A GENERALIZED APPROACH FOR ASSESSING THE DIRECT USER IMPACTS OF MULTIMODAL TRANSPORT PROJECTS

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ABSTRACT

The effects of a transportation project can be estimated either by benefit/cost accounting or by economic development impact analysis, both of which are regularly used by government agencies to plan and justify investments. While these approaches differ in methodology, both rely on the estimation of direct user impacts – those arising from changes in the quantity and quality of travel. However, a survey of published analyses and guides reveals, first, that there is considerable confusion between an *economic benefit* (as used in benefit/cost accounting) and an *economic impact* (as used in impact analysis), and second, that user impacts are frequently estimated too narrowly by ignoring intermodal effects and impacts to freight shippers. To address these issues, we present a framework for estimating direct user impacts that (1) is generalized to accommodate multiple travel modes in a way that avoids double-counting, (2) gives a full treatment of freight shippers and carriers, and (3) differentiates between benefits and impacts for use in either type of analysis.

THE ROLE OF ECONOMIC ANALYSIS IN TRANSPORTATION PLANNING

Assessing the economic impacts of transportation projects and policies is no trivial matter. For a host of government agencies in transportation and metropolitan planning, economic impact analyses and benefit/cost (B/C) studies are used to justify and prioritize billions of dollars worth of investment and policy decisions. The current Federal transportation legislation makes the consideration of the benefits and costs of alternatives explicit *(1)*, and the U.S. Department of Transportation has for years published guides for how to do so *(2,3,4)*. In addition, both public and private agencies use economic impact studies to advocate and market specific policies, and a growing industry has organized around conducting these types of analyses.

Recognizing the importance of these studies, recent efforts have standardized approaches within narrowly-defined analytical scopes. For example, B/C analysis guides are available that focus on specific modes *(2, 3)*, specific geographies such as corridors or metropolitan areas *(5)*, or on certain travel purposes, such as passenger or freight *(4)*. Despite these gains, several methodological problems persist in the economic assessment of transportation projects, two of which are relevant in this paper. First, as just mentioned, B/C accounting methods tend to be unnecessarily narrow in scope, possibly introducing bias. Second, the distinction between an economic *impact* (as measured by employment, output, or income in the economy) versus an economic *benefit* (as calculated for B/C analysis) is frequently blurred.

As will be demonstrated, these two issues overlap at the calculation of *direct user impacts* of transportation projects – those flowing from changes in trips, hours, and miles traveled. This paper presents a generalized framework for calculating these impacts that (1) can accounts for all travel modes, including passengers and a full treatment of freight, and (2) helps practitioners to maintain a clear distinction between benefits and impacts. An important aspect of the framework is that steps are taken to avoid double-counting which can creep in when attempting to account impacts and benefits across multiple modes.
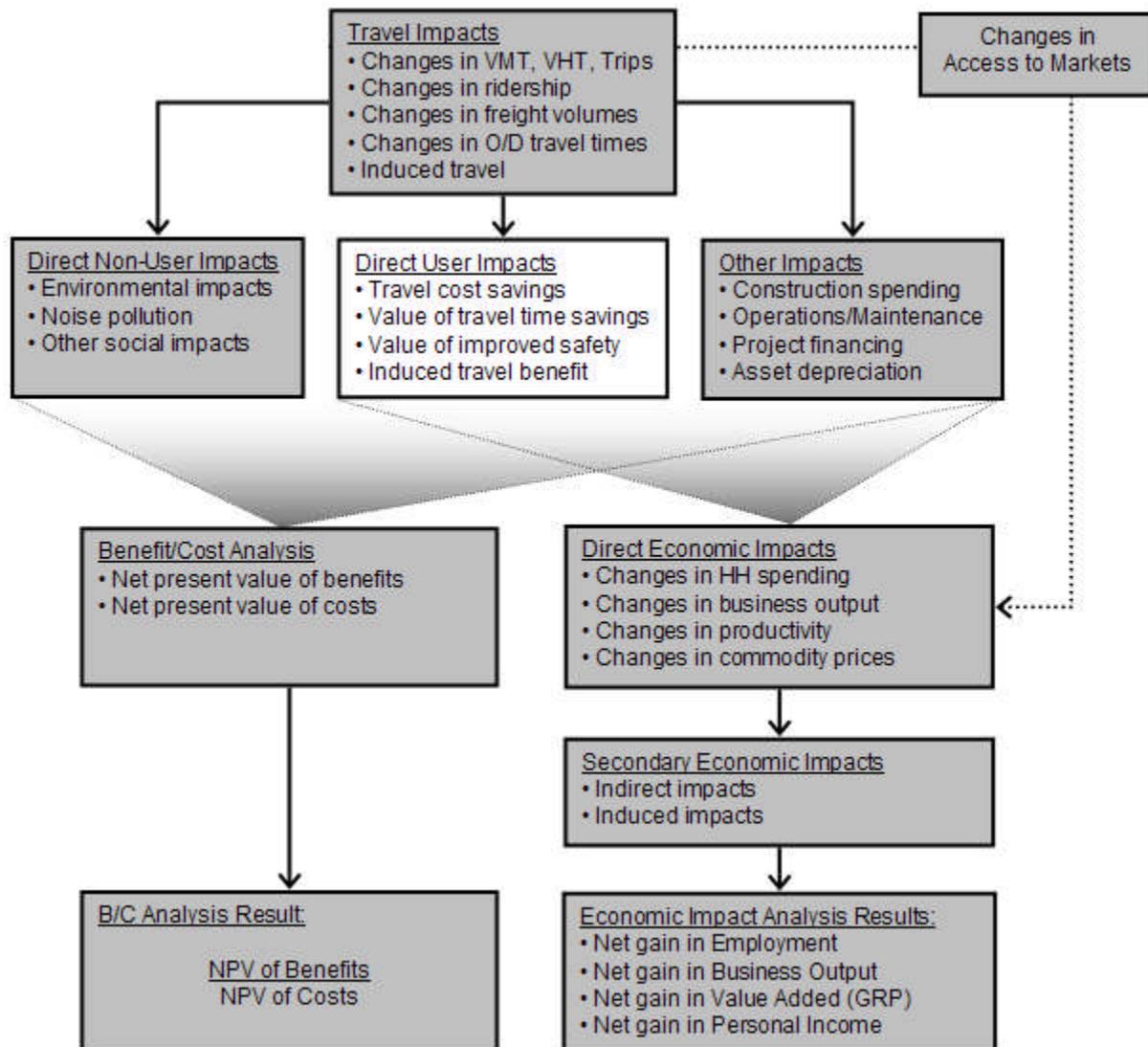
THE ROLE OF DIRECT USER IMPACTS IN ANALYSIS

