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Economic Aspects of ITS Improvements for Delaware: A Brief Review

by

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In this brief article, we describe some of the main implications that economic theory and applications have on the Intelligent Transportation Systems (ITS). The intention is to provide a brief exposure to the theoretical details and practical implications regarding supply, demand, and traffic congestion, the value of time, the value of reliability, the cost of pollution.

Supply, Demand, and Traffic Congestion

The overall objective ITS is to improve the coordination of commuters in order to use existing roads more efficiently. Examples include traffic detectors and signal response, electronic payment systems, improved communication channels with EMS and commuters, etc. However, the economic theory of congestion pricing provides a standardized way of evaluating consumer behavior these systems given a few assumptions and basic observations.

According to theory, travelers consume transport services, and like any consumer, must pay a price to do so. This price is a combination of factors, including the monetary costs of fuel and vehicle depreciation and the time costs of driving. Economists assume that all such factors can be monetized and aggregated. In other words, because people implicitly place a value on the time they spend doing certain activities, time can be converted to money and money can be converted to time. In this section, we discuss the costs of travel as measured purely in minutes (time costs), though that is merely for convenience, as costs could also be measured in dollars (as discussed in an upcoming section).

The congestion pricing theory assumes that we monitor road segments and assume normal operating conditions. If a road segment is normally delayed, some consumers (i.e. drivers) will avoid the delay by reducing the number of trips they make on that segment. The downward sloping line in Figure 1 demonstrates commuter demand. As the average time costs per trip falls (vertical axis), the number of trips that commuters demand increases.

The time costs of traveling on a roadway depend on how many other commuters are also using the road at the same time. If very few commuters use the road, there is little interference between the drivers and traffic moves at free flow conditions. In Figure 1, free flow conditions are assumed to be at a time cost equivalent to 20 minutes for a particular stretch of road. Given any effective capacity (in this case 2000 vehicles), there is a limit, L, to how many vehicles can use the road without raising the average time above free flow conditions. As more vehicles use the road, congestion is created which delays everyone on that road. The average travel time is captured by the purple line in Figure 1. Mathematically it is expressed in equation 1.[1]

$$T_l = T_{l0}\{1 + 0.15(N_l/K_l)^4\} \tag{1}$$

T_l in equation 1 represents the average time to traverse a particular road that has an effective capacity of K_l number of cars. T_{l0} is the time cost under free flow conditions, and N_l is the number of cars demanding to use the road.

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[1] As cited in Beimborn et al. (1993), the Federal Highway Administration released Equation 1 in 1973 to estimate how utilization of a road relates the average time of each commuter.

