metro Vancouver

Congestion Cost Metric	Current Annual Cost ($2011, Millions)
Cost of Road Congestion (Delay and Related Excess Traffic Effects)	$407.16
Deadweight Loss (Time and Vehicle Costs to Motorists)	$220.86
Time Cost - transit riders	$48.50
Accidents	$122.02
Vehicle Emissions	$15.79
Industry Congestion Impacts	
Reduction in Business Revenue	$557.8
Reduction in Employment	2,989
Reduction In Regional GDP	$320.58
Impact on Industrial Competitiveness	$20.00
Impact on Labour Demand/Employment	$300.58

5. CONGESTION COST MODEL EXTENSION TO 2045

As for the 2009 costs, excess congestion costs (above economically optimal or justified level) were estimated in the form of (1) excess traffic, deadweight loss, and corresponding metrics, and (2) industrial costs of congestion in the form of reduction in employment, GDP, industry output, or increase in industry cost. The two elements were estimated in two separate sub-models. The approach for estimation of these costs for 2045 is briefly discussed below

5.1. METHODOLOGICAL APPROACH TO ESTIMATION OF CONGESTION COSTS IN 2045

Excess Traffic, Deadweight Loss and Related Costs

Excess road congestion costs are estimated using the 2009 congestion cost model, assuming the same key parameters such as value of time, elasticity of demand and parameters of the speed-flow relationship. The model is then run with inputs specific for each alternative such as traffic volume and actual (or estimated as the baseline for each alternative) congested speed to estimate all congestion costs metrics.

Industrial Costs of Congestion

The approach leverages the 2009 model of industry congestion costs model by calibrating the parameters pertaining to the overall economy to the 2045 conditions (based on forecasted rates of growth in employment, GDP, employment income, and tourist visits). The input assumptions pertaining to various elasticities are assumed to remain unchanged.

The labour demand impacts (reduction in employment and GDP) are then simulated for the 2045 base case and each strategic transportation alternative using the estimate of excess commuting cost per employee from the road congestion cost model.

Industry congestion impacts are estimated first for the 2045 Base Case using estimates of actual congested speed in 2045 and optimal speed implied by the road congestion cost model. The costs for the various alternatives are then extrapolated from the Base Case costs using the increase in speed under each alternative as compared to the Base Case reduction.

Non-Recurrent Congestion

Estimates of non-recurrent congestion costs for 2045 were estimated by growing Transport Canada's estimate of current costs according to projected growth in peak VKT, and multiplying by the proportion of peak VKT expected to be excess under each scenario (11% in the No Investment scenario and 9% under the Mayors' Plan).

5.2. ESTIMATED CONGESTION COSTS IN 2045

Table 8 and Table 9 report the results pertaining to road congestion and industrial (or overall economy) congestion costs for the Base Case and Mayors' Plan. Table 10 provides a summary of estimated congestion costs in the same format as Table 7 so as to facilitate comparison with results for 2009.

The tables show that the Mayors' Plan achieves a significant reduction in congestion costs as compared to conditions that would prevail under the Base Case.

Table 8: Excess Road Congestion Costs, by Strategic Transportation Alternative

		Base Case	Mayors' Plan
Optimal Traffic, M VKT	Facility Type 1	1,536	1,393
	Facility Type 2	2,466	2,154
	Facility Type 3	4,909	4,139
Optimal Speed, km/h	Facility Type 1	43.0	43.6
	Facility Type 2	50.5	51.7
	Facility Type 3	64.7	65.8
Proportion of peak VKT projected to be "excess"		11%	9%
Cost (Deadweight loss)) $M 2011 Dollars	Motorist Costs (time+operating)	$601.35	$379.62
	Time Cost - transit riders	$129.35	$92.64
	Accidents	$201.96	$145.94
	Vehicle emissions	$8.80	$5.97
	TOTAL	**$941.46**	**$624.18**
Weighted Average Peak Period Speeds , km/.h	Congested	48.5	51.3
	Optimal	56.7	57.4
Excess Delay	Total Excess Delay, $M 2011 Dollars	$841	$533

Table 9: Industry Congestion Impacts, by Strategic Transportation Alternative

Congestion Cost Metric	Base Case	Mayors' Plan
Industry Congestion Costs Impacts		
Increase in Industry Costs, $ Millions	$109.7	$80.4
Reduction in Industry Revenues, $ Millions	$181.3	$133.0
Reduction in Industry GDP, $ Millions	$72.5	$53.2
Reduction in Industry Employment, FTE Jobs	665	487
Labour Demand Impacts due to Commuting Costs		
Reduction in Revenues, $ Millions	$1,478.4	$850.1
Reduction in Regional GDP	$877.2	$504.4
Reduction in Employment, FTE Jobs	4,245	2,441
Total Industry Impacts		
Increase in Industry Costs, $ Millions	$109.7	$80.4
Reduction in Revenues, $ Millions	$1,659.8	$983.0
Reduction in Industry GDP, $ Millions	$949.7	$557.6

Reduction in Industry Employment, FTE Jobs	4,910	2,928

Table 10: Summary of Projected 2045 Congestion Costs in Metro Vancouver for Key Metrics ($2011, Millions)