Direct user impacts arise from changes in travel costs following an infrastructure investment or policy change. They are "direct" in the sense that they flow "directly" – that is, linearly – from changes in travel characteristics such as number of trips, trip distances, travel times, or vehicle occupancy (among other variables). These impacts are considered as "user" because the cost changes accrue to those utilizing the network (as distinct from "non-user" or "external" impacts, which accrue to society in general). In practice, direct user impacts are calculated for a well-defined geography (for example, county or planning district), they reflect the difference in costs between two alternative futures (scenarios), and they are calculated for a specific future analysis year.

Benefit/Cost Accounting vs. Economic Impact Analysis

Figure 1 illustrates that the calculation of direct user impacts (shown in the white box) is a key step of B/C and impact analysis. These two analytical approaches are in practice quite different from each other, and are performed for different reasons. An impact analysis might be conducted as part of an Environmental Impact Study (EIS) to identify expected social and economic development consequences of a project *(6)*. In such cases, it is important to determine the "full" impact in terms of population, employment, personal income, or business output,

because these may lead to subsequent environmental and/or land use impacts. Impact analysis can also be used for political or public information reasons, for example, to show that a particular project will draw jobs to a region. Benefit/Cost studies, on the other hand, are used to justify a particular investment strategy, to select among a list of project alternatives, or to prioritize the scheduling of reconstruction projects *(7)*.

FIGURE 1 Role of direct user impacts in benefit/cost accounting and economic impact analysis.

While direct user benefits are an important component of both types of analysis, differences between them warrant close attention to how impacts are calculated. It has been noted *(8)*, that there has been significant blurring of the differences between economic impact calculations and benefits. In particular, not all travel-related benefits lead to economic impacts (as measured by, say, gross regional product or employment), and further, some economic impacts are, by rule, excluded from B/C accounting *(9)*. For example, reductions in passenger travel time clearly lead to benefits, and these are typically quantified by multiplying the total change in travel time by

the per-hour value of that time. However, whether or not these benefits yield any economic impact depends, in turn, on whether some of the passengers are commuting, on-the-clock, or making a personal trip. In the first two cases, businesses save money (although at different rates) from reduced travel time, and this direct *economic impact* then leads to secondary economic impacts. Personal trips, however, register no direct economic impact because they do not change the flow of dollars through the economy. As another example, induced personal trips may lead to additional out-of-pocket travel costs for households, thereby dampening economic impacts, but they are typically counted as benefits in B/C studies (due to households' increase in consumer surplus). Finally, a road user fee (toll) is typically excluded from the calculus of benefits and costs because it reflects a transfer between parties. However, to the extent that tolls affect income levels, they lead to direct economic impacts.

These examples illustrate the complexity of properly assigning benefits and impacts for different types of analysis. As noted by the grey area in Figure 1, this is also where much of the "blurring" occurs. A more complete description of these differences is provided by other sources *(9, 10, 11)* and is not the primary goal of this paper; the main point here is to highlight that whether a direct user impact counts as a benefit, a cost, or a direct economic impact fundamentally depends on the type of user cost (for example, passenger time cost, vehicle operating cost, or safety cost), travel mode, and trip purpose. Therefore, any method of generating direct user impacts that is to be applied for either type of analysis (such as ours) must calculate impacts discretely across these categories. Any aggregation of these groups beforehand may unintentionally pool one type of impact with another, lump costs with benefits (or vice versa), or misspecify the calculation of impacts.

