# 3 DEMAND SIDE: CONSUMER SURPLUS METHODOLOGY

**Introduction:** For the purposes of the Ohio Hub Study the US DOT FRA Cost Benefit Methodology was adopted. This methodology as set out in the US DOT FRA report "High Speed Ground Transportation for America" September 1997[6] and as also used in the assessments of the "Maglev Deployment Program" October 1999[7] provides the most authoritative guide to the US DOT FRA economic evaluation requirements for an intercity rail project to attract federal funds. It should be noted that the US DOT FRA regards these requirements as the minimum to attract funding. The analysis also recognizes that there are often benefits that it has not considered, e.g. land use impacts.

**Definition**: In normative or allocative economics, the worth or value of a thing to a person is determined simply by what a person is willing to pay for it. If a person is willing to pay $100 for a gallon of cider, it may be inferred that it is (in his own estimation) worth to him no less than $100. If the gallon is priced at $5, the purchase of one gallon of it provides him with a consumer's surplus of $95 (i.e. $100 less $5).

The consumer's surplus is one of most crucial concepts in the measurement of social benefits in any social cost-benefit calculation and typically accounts for 40 to 60 percent of the benefits. For all except marginal changes in the amount of a good, the market price prevailing in a perfectly competitive setting is an inadequate index of the value of the good. Using partial analysis, therefore, the economist engaged in a cost-benefit calculation has to go beyond a simple price, times quantity measure of the benefits arising from the products or services of a project. Instead, ceteris paribus (all things being equal), the economist makes use of the area under the entire demand curve. Even in common sense terms, when an investment project is designed to save some part of the costs incurred in making use of existing facilities, the consumers' surplus concept is implicit in the cost-saving calculation. Indeed, the magnitude of this cost saving is itself no more than a part, the major part it is true, of the horizontal segment of consumers' surplus that is measured by the fall in the price of the service. In addition, as a result of a reduced price, new purchasers will enter the market and inasmuch as they are willing to pay a price higher than that proposed they will also receive a benefit.

Given that the market demand curve is the required analysis framework, it is important to understand what goes into its profile. This will include the nature of the population for given size, tastes, the price of all other goods and productive services, and the distribution of society's assets among its members. A change in any of these things can change the shape of the demand curve in question. Any resulting change in the measure of consumers' surplus will then require careful interpretation. It should be noted that the interpretation of consumers' surplus demands a reversal of the causal direction usually implied in the interpretation of the demand curve. Instead of analysis considering the maximum amount consumers are willing to buy at a given price, the analysis considering the maximum price the consumers are willing to pay for the last unit of that good.

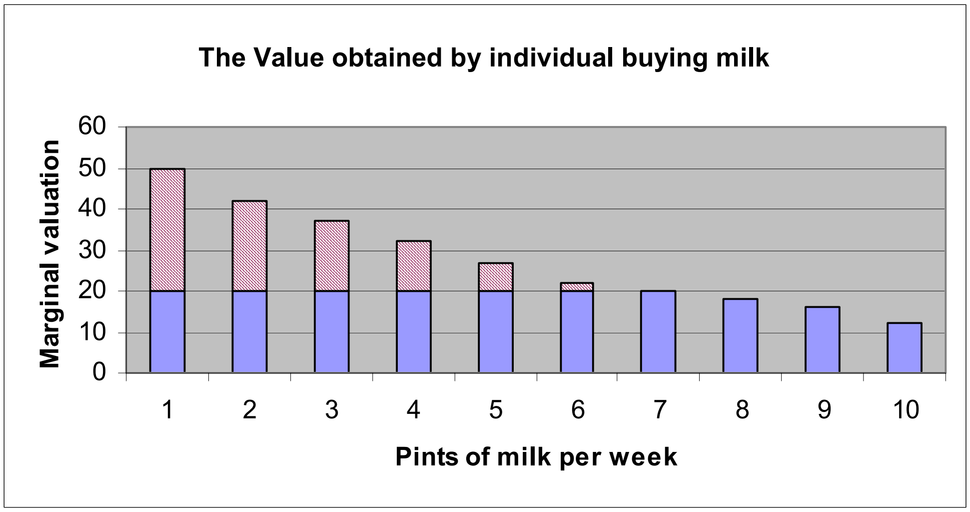
Alfred Marshall [14] provided a simple yet workable definition of consumer's surplus: the maximum sum of money a consumer would be willing to pay for a given amount of the good, less the amount he actually pays. We may extend the idea by thinking about asking a consumer the maximum sum per week he would be willing to pay for a good, say, one pint