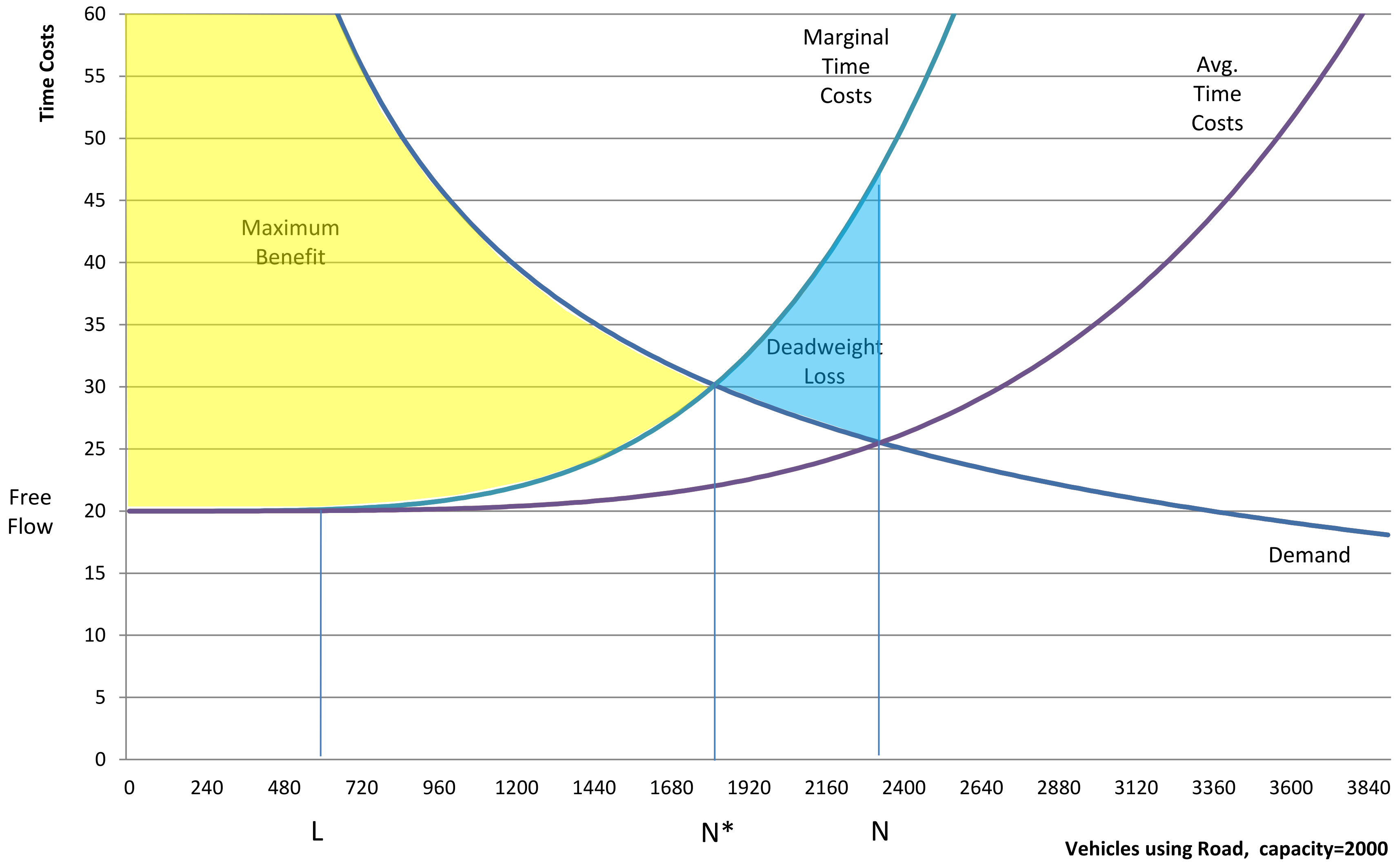

Figure 1 - Economic Analysis of Traffic Congestion

The expected number of cars on the road will be determined by the intersection of demand and the average time cost of driving. In Figure 1, this occurs at point “N” where utilization is approximately 1.165 (2,330 vehicles demand a road with a given capacity of 2000). This imposes an average time cost of approximately 25.5 minutes per driver. For each of the 2,330 drivers, congestion is imposing 5.5 more minutes than free flow conditions. This translates into (2330 drivers ×5.5 minutes ÷ 60) 213.6 unnecessary hours that all drivers are forced to pay because of congestion.

As additional drivers use the road, congestion increases and delays all drivers. From the previous example, if one more driver uses the road, the average delay increases by 1.2 seconds. However, because this 1.2 seconds impacts all drivers equally, the total time delay for society (i.e. all commuters) increases by 47.6 minutes. This is the marginal cost, as indicated by the light blue line in Figure 1. The formula for marginal cost is listed in equation 2.

$$MC_l = T_{l0}\{1 + 0.75(N_l/K_l)^4\} \tag{2}$$

Theory tells us that society should produce up to the point where the marginal benefit of society (as represented by the demand curve) equals the marginal cost. This occurs at N*in Figure 1, which is less traffic than how much actually occurs in equilibrium (N). If society produces N*, it could gain a total benefit for commuters equal to the yellow area below demand and above the marginal cost. However, if the equilibrium amount of traffic, N, occurs, then the societal benefit will be the maximum benefit minus the unnecessary costs that additional congestion creates. These unnecessary costs, called a deadweight loss, are represented by the blue region in Figure 1.

Now that the economic theory of congestion pricing has been introduced, the next step is to describe how the theory can be used to calculate the benefits of ITS systems. Presumably, no matter which ITS system is put into place, existing roads will be able to handle more vehicles as a result of decreased variability in the operating process without increasing congestion as much. This means that the ITS investment effectively increases the road's capacity.

Greater effective capacity ($\uparrow K_l$ in Eq. 1 and in Eq. 2) implies that both the average and marginal cost curves decrease. Figure 2 shows the effect of implementing the ITS system. The red marginal cost and average cost curves both shift to the right. The new curves are highlighted in green. Because of the lower marginal costs, the socially optimal number of trips increases from N* to N'*. However, because no congestion pricing scheme is enacted, commuters will still respond to the average cost of driving, so the actual number of trips increases from N to N'.

Figure 2 also highlights the total change in social welfare. The benefit to society increases by the green area (C_1) as a result of lowering the marginal cost for those drivers who should have been using the road initially (N*).[2] However, the lower marginal cost will also increase the optimal number of drivers (N*'), which creates social surplus for these additional "optimal" commuters. The social gain from the extra optimal drivers is shown by the yellow area (C_2) in Figure 2.