The Variety of Definitions of "User"
In addition to the terms "benefit" and "impact", the term "user" has often been interpreted differently across a variety of B/C and impact analysis applications. An NCHRP Synthesis report published in 2000 *(11)* identified over two hundred analyses published in the 1990s. A sampling of these studies reveals two issues relevant to the calculation of direct user impacts.

First, impacts are frequently estimated for only a single mode or facility. This omission is problematic because many trips utilize more than one mode. For example, air and rail passenger trips typically begin and end in a private vehicle; similarly, freight trips may begin and end in a truck, regardless of what other modes are utilized over the haul. More significantly, travel patterns reflect a complex supply-demand equilibrium that is inherently multimodal. Impacts from changes to a single mode are rarely confined to users of that mode because they may induce changes in mode choice, origin/destination patterns, departure times, or travel routes. Therefore, an analysis of highway investment (by far the most common application in the survey), should include other modes whenever they act as substitutes for the facility. This is particularly relevant for urban transportation, where public transportation frequently competes with highways to satisfy demand, or long-distance freight corridors, where rail may compete with trucking.

The second issue – the treatment of freight – was emphasized in recent Federal Highway Administration research *(12)*. The following quote applies to analyses of highway improvements:

> In the standard models, the treatment of trucks is parallel to that of passenger cars. Benefits are reckoned on the basis of reduced travel time, reduced operating costs, and reduced costs from accidents. Where cost of travel time for a car is based on value of time for the occupants, cost of travel time for a truck is based on drivers' wages. In other words the benefit valuation is based entirely on reduction in cost to the owner of the truck – in the freight context, the benefits estimated are the benefits to the *carrier*. But any effects on the owner of the cargo – the *shipper* – are not explicit or may not be fully accounted for in the approach. [p. 3, emphasis added]

This "standard" treatment is problematic for several reasons. First, costs to the carrier frequently extend beyond the narrow calculation of vehicle costs and the drivers' wages. Weisbrod et al. *(13)* have shown, for example, that costs to carriers may also include ground operations such as dock workers. Second, *shipper* firms can benefit substantially from travel time savings. FHWA *(14)* has noted that these benefits may include freight time reduction (which has an opportunity cost, and may also interact with travel time reliability), logistical reorganization, or productivity changes. The latter two effects are profit-enhancing adjustments at the firm or industry level *enabled* by the transportation improvement, and they include inventory management, just-in-time delivery, or product improvement. The main point here is that a distinction must be made between travel efficiency impacts (at the vehicle level) and direct economic impacts to users, which may be passengers, freight carriers, or freight shippers.

In the following section, we present a framework of calculating direct user impacts that addresses the confusions discussed above. Namely, costs are separately categorized by type, mode, time-period, and trip purpose. This resolution of travel changes allows benefits to be properly matched with users, and benefits to be properly distinguished from impacts.

PROPOSED GENERALIZED FRAMEWORK

The framework proposed here follows similar approaches in that economic impacts are estimated based on (1) a specific geography, (2) at least one time period, (3) at least two alternative scenarios, and (4) a particular analysis year. The concept of time period is particularly important because it provides a mechanism to capture dynamic aspects of demand, for example, peak vs. off-peak. However, for each scenario, time periods must exhaustively account for annual demand, as all results reflect annual direct user impacts. Generally, costs are estimated for each alternative policy, and direct economic impacts are calculated as the difference in total costs between the two scenarios, after accounting for induced travel *(15)*.

Table 1 shows travel modes potentially included in the model, along with a distinction of what is typically carried by the mode. A large "X" indicates the mode's primary use, but a small "x" indicates that freight may also be carried aboard passenger-focused modes.

TABLE 1 Travel Modes Potentially Included in Model

Modes	Passenger[1]	Freight[2]
Passenger Car / Light Truck	X	x
Bus (transit, intercity)	X	
Light Rail	X	
Commuter Rail	X	
Intercity Rail (conventional, high-speed)	X	x
Airplane (general aviation, air carrier)	X	x
Ferry (or water taxi)	X	x
Freight Truck		X
Freight Rail		X
Seaborne Freight (container, bulk)		X
Air Freight		X

[1] Passenger travel is further categorized by purpose: *on-the-clock*, *commute*, or *personal*

[2] Freight-focused travel is assumed to be *on-the-clock*

In addition, for passenger-focused modes, trip purposes are specified separately as on-the-clock, commute, or personal (although others could be added). Doing so is important for economic impact analyses, because how direct user impacts affect the economy depends on who assumes the costs and benefits of travel (for example, firms or households). All freight-focused travel is assumed to be on-the-clock.