[6] The report is available online on www.fra.dot.gov/Downloads/RRDev/cfs0997all.pdf

[7] For more details see: http://www.fra.dot.gov/us/content/567

of milk, the maximum sum he will then pay for a second, the maximum for a third, and so on. These sums, which we can speak of as 'marginal evaluations', are plotted as the heights of successive columns in Exhibit 3.1. If a price per pint of milk is fixed at, say twenty cents, he continues to buy additional pints of milk until his marginal valuation is equal to that price. Exhibit 3.1 illustrates a case in which the person buys seven pints of milk at twenty cents, so spending $1.40 per week on milk. The area contained in the shaded parts of the columns above the price line is a sum of money equal to the person's consumer's surplus.

Exhibit 3.1

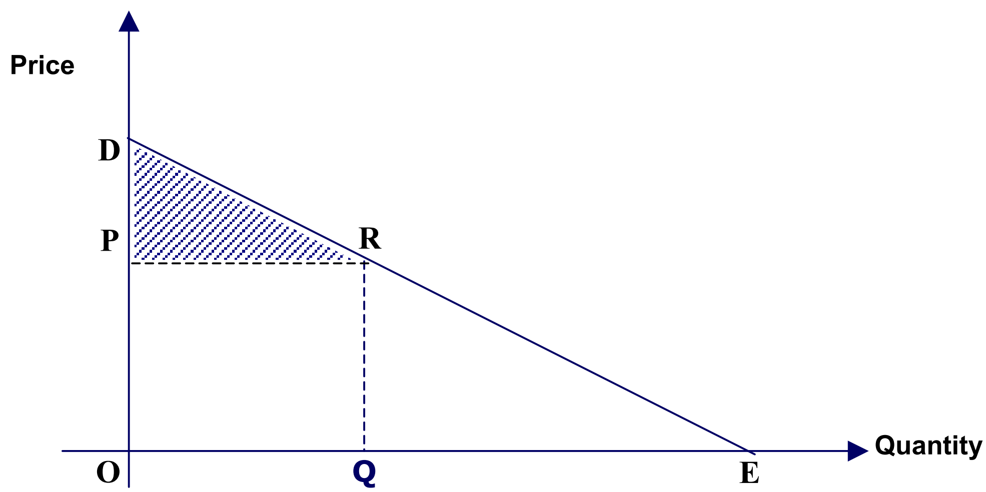



Once perfect divisibility is assumed, the stepped outline of the columns gives way to a smooth demand curve. From a point on the vertical, or price axis, the horizontal distance to the curve measures the maximum amount of the good he will buy at that price. The market demand curve, being a horizontal summation of all the individual demand curves, can be regarded as the marginal valuation curve for society. For example, the height QR in Exhibit 3.2, corresponding to output OQ, gives the maximum value some person in society is willing to pay for the $Q^{th}$ unit of the good—which, for that person, may be the first, second or nth unit of the good bought. But to each of the total number of units purchased, which total is measured as a distance along the quantity axis, there corresponds some individual's maximum valuation. The whole area under the demand curve, therefore, corresponds to society's maximum valuation for the quantity in question. If say, OQ is bought, the maximum worth of OQ units to society is given by the trapezoid area ODRQ. Now the quantity OQ is bought by the market at price OP. Total expenditure by the buyers is therefore represented by the area OPRQ. Subtracting from the maximum worth of buyers what they have to pay leaves us with a total consumers' surplus equal to triangle DRP.