As the old deadweight loss no longer applies, the change in social surplus will also depend on the change in deadweight loss. This is shown as the blue area minus the red area ($C_3 - C_4$) in Figure 2. Thus, the total improvement in societal welfare in Figure 2 is therefore the green area, plus the yellow area, plus the blue area, minus the red area ($C_1 + C_2 + C_3 - C_4$).

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[2] Assuming, of course, that the economically optimal number of drivers *should* be using the roads.

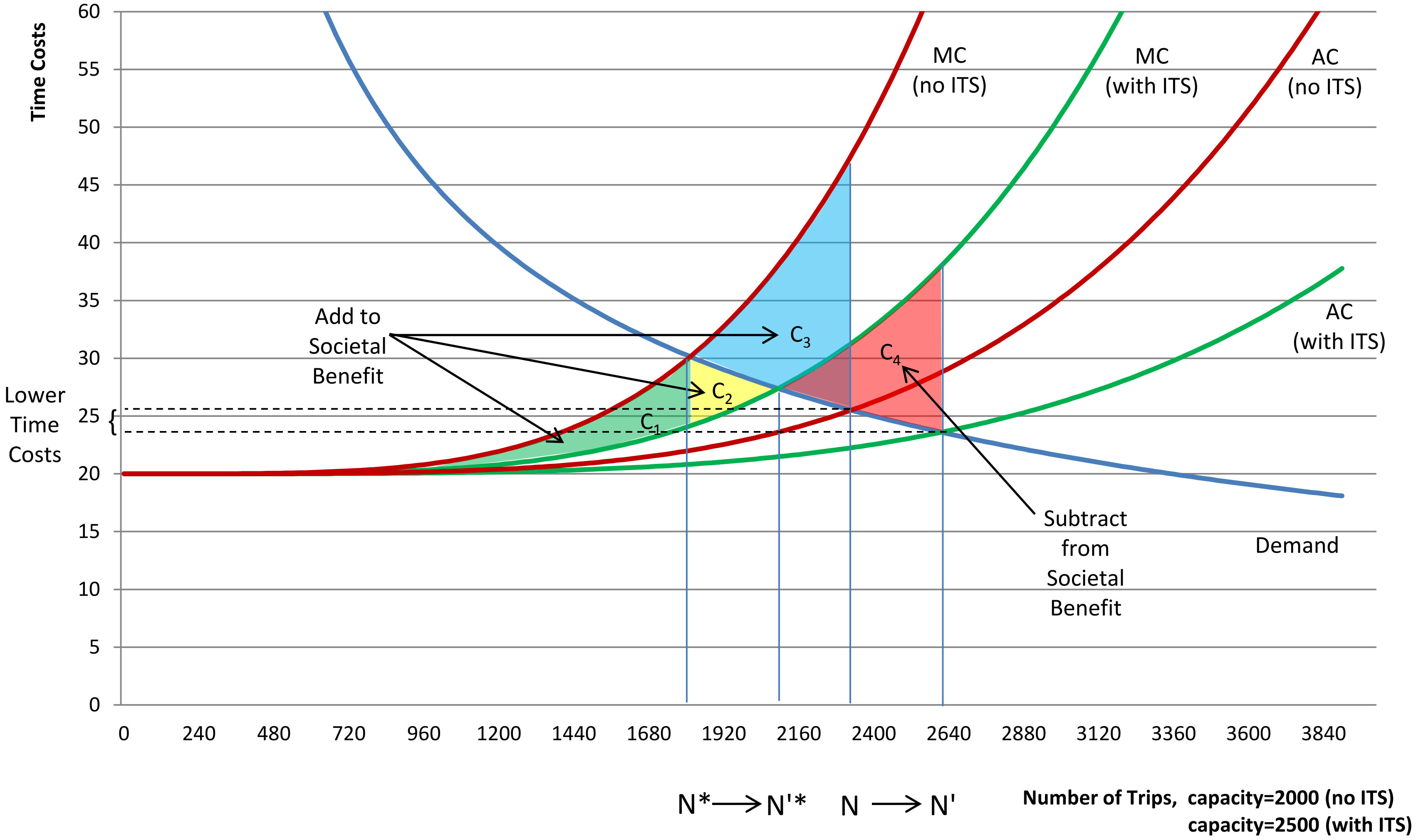

Figure 2 - Change in Societal Benefit of increasing Capacity

Given a specific mathematical function for the demand curve,[3] the estimated change in social welfare can be calculated after observing changes in time costs and how many additional commuters can be accommodated. The only other input needed to perform these calculations is the estimated elasticity of demand. It is trivial to show that social benefits equal the benefits of each trip multiplied by the number of trips if consumers have a perfectly inelastic demand.