Data Requirements
Our framework operates on two types of input data. The first category relates to the amount and type of travel being made, shown in Table 2, and the second captures factors relating to the costs of travel, shown in Table 3. The tables also show each variable's unit of measure as well as the categories over which it can vary. Note that the following tables show *inputs* to the model; intermediate and final results are discussed later.

TABLE 2 Travel-Related Input Variables

Travel-Related Variables	Abbreviation	Unit	Varies By[1]
Vehicle-trips made	*VehTrips*	veh*trip	*s, t, m, p*
Vehicle-miles traveled	*VMT*	veh*mi	*s, t, m, p*
Vehicle-hours traveled	*VHT*	veh*hr	*s, t, m, p*
A congestion factor (between 0 and 1)	*Cong*	-	*s, t, m, p*
Buffer time index (a reliability measure)	*BTI*	-	*s, t, m, p*
Number of crew members per vehicle	*CrewPerVeh*	people/veh	*s, t, m, p*
Number of passengers per vehicle	*PassPerVeh*	people/veh	*s, t, m, p*
Amount of freight per vehicle	*FreightPerVeh*	tons/veh	*s, t, m, p*
The portion of trip-ends that are local	*FractLocal*	-	*s, t, m, p*
Accident rates	*AccPerVMT*	crash/(veh*mi)	*s, m, p*
Fraction of new demand from mode shift	*ModeShift*	-	*t, m, p*

[1] *s* = scenario; *t* = time period *m* = mode; *p* = trip purpose

TABLE 3 Cost-Related Input Variables

Cost-Related Variables	Abbreviation	Unit	Varies by[1]
Passenger's value of time	*PassVOT*	$/hr	*m, p*
Crew member's value of time	*CrewVOT*	$/hr	*m, p*
Additional logistical time value	*LogisticVOT*	$/hr	*m, p*
Freight shipment's value of time	*FreightVOT*	$/hr	*m, p*
Per-mile vehicle cost (uncongested)	*VCperMiUn*	$/mi	*m*
Per-mile vehicle cost (congested)	*VCperMiCong*	$/mi	*m*
Per-hour vehicle cost (uncongested)	*VCperHrUn*	$/hr	*m*
Per-hour vehicle cost (congested)	*VCperHrCong*	$/hr	*m*
Average toll per trip	*TollPerTrip*	$/trip	*s, t, m, p*
Average cost per accident (by type)	*CostPerAcc*	$/crash	*m*

[1] *s* = scenario; *t* = time period *m* = mode; *p* = trip purpose

It should be noted that several of the variables in Table 3 reflect values over a heterogeneous group. For example, passengers' value of time can vary by driver, even for equivalent trip purposes *(16)*, and freight's value of time can vary considerably across commodities *(13)*. The variables used in the current framework represent averages across the categories, but accommodating greater variation within user groups is a relatively straightforward extension of the model. Furthermore, the specific cost functions detailed below are generalized to accommodate all modes. In practice, many of these could be expanded to provide more cost detail on a mode-by-mode basis. For example, the Highway Economic Requirement System (HERS) *(2)* describes highway operation costs in terms of grade, curvature, and passing lanes. These features could be adopted into our framework as long as costs are specified by mode, time period, and trip purpose, and as long as a clear distinction is made as to whom the cost applies (passenger, carrier, or shipper).

On the surface, the model looks very data-hungry. For example, an application with two scenarios, two time periods, three modes, and three trip purposes will generate 155 different inputs *available* to the user. In practice, however, very few applications will utilize all of the model's capabilities, and travel-related variables set to zero won't influence the results. As such, the model can be used for sketch-planning (at a minimum, it will generate impacts based on VHT and passenger value of time), but given appropriate input, it can also exhaustively account for the direct user impacts of travel across all interacting modes. This flexibility is important, given the range of sophistication of travel models used in planning.

Calculation of Direct User Impacts
Impacts are generally calculated by matching cost factors to the number of trips, miles, and hours traveled. In all the following equations, the indexes *s*, *t*, *m*, and *p* refer to scenario, time period, mode, and trip purpose, respectively. As such, with the exception of induced benefits, all costs are first calculated as levels (for each scenario), and benefits are calculated differences between scenarios.

Adjusting for Travel Time Unreliability
Before calculating time costs, it is necessary to make adjustments to account for unreliable travel conditions for select cost types. Travelers form expectations about travel times based on past experience, weather reports, real-time traffic/schedule updates, and other sources. When a

particular trip's travel time is highly predictable (conforms to expectations), then travelers can streamline the execution of that trip by accurately choosing departure time. However, if a trip's travel time is highly variable, then the driver must build a time cushion into the selection of departure time, to account for unforeseen delay. This extra time has opportunity costs for drivers, passengers, and freight.