If an entirely new good x is introduced into the economy, and is made available free of charge, the area under the resulting demand curve, ODE (given that prices of all other goods are unaffected) is a good enough measure of the gain to the community in its capacity as consumer. This is the methodology that is typically used for justifying highway investments, based on the user's value of time savings. Again, however, if the project is a rail project and a price OP is charged for the use of the system, the amount OQ will be bought, leaving the triangular area PDR in Exhibit 3.2 as the consumers' surplus. This is the estimated consumers' surplus that needs to be entered as benefits in all cost-benefit calculations.

It is worth noting that because many transport projects often do not charge a price to users, e.g. new highways, bridges, tunnels, while other projects do charge users for services offered e.g. railroads, airlines, buses, the US DOT FRA has recommended including revenues (a transfer payment to operators) within the benefits of a Cost Benefit analysis. This is to assure modal equity and treat all modes equally in the project evaluation process.

Exhibit 3.2




**Consumer Surplus for a Good or Service**

Any investment having the object of reducing the cost of a product or service is deemed to confer a benefit on the community, often referred to as a cost difference or cost saving. The benefit of a new motorway, or flyover, is estimated by reference to the expected savings of time, and of the cost of fuel and other resources, by all motorists who will make use of the new road or flyover.

It has become the convention in transport economics to argue that time has value and as such economists have measured the value of time.[8] In transportation economics cost-benefit analysis it is agreed that both time and money have a cost and that they should be incorporated into a single metric called "generalized cost".

Generalized cost is defined as:

$$GC_{ijmp} = TT_{ijm} + \frac{TC_{ijmp}}{VOT_{mp}} \qquad (1)$$

[8] Measurements suggest that business time is valued at 20-50 dollars per hour, while commuter and social trips are valued at 10-20 dollars per hour.

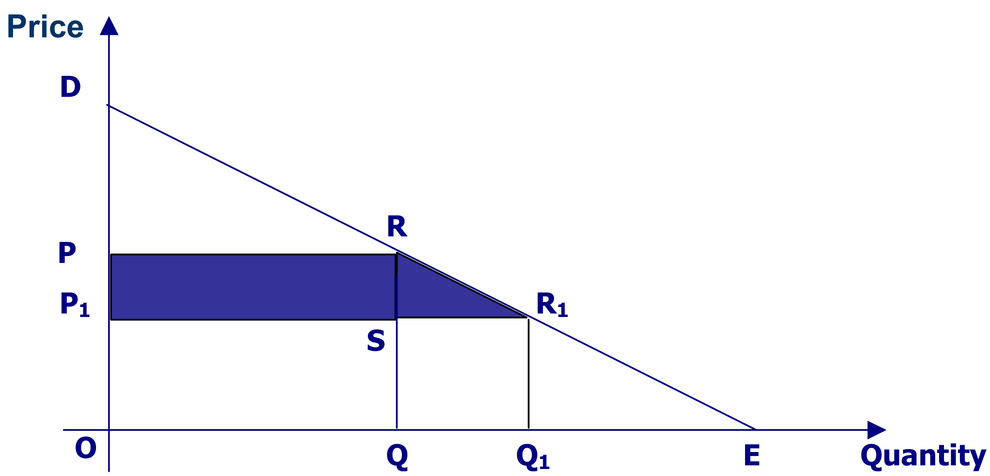
Where:

$TT_{ijm}$ = Travel Time between zones i and j for mode m;
$TC_{ijmp}$ = Travel Cost between zones i and j for mode m and trip purpose p;
$VOT_{mp}$ = Value of Time for mode m and trip purpose p.

In transport economics cost-benefit studies, the price of travel is redefined to include both the time and cost of travel as specified in the generalized cost metric.