Value of Time

In the discussion above, we assume that travel time can be converted to money and money can be converted to travel time. Theoretically, time is a scarce resource, like income, which people choose how to spend. Also like income, people could have chosen to spend their time on things other than transportation, such as leisure. The value of that next best alternative is the opportunity cost of time. This opportunity cost is the benefit of reducing travel time. Economists have long been interested in calculating this measure.

Although traffic engineers began calculating the nonmonetary cost of travel in the 1940's, (M. H. West, 1946; Fratar, 1949), the topic really received mainstream attention from economists in the late 1950's and early 1960's. After more than half a century of development, the value of travel time has become a standard topic in transportation economics.[4]

Unlike operational costs, the value of reduced travel time cannot be measured directly. Instead, empirical estimates are obtained by applying econometric models to observed transportation decisions. Those models find the statistical relationship between traveler choice and travel time as well as a statistical relationship between traveler choice and the monetary costs of travel.

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[3] Demand functions expressing constant elasticity ($N = a \times T_l^{-\varepsilon}$) are well suited for this model.

[4] See McCarthy (2001) for many such examples.

To put this in a simplistic mathematical context[5], suppose that a trip may be taken by either an automobile (A) or bus (B). On the one hand, automobiles have higher monetary costs than busses ($C_a>C_b$). On the other hand, busses have higher time costs than automobiles ($T_b>T_a$). Moreover, suppose that bus transportation is an inferior good, meaning that people tend to prefer automobiles as a method of transportation as their income (Y) rises.

An indirect utility function describes the highest level of utility that an economically rational person can reach given a level of income, prices, or other constraints. In this example, the indirect utility of automobile transportation (V_a) and bus transportation (V_b) is assumed to be written as,

$$V_a = B_1P_a + B_2Y + B_3T_a$$

$$V_b = B_1P_b + B_4Y + B_3T_b$$

Under this specification, the indirect utility of either automobile or public transportation decreases by B_1 when the price of either alternative (P_i) increases by $1 (or some other monetary unit). Similarly, the indirect utility decreases by B_3 when the time it takes to use either alternative increases by 1 hour (or some other time unit).[6] Under this simple model, decreases in indirect utility that stem from higher travel times can be offset by a corresponding increase in indirect utility coming from lower in monetary costs. This implies that travelers are indifferent between substituting time costs for monetary costs at some point. Given the simplistic model above, this rate of substitution can be calculated as $\frac{\partial V/\partial T}{\partial V/\partial P}$, or simply B_3/B_1.

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[5] The following discussion largely follows McCarthy (2001).

[6] Typically, both B_1 and B_3 are negative, indicating that utility falls as someone must spend more time and money on transportation.

Because people choose the method of transportation that brings the most utility, automobile transportation occurs if $V_a>V_b$ and bus transportation occurs if $V_b>V_a$. Given this assumption, the coefficients to the indirect utility model can be empirically estimated using discrete choice econometric techniques, called “random utility models”.[7] To perform such a technique, data is needed on trip selection, monetary costs, time requirements, and income, in addition to knowing whether the trip was made by automobile or public transportation.[8]

Much empirical research has been conducted on the value of saved transportation time leading to numerous specifications of indirect utility functions. For example, the estimates of the value of time have included geography, purpose of travel, mode of travel, demographic, waiting time, walking time, type of delay, time of day, etc.[9]

The literature reviews on the value of travel time indicate that the empirical estimates do vary depending on context-specific information. In addition, time savings often represent the majority of reduced travel costs. Unfortunately, the combination of these factors makes the application of any single estimate of the value of travel costs sensitive to modeler’s assumptions. For this reason, the US DOT (Office of the Secretary of Transportation, 1997) released an official memo detailing consistent rules to be used when making empirical estimates of saved travel time. By promoting consistent treatment of the value of time, cost-benefit analyses can be compared to one another without worrying about the sensitivity due to differences in valuation methodology.

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[7] Econometric methods include binary logit or probit models, the multinomial logit model, mixed logit, multinomial probit models, etc.

[8] Not all decisions must be constrained to modal choice. For example, route choice is also commonly modeled in the literature.

[9] For a recent literature review, see Victoria Transport Policy Institute <http://www.vtpi.org/tca/>.