Several publications review the theory and practice of travel time reliability's impact on passengers *(16, 17, 18)* and shippers *(19, 20)*. While most have focused on road-based travel, we adopt a method similar to that proposed by FHWA *(18)* and applied by the Southern California Association of Governments *(19)*. It recognizes that travel time unreliability has the effect of scaling in-vehicle travel time to account for travel time "buffers", where the buffer generally increases as level-of-service deteriorates. Our model performs this scaling with the following equation:

$$VHTRelAdj_{mp}^{st} = \left(VHT_{mp}^{st}\right)\left(1 + BTI_{mp}^{st}\right), \tag{1}$$

where *VHT* is gross "raw" travel time, *VHTRelAdj* is travel time adjusted for reliability, and *BTI* is the "buffer-time-index," which reflects the additional time as (a fraction of the *average* travel time) necessary to complete a trip on-time 19 out of every 20 days (roughly 1 day per month). Note that because *BTI* is estimated relative to average (and not free-flow) travel time, *VHT* is *not* adjusted for "background" travel time variability. Select vehicle-based time costs are then calculated based on the adjusted measure of travel time. It should also be noted that while our framework makes this adjustment available for all modes, its applicability is limited to situations where operators can form expectations of travel time *and adjust for them*.

Passenger Time Costs
Passenger time costs are calculated as the product of total travel time, passengers per vehicle (*PassPerVeh*), and passengers' value-of-time (*PassVOT*). A clear distinction should be made, however, between a passenger and a crew member (treated next). For most modes, the vehicle driver acts as part of the crew – however, for automobiles, the driver is typically counted as a passenger.

$$PassengerCost_{mp}^{st} = \left(VHTRelAdj_{mp}^{st}\right)\left(PassPerVeh_{mp}^{st}\right)\left(PassVOT_{mp}\right) \tag{2}$$

Crew Time Costs
Vehicles hired to carry passengers or freight require one or more operators, who form the crew. This crew time cost, which accrues to the carrier (as distinct from the passenger or the shipper) is calculated as product of vehicle hours traveled (*VHT*), the number of vehicle operators (*CrewPerVeh*), and the average hourly wage across all crew members.

$$CrewCost_{mp}^{st} = \left(VHT_{mp}^{st}\right)\left(CrewPerVeh_{mp}^{st}\right)\left(CrewVOT_{mp}\right) \tag{3}$$

Additional Logistics Costs
As described above, crew costs reflect carriers' time-cost of in-vehicle operators. However, some transport activity may rely on non-vehicle operators for on-the-ground handling or

intermodal transfers *(13)*. For certain types of shipments or supply-chain arrangements, these costs may be exacerbated by additional travel time. However, in the present framework, crew costs and logistic costs scale only with "raw" travel time (unadjusted for reliability). In practice, whether the cost of reliability accrues to the carrier or the shipper depends on many factors, but applying it to both would likely overstate the direct impact. As such, only the freight time is adjusted for unreliability.

$$LogisticCost_{mp}^{st} = \left(VHT_{mp}^{st}\right)\left(LogisticVOT_{mp}\right) \tag{4}$$

Freight Time Costs
Reduced travel times benefit shippers due to the opportunity cost of the freight travel. These impacts, referred to as *first order* by FHWA *(12)*, are distinct from logistical reorganization or other productivity gains. Our framework calculates freight time cost as the product of adjusted travel time (*VHTRelAdj*), the average freight carriage per vehicle (*FreightPerVeh*), and freight's estimated value of time (*FreightVOT*). As one example of how this might be calculated, the Highway Economic Requirement System (HERS) *(2)* model estimates the hourly value of freight time by applying a discount rate to the average cargo value. However, research *(4)* has also shown that certain commodities (such as perishables) may have much greater sensitivities to travel time (and unreliability). These differences could be accommodated by adding an industry-specific index to the following equation.

$$FreightCost_{mp}^{st} = \left(VHTRelAdj_{mp}^{st}\right)\left(FreightPerVeh_{mp}^{st}\right)\left(FreightVOT_{mp}\right) \tag{5}$$

Vehicle Operation Costs
Costs arise from vehicle ownership and operation. These costs vary by mode, and typically include depreciation, fuel, and maintenance (but exclude driver's wages and insurance, as these are captured elsewhere). Our model calculates operating costs either by distance or by time, because across modes, these may be known more precisely by mile (for example, passenger car) or by hour (for example, airplanes). Accommodating both therefore lends to more accurate overall cost estimates. In addition, unit costs are separately specified for uncongested and congested travel conditions. This accounts for the fact that level-of-service improvements may have an indirect effect of reducing operating costs. This effect is well-known for highway travel, where reducing congestion can significantly reduce per-mile fuel consumption, but the effect is transferable to other modes as well.