Congestion Cost Metric	Base Case	Mayors' Plan
Cost of Recurrent Road Congestion (Delay and Related Excess Traffic Effects)	$941.46	$624.18
Deadweight Loss (Time and Vehicle Costs to Motorists)	$601.35	$379.62
Time Cost - transit riders	$129.35	$92.64
Accidents	$201.96	$145.94
Vehicle Emissions	$8.80	$5.97
Cost of Non-Recurrent Congestion	$83	$56
Total Cost of Congestion	$1,024	$680
Industry Congestion Impacts		
Reduction in Business Revenue	$1,659.8	$983.0
Reduction in Employment	4,910	2,928
Reduction In Regional GDP	$949.7	$557.6
Impact on Industrial Competitiveness	$72.5	$53.2
Impact on Labour Demand/Employment	$877.2	$504.4

6. STUDY SUMMARY AND INTERPRETATION OF RESULTS

This study quantified current costs of congestion in Metro Vancouver (for a benchmark year of 2009) and projected into the future in 2045 under various strategic transportation alternatives. Table 11 provides a summary of the estimated costs for key metrics reported in previous sections and adjusted to 2015 dollars.[23]

For presentation purposes, the quantified costs were grouped under two broad cost categories that represent various manifestations of congestion costs, or various perspectives on congestion impacts:

1. Delay, vehicle operating, and related costs. Costs of recurrent congestion include (1) deadweight loss due to excess travel time and vehicle operating costs, (2) excess travel time to transit users, (3) excess emissions costs, and (4) excess collisions. Costs of non-recurrent congestion are summed with non-recurrent costs for total congestion costs.
2. Business inefficiency costs and reduction in economic activity. These include increased business operating costs, loss in competitiveness in product markets, impaired access to labour pools and other production inputs, reduced business revenue, GDP, and employment.

It should be noted that while many of the above impacts are measured in dollars, they are in general not additive and therefore reported separately. The two cost categories are not additive because:

a) They measure different dimensions of congestion. For example, Delay, Vehicle and Related Costs estimate the dollar value of excess travel (time, vehicle operating, and related costs) while Business Inefficiency Costs reflects the dollar value of regional production lost due to congestion.
b) There is some overlap between the impacts. For example, both Delay, Vehicle and Related Costs and Business Inefficiency Costs include excess travel time to freight transportation: the former as a total travel cost and the latter as an input to estimating increased business operating costs.

Table 11 shows that currently congestion costs are estimated at about $487 million in delay, vehicle operating, and related costs, $592 million in lost business revenue, $340 million in lost regional GDP, and a reduction in employment of 2,989.

Over time, these impacts are projected to increase substantially as population and traffic in the region grow. By 2045, under the Base Case transportation alternative the various congestion costs are forecasted as follows:

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[23] Monetary cost estimates were adjusted to 2015 dollars by inflating them by the rate of inflation between 2011 and 2015. This inflation rate was based on the Consumer Price Index and amounted to 6.1%.

- Delay, Vehicle Operating, and Related Costs: over $1 billion, or more than double of current cost;
- Reduction in Business Revenue: nearly $1.8 billion, more than three times the current cost;
- Reduction in Employment: 4,910 jobs, or almost twice the current impact, and
- Reduction in GDP: over $1 billion, or nearly triple of the current cost.

Implementing the Mayor's Plan for Transit and Transportation will temper these increases reducing the various cost measures by about one third to 40% compared to the Base Case.

Table 11: Summary of Current and Projected 2045 Congestion Costs in Metro Vancouver for Key Metrics, by Strategic Transportation Alternative (2015 $)

Congestion Cost Metric	Current Cost (2009 Benchmark)	2045 Base Case	2045 Mayors' Plan	2045 Base Case vs Mayors' Plan	
				Difference, $	Percent Change, %
Delay, Vehicle Operating and Related Costs					
Deadweight Loss (Time and Vehicle Costs to Motorists), $ Million	$234.3	$638.0	$402.8	$235	36.9%
Time Cost - Transit Riders, $ Million	$51.5	$137.2	$98.3	$39	28.4%
Accidents, $ Million	$129.5	$214.3	$154.8	$59	27.7%
Vehicle Emissions, $ Million	$16.8	$9.3	$6.3	$3	32.2%
Total Cost of Recurrent Road Congestion (Excess Traffic Effects), $ Million	**$432.0**	**$998.9**	**$662.2**	**$337**	**33.7%**
Cost of Non-Recurrent Congestion, $ million	**$55**	**$88**	**$60**	**$28**	**32.0%**
TOTAL COST OF CONGESTION, $ MILLION	**$487**	**$1,087**	**$722**	**$365**	**33.6%**
Business Inefficiency Costs and Reduction in Economic Activity					
Reduction in Business Revenue, $ Million	$591.8	$1,761.0	$1,042.9	$718	40.8%
Reduction in Employment, Jobs	2,989	4,910	2,928	1,982	40.4%
Reduction In Regional GDP, $ Million	$340.1	$1,007.6	$591.6	$416	41.3%
Impact on Industrial Competitiveness	$21.2	$76.9	$56.4	$20	26.6%
Impact on Labour Demand/Employment	$318.9	$930.7	$535.2	$396	42.5%

Note: All dollar figures are in 2015 dollars.