Table 1 DELDOT's Assumed Value of Time by Vehicle Type, 2011

Vehicle Type	Occupancy	Wage Factor	Compensation	Wage Rate	Value of Time
Automobiles	1.67	0.5	1	$22.25/hr	$18.58/hr
Light Trucks	1.12	1	1.30	$16.60/hr	$21.66/hr
Heavy Trucks	1.025	1	1.30	$19.90/hr	$28.90/hr

Source: Delaware Department of Transportation, Division of Transportation Solutions

The USDOT recommended that empirical point estimates of travel time costs should use “50% of the wage for all local intercity personal travel and 100% of the wage (plus fringe benefits) for all local and intercity business travel, including travel by truck drivers.” Since the publication of this advice, many states have adopted their own values of time for transportation-specific applications. According to a recent Delaware Department of Transportation (DELDOT) memo (Division of Transportation Solutions, 2010), Delaware also has adopted a methodology for consistent treatment of the value of time. The formula for the value of time is:

$$\text{Value of Time} = \text{Vehicle Occupancy} \times \text{Wage Factor} \times \text{Compensation Factor} \times \text{Wage Rate}$$

As per the US DOT recommendations, DELDOT assumes that the value of time for automobile drivers is 50% of the average wage rate for each occupant. The average wage rate is obtained from the Delaware’s Occupational Employment Survey (OES) program, which in 2009 was found to be $22.25. Average vehicle occupancy rate for automobiles (1.67) is taken from the 2009 National Household Travel Survey. Thus, the average value of time for automobiles is assumed to be $18.58 per hour.

Because people driving heavy trucks are most often working, DELDOT assumes that the value of their time is paid by their employers, and therefore equals 100% of the average compensation for each occupant. According to the Delaware OES program, heavy truck drivers received an average wage equal to $19.90 per hour. Assuming an average compensation to wage ratio of 1.30 (obtained from Bureau of Economic Analysis total wage and compensation estimates for Delaware) and an average vehicle occupancy of 1.12 (also obtained from the 2009 National Household Travel Survey), DELDOT uses $28.90 as the average value of time for heavy trucks.

Like heavy trucks, the average value of time for light trucks was also equal to 100% of the average compensation for each occupant. The Delaware OES program estimated that light truck drivers received an average wage of $16.30 in 2009. Using data published from the 2002 Highway Economic Requirements System, DELDOT estimates that the average occupancy rate for light trucks is 1.025 persons per vehicle. Using the same compensation factor used earlier (1.30), DELDOT estimates that the value of time is $21.66 per hour for light trucks.

Finally, the estimated proportion of automobiles, light trucks, and heavy trucks are estimated within a given road segment to predict the average value of time for travelers on a particular roadway. For example, a road segment with an equal number of cars, light trucks, and heavy trucks, would have an average value of time equal to $23.05 per vehicle-hour, which is simply the average across the three separate values of time.

Value of Reliability

Engineers and economists have long recognized that the variability of travel time is an important factor affecting the value of transportation. Although some drivers may simply value reliability in and of itself, the major reason why reliability is important is because it affects planning decisions. Variable trip times imply that travelers not likely arrive at their desired time, and being late or early imposes costs on travelers. The economic literature on this topic began in the early 1980’s.

There are two basic approaches that economists use to model the value of reliability: scheduling delay and mean-dispersion. The scheduling delay approach assumes that travelers plan on reaching their destination at a certain time, and that they do not want to arrive too early or too late. These scheduling delays are modeled directly into a utility function, along with monetary costs and the mean travel time. The monetary cost of arriving early or of arriving late are calculated by again uncovering the substitution between scheduled delays and monetary costs $\left(\frac{\partial U/\partial Early}{\partial U/\partial \$}, \frac{\partial U/\partial Late}{\partial U/\partial \$}\right)$. As before, the parameters are estimated through discrete econometric models. A literature review by Noland and Polak (2002) primarily focuses on this approach.

In order to implement the scheduling delay method of measuring reliability, one must be in a situation where the preferred arrival time is known. In this situation, the optimal departure time can be calculated for a given trip time distribution by choosing that time which minimizes the expected costs of arriving early or of arriving late. As roadways become more reliable, travelers optimally adjust their departure time to reduce expected costs. The value of improved reliability is therefore the reduction in expected early and late costs.