Operating costs are calculated as a weighted average of operating costs in free-flow and congested conditions, where the fraction of travel subject to congestion (*Cong*) serves as the weighting factor. Which equation is used is governed by the choice of whether unit costs are entered as per-hour or per-mile. If the second equation is used, VHT is *not* adjusted for travel time unreliability.

$$OperCost_{mp}^{st} = \left(VMT_{mp}^{st}\right)\left[\left(VCperMiFree_m\right)\left(1 - Cong_{mp}^{st}\right) + \left(VCperMiCong_m\right)\left(Cong_{mp}^{st}\right)\right] \tag{6a}$$

$$OperCost_{mp}^{st} = \left(VHT_{mp}^{st}\right)\left[\left(VCperHrFree_m\right)\left(1 - Cong_{mp}^{st}\right) + \left(VCperHrCong_m\right)\left(Cong_{mp}^{st}\right)\right] \tag{6b}$$

Toll/Fare Costs
Tolls and fares contribute to overall travel costs for passengers, carriers, and shippers. Our framework incorporates these based on the number of trips and average toll or fare per trip. It should be noted that whether this cost is interpreted as a toll or a fare has implications for whether it is counted as a transfer or a cost.

$$TollCost_{mp}^{st} = \left(TollPerTrip_{mp}^{st}\right)\left(VehTrips_{mp}^{st}\right) \tag{7}$$

Safety Costs
Driving or riding in a vehicle carries risk. When crashes occur, costs result from property damage, personal injuries, and fatalities. One approach *(10)* is to estimate costs as the product of distance traveled, average crash rates, and estimated costs per crash. In practice, the following equation can be separately specified for different crash severities, and total safety costs are a summation across all crash types.

$$SafetyCost_{mp}^{s} = \left(AvgCrashRate_{m}^{s}\right)\left(AvgCostPerCrash_{m}\right)\left(VMT_{mp}^{s}\right) \tag{8}$$

Total User Costs
Total user costs, which enter into the calculations of induced benefits, are simply the sum of equations (2) through (8):

$$UserCost_{mp}^{st} = PassengerCost_{mp}^{st} + CrewCost_{mp}^{st} + LogisticCost_{mp}^{st} + \tag{9}$$
$$FreightCost_{mp}^{st} + OperCost_{mp}^{st} + TollCost_{mp}^{st} + SafetyCost_{mp}^{s}$$

Adjusting for Trip-End Leakage
Equations (1) through (8) calculate gross travel costs for each scenario, time period, mode, and trip purpose. These costs, however, may contain trips that are either wholly or partially external to the study area. In this case, the economic impact or benefit will be smaller than the gross impacts. In our framework, benefits and costs are sited with the location of the economic actors (households or firms) engaged in a trip, regardless of what portion of the trip *actually* occurs in the study area. To account for this leakage, costs are reduced by the fraction of non-local trip-ends. *LocalUserCost* is equivalently calculated as the sum of all local costs.

$$LocalPassengerCost_{mp}^{st} = \left(PassengerCost_{mp}^{st}\right)\left(FractLocal_{mp}^{st}\right) \tag{10a}$$
$$LocalCrewCost_{mp}^{st} = \left(CrewCost_{mp}^{st}\right)\left(FractLocal_{mp}^{st}\right) \tag{10b}$$
$$LocalLogisticCost_{mp}^{st} = \left(LogisticCost_{mp}^{st}\right)\left(FractLocal_{mp}^{st}\right) \tag{10c}$$
$$LocalFreightCost_{mp}^{st} = \left(FreightCost_{mp}^{st}\right)\left(FractLocal_{mp}^{st}\right) \tag{10d}$$
$$LocalOperCost_{mp}^{st} = \left(OperCost_{mp}^{st}\right)\left(FractLocal_{mp}^{st}\right) \tag{10e}$$
$$LocalTollCost_{mp}^{st} = \left(TollCost_{mp}^{st}\right)\left(FractLocal_{mp}^{st}\right) \tag{10f}$$
$$LocalSafetyCost_{mp}^{st} = \left(SafetyCost_{mp}^{s}\right)\left(FractLocal_{mp}^{st}\right) \tag{10g}$$

Accounting for Induced Travel
The travel costs calculated by equations (2) through (8) reflect levels for a particular scenario, and direct user benefits are therefore calculated as cost differences between scenarios. However, basing total impacts only on these differences would ignore impacts from induced travel. Induced travel occurs because of travelers' and shippers' economic response to travel cost changes. A new piece of infrastructure or policy may reduce travel costs through any of the cost types listed above. Over time, firms and households recognize this lower price as an opportunity to decrease production costs or satisfy new trips. In both cases, the total number of trips (or miles traveled) may increase in the long-term. If direct impacts are calculated as the "simple" user cost difference between scenarios, the overall benefit might be underestimated because the new (induced) trips are tallied as having costs but no benefits. In reality, induced trips are made *precisely because they have value*, which outweighs the cost of making the trip. The following figure demonstrates graphically the standard economic interpretation of induced travel *(20)*.
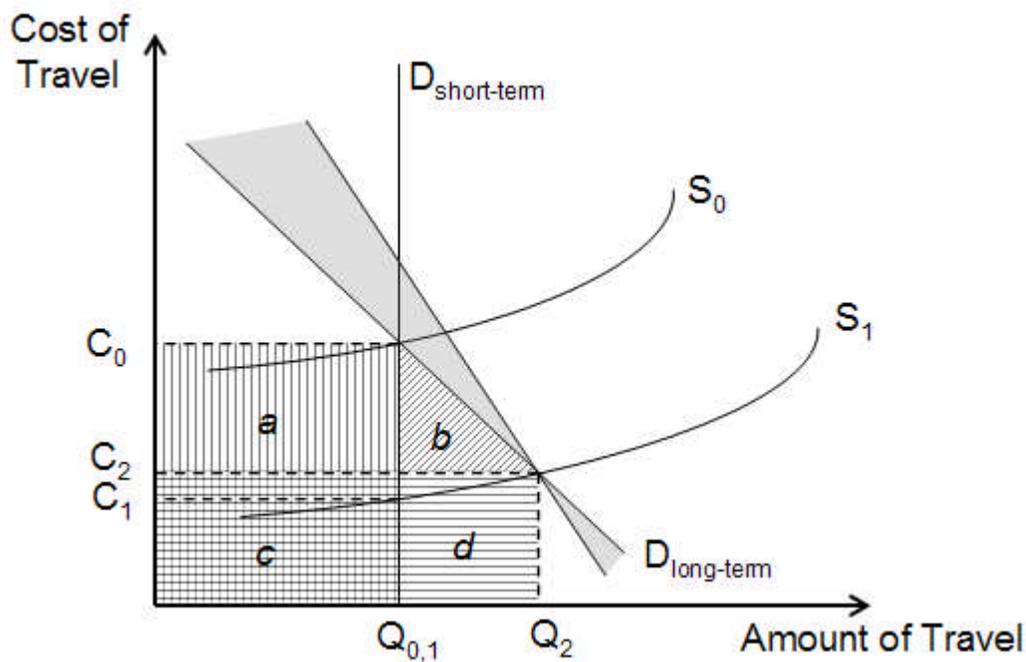
FIGURE 2 A graphical representation of induced travel.

Over the short-term, travel demand is relatively insensitive to cost changes. This is reflected by a vertical (inelastic) short-term demand curve. Thus, following an investment that increases supply, travelers initially consume the same amount of travel ($Q_0 = Q_1$) and simply enjoy the lower costs. Over time, however, households and firms decide to purchase more travel, which may again increase the unit cost of travel (from C_1 to C_2) due to congestion. This is reflected in a long-term demand curve that has pivoted or shifted (or both), such that it crosses the new supply curve at a lower cost (C_2) but higher travel volume (Q_2). The short-term benefit is shown as area *a*, and the induced benefit as area *b*; together, they comprise the net increase in consumer (or producer) surplus from the change in supply.

The interpretation of the induced benefit, however, depends on whether the mode is passenger-focused or freight-focused. In the first case, the induced benefit reflects an increase in consumer surplus from passenger's gain (in utility) from satisfying additional or longer trips. In the second case, the induced benefit may reflect logistical restructuring or other productivity gains at the firm or industry level *(14)*. This distinction is important, because the increased consumer surplus on the part of households yields no additional economic impacts because it doesn't affect the flow of dollars through the economy. The producer surplus to firms, on the other hand, does generate impacts through increased productivity, potentially leading to greater local output, value added, and employment. As such, only the latter needs to be estimated for economic impact analysis, but both should be calculated for benefit/cost accounting.

Before continuing, it should be noted that for induced travel to be captured by our framework, it must be explicitly included in the estimates of travel demand (Table 2) that serve as inputs to our framework *(22)*. In practice, the precise nature of the demand curve is rarely known (as such, the long-term demand curve is shown as a range), but a significant amount of research has attempted to measure this effect for highways in the form of elasticities *(21, 23, 24)*, and the FHWA provides a spreadsheet tool for practitioners *(24)*. If these or other methods are used to model induced travel, then Figure 1 illustrates how induced benefits can be captured in our framework.

Let S_0 and S_1 reflect the supply curves for a *base* and *alternative* scenario. Area b is the induced benefit, and following B/C procedures, area $a + b$ accounts for the total net increase in consumer (or producer) surplus between the two scenarios. However, as applied to the *base* scenario, equations (1) through (8) represent the area $a + c$, or C_0*Q_0. Similarly, as applied to the *alternative* scenario, they yield area $c + d$, or C_2*Q_2. While a "simple" difference between user costs for each scenario is appropriate for impact analysis, this does not properly account for benefits ($a + b$) for B/C studies. This is because user costs generated by induced travel should not be included in the calculation of non-induced benefits (area a). To properly calculate the change in consumer surplus, straight differences in travel costs must be adjusted by areas d and b. The following steps outline how this is accomplished.