The second, mean-dispersion, method places monetary values on measures of variation in trip-time distribution, instead of costs of arriving early or late. The method achieves this goal by specifying a utility function that is directly influenced by the average travel time, the variation of travel time, and the monetary costs. Similar to the value of time, the value of reliability is the tradeoff people are willing to make between reliability and monetary costs $\left(\frac{\partial U/\partial Reliability}{\partial U/\partial \$}\right)$. Also like the estimates for the value of time, discrete choice econometric models are used to derive the tradeoffs. Tseng (2008) and Carrion and Levinson (2011) offer literature reviews on both the schedule delay and mean-dispersion approach to reliability.

Empirical estimates of the value of reliability are most often derived from carefully constructed surveys in which people answer how they would respond to hypothetical trips of different reliability. Known as “stated preferences”, these methods are always subject to the criticism of being hypothetical and not necessarily demonstrative of actual driver behavior. An alternative method, known as “revealed preference”, use data from special situations to uncover what actual behavior implies about the value of reliability. For example, Small, Winston, and Yan (2005) combined actual decisions of whether a driver chose to pay a toll in order to use a congestion free lane with hypothetical survey questions to estimate the value of travel time and reliability.

To apply such measures with ITS improvements, empirical estimates of the trip time distribution must be measured to calculate how those improvements changed roadway reliability. Unfortunately, there has been no agreement on how measures of reliability should be measured. Most reports define variability as the standard deviation, coefficient of variation, or percentile differences and report the value of these specific measures. There are two reasons for such discrepancies. First, there is no theoretical reason to prefer one measure of variation over another. Second, it is difficult to convey mathematical parlance in surveys.

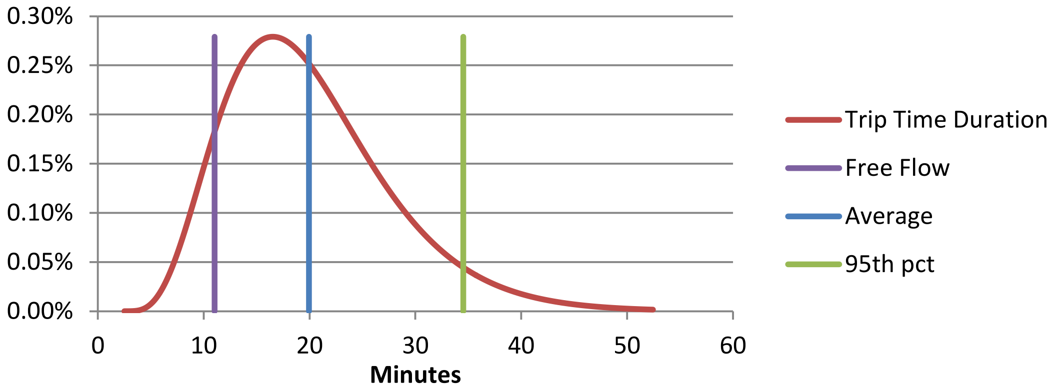
To combat the inconsistent methods, meta-analyses often apply transformative ratios to different reliability measures in an attempt to approximate the standard deviation of a normal distribution. The *reliability ratio*, calculated as the value of reliability divided by the value of time, can then be compared across studies. For example, using the estimates of Carrion and Levinson (2011), the average reliability ratio found in the literature is 0.98. This implies that improving the standard deviation of a trip time distribution by one hour is valued at nearly 98% of one hour of saved travel time.

However, the estimates are still sensitive to a number of factors, such as country, time of day, etc. More empirical research is needed before measures of traffic reliability can be valued as monetary benefits to society. Perhaps because the economics literature has failed to come up with a consistent way of valuing reliability, the Federal Highway Administration has pushed for four alternative methods of measuring reliability. Each measure expresses a characteristic of a distribution of travel times. Specifically, for any given trip time distribution, the FHWA suggests one of the following measures of effectiveness be estimated:

a. Planning Time = 95th Percentile
b. Planning Time Index = 95th Percentile / Free Flow
c. Buffer Time = 95th Percentile – Average Time
d. Buffer Index = (95th Percentile – Average Time) / Average Time

Figure 3 on the following page demonstrates a hypothetical trip distribution and the corresponding points in the distribution that would enable each of these four measures to be calculated.

Figure 3 Hypothetical Distribution of Trip Times



The Planning Time reflects the shortest trip duration that is greater than at least 95 percent of the vehicles trip times. For example, consider the hypothetical distribution of trip times shown in Figure 3. In this example, 95% of vehicles take no longer than 35 minutes for the particular trip. This implies that a traveler wishing to risk no more than a 5% chance of being late would have to allocate 35 minutes to make this trip.