First, total travel volume is calculated and reconciled across all modes. This step is important because increases in demand for one mode may simply reflect a switch from another. If this occurs and both modes are included in the model, then including mode-shift as induced would be double-counting, because the benefits of mode-switching would be captured by the net changes in user costs across both modes (however, if only one of the modes is included, then the induced benefit may be used to proxy the consumer surplus gain in the mode switch). We measure the quantity of travel consumed (Q) as either *passenger*miles* or *ton*miles*, depending on whether the mode is passenger-focused or freight-focused. Note that these measures normalize demand among all competing modes, and the benefits of more trips, longer trips, and increased ridership are captured.

$$PassVol_{mp}^{st} = \left(VMT_{mp}^{st}\right)\left(PassPerVeh_{mp}^{st}\right) \tag{11a}$$

$$FreightVol_{mp}^{st} = \left(VMT_{mp}^{st}\right)\left(TonsPerVeh_{mp}^{st}\right) \tag{11b}$$

These measures of travel volume are calculated for each of the two scenarios and differences are generated for each mode/trip purpose combination. For any instances where total volume

increases, the modeler then determines the fraction of increased volume that resulted from mode switching. This is captured by the variable *ModeShift* in Table 2. Any remaining increase is assumed to be induced, as shown in the following equation, where Q may be either of the measures (11a) or (11b):

$$InducedQ_{mp}^t = \left(Q_{mp}^{alternative,t} - Q_{mp}^{base,t}\right)\left(1 - ModeShift_{mp}^t\right). \tag{12}$$

In practice, equation (11a) is be used for all passenger-focused modes, and equation (11b) is used for freight-focused modes (see Table 1). Unit travel costs for each scenario are then calculated as

$$C_{mp}^{st} = \frac{UserCost_{mp}^{st}}{Q_{mp}^{st}}, \tag{13}$$

where, again, Q may be either measure of travel volume. Equations (12) and (13) allow for the calculation of induced travel costs (area *d*) as

$$InducedCost_{mp}^t = \left(InducedQ_{mp}^t\right)\left(C_{mp}^{alternative,t}\right), \tag{14}$$

and induced benefits (area *b*) as

$$InducedBenefit_{mp}^t = \tfrac{1}{2}\, InducedQ_{mp}^t \left(C_{mp}^{base,t} - C_{mp}^{alternative,t}\right). \tag{15}$$

The induced benefit adjustment is the sum of these two terms:

$$InducedAdjustment_{mp}^t = InducedCost_{mp}^t + InducedBenefit_{mp}^t. \tag{16}$$

Adding this value to the difference in user costs between scenarios yields net consumer surplus.

The induced travel calculations shown above are based on total (local plus non-local) demand. As such, the benefits derived from them also reflect a total value. Whereas for impact analysis, the distinction between local and total impacts is frequently very important, traditional benefit-cost accounting typically doesn't report region-specific values (only totals are shown). However, in practice, a local government agency funding a local project may have a valid interest in local benefit/cost ratio, and this could be calculated using the *FractLocal* variable. If the framework were extended in this way, extreme care would be needed to ensure that the spatial source of investment spending was properly accounted for.

Results
The above framework yields as its output a matrix of direct user impacts. The "core" results are changes in user costs for the seven types shown in equations (2) through (8), and the induced benefit adjustment in equation (16). Each of these values is separately reported by mode, time-period, and trip purpose (and can be shown as total or local). The resolution of direct impacts

across these categories is the key to the framework's utility, because the precise interpretation of each result as a benefit or impact, *and to which user it applies*, depends on where it lies in each category.

CONCLUSION

The past several decades have marked the increased importance of multimodalism in transportation planning. This is due to many factors, but growing highway congestion and international freight movement are among the most important. The main goal of this paper, therefore, is to recognize the integrated nature of transportation supply and demand, and to build a framework for estimating direct user impacts that can be used for B/C or impact analysis, can accommodate multiple modes and trip purposes, that minimizes double-counting, and that allows for price-feedbacks on demand (induced travel).

The end result is a framework that is multimodal at its core, but that produces direct user impacts that can easily be matched to specific users. The cost equations (1-8) provide one example of how it can be applied, but more sophisticated specifications could easily replace them without affecting the core of the model, as long as costs are estimated by mode, trip-purpose and time-period. Further extensions such as risk analysis and differential impacts across commodities could also be incorporated into this core framework. However, this framework begins to incorporate the recommendations of reports and guides published by USDOT *(4)*, NCHRP *(26)*, and the Government Accountability Office *(27)*, and it is also incorporated in the Transportation Economic Development Impact System (TREDIS).

The ultimate benefit of the framework is that it may lead to better policy analysis. Practically, the framework is useful because of the great resolution of direct user impacts. This has the potential to reduce error and double counting in B/C analysis, but it could also improve integration with national or regional impact models, because costs and benefits could more easily matched to available "policy levers" in regional economic models. However, more fundamentally, if public agencies are to make appropriate investment decisions in the future, it is increasingly important that they recognize the difference between impacts and benefits, as well as interactions between and among modes. Our framework provides such a tool.

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