The Planning Time Index divides the Planning Time by the Free Flow Time. In this case, we assumed that the free flow time was 11 minutes, so that the Planning Time Index equals 3.2. As congestion increases and the Planning Time increases, so too does the Planning Time Index. Thus, it is not uncommon for the Planning Time Index to increase during peak demand periods.

For a traveler wanting to risk being late no more than 5% of the time, the Buffer Index is a term that indicates how many minutes that traveler needs to allocate to the trip *in addition to* the expected time of travel. For example, in the hypothetical example shown in Figure 1, the average travel time is 20 minutes, but 35 minutes is the duration at the 95th percentile. This implies that the driver would need to leave at least 15 minutes of buffer time in addition to the average travel time in order to be late no more than 5% of the time.

The Buffer Index is the Buffer Time expressed as a percent of average trip time. For example, the additional 15 minutes of Buffer Time that a driver would need to give himself or herself not to be late in the example above is 75% of the average trip time. Like the Planning Time Index, the 95th percentile increases during periods of high congestion. However, the denominator to the Buffer Index (average travel time) also increases during periods of high congestion, implying that it is theoretically possible for the Buffer Index to decrease during periods of high congestion. Of course, since distributional tails are likely more sensitive to changes in congestion than averages, the Buffer Index will almost certainly increase with congestion.[10]

One advantage of the measures of trip time reliability is that they describe reliability in a way that is easy for a driver to comprehend and simple to calculate given appropriate data. The disadvantage of using these measures is that their value to travelers is not yet understood well enough to convert into monetary benefits. For example, the 95th percentile chosen in the above concepts is highly stylized, and any other percentile above the median would be just as appropriate. Some travelers, for example, may not have a specific arrival time or may have a flexible arrival time, and therefore care little about being late. Of course, other travelers may be more sensitive of arriving too early (suggesting a lower percentile should be used) or of arriving too late (suggesting a higher percentile should be used).

Ultimately, which percentile should be used is an empirical issue. As future economic research integrate such measures into stated preference econometric models, it is possible that consistent practice will emerge much like the valuation of saved travel time.

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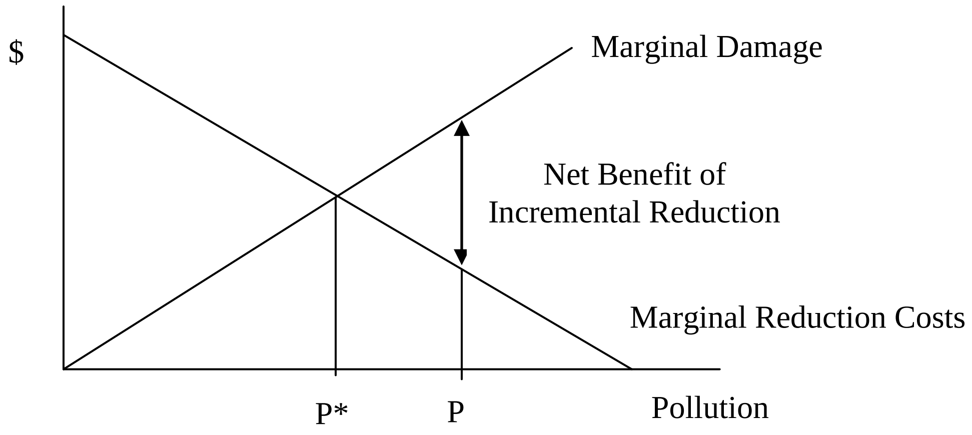
[10] For multiple segments, the Buffer Index and Planning Time Index are calculated using a weighted average based on each segment’s associated vehicle-miles travelled.

Figure 4 Theoretical Treatment of Pollution Damage



Value of Pollution Reduction

The last major section we address in this brief concerns the valuation of pollution. By reducing congestion and increasing speeds, ITS improvements also reduce vehicle emissions. However, like the value of saved travel time and the value of reliability, it is difficult to quantify the benefits of pollution reduction directly. Also like the value of time, the monetary costs of pollution has been major a topic in economics. In this section we briefly review the theoretical justification and empirical estimates for the valuation of reduced transportation emissions.

Theoretically, the social value of reducing vehicle emissions is simple. The value equals the marginal damage of those emissions minus the marginal costs of reduction. The optimal level of pollution is where the marginal damage equals the marginal costs, indicated by point P* above. Assuming that the current laws and regulations have not already placed society at this point or lower level of pollution, then society will currently emit more pollution than is socially optimal (indicated at point P). If so, there will be a net benefit to society as pollution is reduced (from P to P*).

In the context of a reduction in emissions through an ITS improvement, the costs of cutting pollution refers to the cost of implementing an ITS program. Since most cost-benefit studies treat costs separately from benefits, economic studies tend to concentrate on the damage of vehicular emissions.

There are traditionally two ways that economists use to estimate the damage from pollution.[11] The first technique, known as the "control-cost" method, assumes that government policy has already placed society at the optimal level of pollution (P*) by imposing fines on companies for noncompliance. Under this assumption, the marginal damage of pollution equals whatever fines are imposed for exceeding certain threshold amounts. However, because the fines imposed by government regulatory agencies are primarily motivated to guarantee compliance or for political reasons, it is doubtful that such fines actually reflect the true social values.

The second method, called the "damage-valuation" method, models the damage of emissions directly. There are four basic steps in this method. The first step chooses which chemical compounds are considered to be pollutants. The second step estimates how these pollutants affect air quality due to vehicular transport.[12] The third step estimates how air quality impacts human health, and the final step places a monetary value on those changes in human health. As a result of these four steps, vehicle emissions can be linked to monetary damage. While there is uncertainty at each of these levels, the final step is notorious for highly variable estimates, sometimes differing by an order of magnitude (Delucchi, Murphy, and McCubbin, 2002).[13]

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[11] Hedonic pricing methods have also been used. In these models, the value of pollution is estimated by forming a relationship between an area's concentration of pollution and the price of housing.

[12] Environmental and engineering software programs, such as EPA's MOVES model, enables users to estimate how changing vehicular traffic patterns will affect the concentration of many different types of pollutants.

[13] Estimating the value of human health is a very contentious field known as forensic economics. Researchers use both stated-preference and revealed preference to estimate these relationships. For example, surveys may ask how much money people would accept for a small increase in the chance of lower health. The probability of reduced health is adjusted to a "statistical life", and their answers are adjusted similarly to give that statistical life value. Adjustments based on the age and pre-existing health of persons are also common-practice. For a healthy young adult, values of life range from less than $1 million to more than $10 million are common.

Table 2 Estimated Cost per Ton of Vehicle Emissions

	HERS-ST	CHART	Small
HC	-	6,700	-
CO	100	6,360	-
VOC	2,750	-	2,920
NOX	3,625	12,875	10,670
SO2	8,400	-	109,900
PM	4,825	-	102,000
Road Dust	4,825	-	-
CO2	-	23*	-
Year ($)	2000	2008	1992

* $/metric ton

As a result of estimating the highly contentious value of life, there has not been much agreement in the estimating the damage of pollution. Likely due to a need for consistency, most empirical applications that monetize pollution reductions rely on historical valuations of pollution. For example, a 2009 performance evaluation report by Maryland's Coordinated Highway Action Response Team (CHART) references damage costs of pollutants found in a 1998 article by DeCorla-Souza, et al. The 1998 DeCorla-Souza article references a 1995 article by Wang and Santini, which was itself a meta-analysis of previous estimates. Similarly, the technical documentation for the Highway Economic Requirements System-State Version (HERS-ST) uses pollution costs calculated from a 1994 study by McCubbin and Delucchi.

The Federal Highway Administration (2011) explicitly warns that “[m]uch uncertainty surrounds” monetized values of reducing pollution. They go on to say that “[v]alues can vary from project to project due to location, climate, and pre-existing environmental conditions.” Table 2 demonstrates this by listing three widely cited estimates of reducing one ton of pollution. The table indicates that not only are the values quite different, the literature does not necessarily focus on the same types of pollutants. Given such dispersion, the US DOT advises analysts to run sensitivity tests on the variety of per-unit emission values.

State agencies, such as Delaware Department of Transportation and the Department of Natural Resources and Environmental Control, do not use a monetary value when assessing the benefits of pollution reduction. Instead, the agencies merely respond to the mandated limits as specified by the Environmental Protection Agency (EPA). The Clean Air Act gives the EPA the regulatory authority to demand that current pollution and projected future pollution levels be below a specified threshold. Based on discussions with agency representatives, the penalties for failing to meet attainment or conformity are so large, that the control-cost method of pricing pollution is unlikely to reflect social benefits.

Benefits from reducing pollution are highly variable and depend critically on valuation of health, so from a practical matter analysts should be cautious about aggregating the financial value from pollution reduction with other, more consistent measured financial benefits (e.g. fuel costs, maintenance, value of time, etc.). Empirical applications should heed the FHWA’s (2011) advice and run sensitivity tests on various values of pollution reduction, as was done in Daniel and Bekka (2000).

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