As already indicated, however, the concept of cost-saving is derived directly from the concept of consumers' surplus, as can be shown by reference to Exhibit 3.3. Thus, prior to the introduction of a new transport system, the consumers' surplus as measured by time and money savings from using this particular facility is the triangle PDR. If the facility halves the cost of the journey (in terms of both time and money) from OQ to $OQ_1$, the consumers' surplus increases from PDR to $P_1DR_1$, an increase equal to the shaded strip $PP_1R_1R$.

Exhibit 3.3




**Consumer Surplus as a Result of Reduced Price**

This increase of consumers' surplus can be split into two parts. The first part is the cost-saving component, the rectangle $PP_1SR$, which is calculated as the saving per journey, $PP_1$, multiplied by the original number of journeys made, OQ. The other component, represented by the triangle $SRR_1$, is the consumers' surplus made on the additional journeys undertaken, $QQ_1$, either by the same motorists or by additional motorists. The cost saving item that enters a cost-benefit calculation is, as indicated, no more a portion of the increment of consumers' surplus from a fall in the cost of the good. Since it takes no account of the additional goods that will be bought in response to the fall in cost, the cost-saving rectangle alone can be accepted as a minimum estimate of the benefit.

The extent of the collective improvement from the introduction of a transport facility is, then, expressed in terms of a sum of money (in terms of cost and time) that is measured by a triangle of consumers' surplus, such as PDR in Exhibit 3.3. Its interpretation is simply the maximum amount of money the group, as a whole, would offer in order to be able to buy OQ of this new good at price P. The extent of the collective improvement from a reduction in its price, however, is expressed as an increment of consumers' surplus, as for example the strip $PP_1R_1R$ in Exhibit 3.3. The strip can be interpreted as the maximum amount of money the group as a whole would offer in order to have the price reduced from OP to $OP_1$.

Thus:

Consumer Surplus = Area (Rectangle PRP1S) + Area (Triangle $RSR_1$)

$$\text{Consumer Surplus} = PR * PP_1 + ½ * RS * SR_1 \qquad (2)$$

**Consumer Surplus Measurement:** The analysis of Consumer Surplus is based on a measurement of the improvements in generalized cost of travel, which includes both time and money provided by a transport investment. Time is converted into equivalent monetary values by the use of Values of Time. The Values of Time (VOT) used are derived from stated preference surveys used in the TEMS COMPASS™ Multimodal Demand Model for development of the ridership and revenue forecasts (see Chapter 5). These VOTs are consistent with previous academic and empirical research.

The Consumer Surplus benefits are measured as the sum of both system revenues and consumer surplus. Consumer surplus is defined as the additional benefit consumers receive from the purchase of a commodity or service (travel), above the price actually paid for that commodity or service. Consumer surpluses exist because there are always consumers who are willing to pay a higher price than that actually charged for the commodity or service, i.e., these consumers receive more benefit than is reflected by the system revenues alone.

Revenues are included in the measure of consumer surplus as a proxy measure for the consumer surplus foregone, because in the Ohio Hub rail study the price of rail service is not zero. This is an equity decision made by the USDOT/FRA to compensate for the fact that highway users don't have to pay for use of the road system (the only exception being the use of toll roads etc). FRA's decision recognizes that operating revenues are in fact a portion of consumer surplus benefits that have been transferred from the rail user to the rail operator[9]. The benefits apply to existing rail travelers as well as new travelers who are induced (those who previously did not make a trip) or diverted (those who previously used a different mode) to the new passenger rail system.

The COMPASS™ Demand Model estimates consumer surplus by calculating the increase in regional mobility, traffic diverted to rail, and the reduction in travel cost measured in terms of generalized cost for existing rail users. The term 'generalized cost' refers to the combination of time and fares paid by users to make a trip. A reduction in generalized cost generates an increase in the passenger rail user benefits. A transportation improvement that leads to improved mobility reduces the generalized cost of travel, which in turn leads to an increase in consumer surplus.

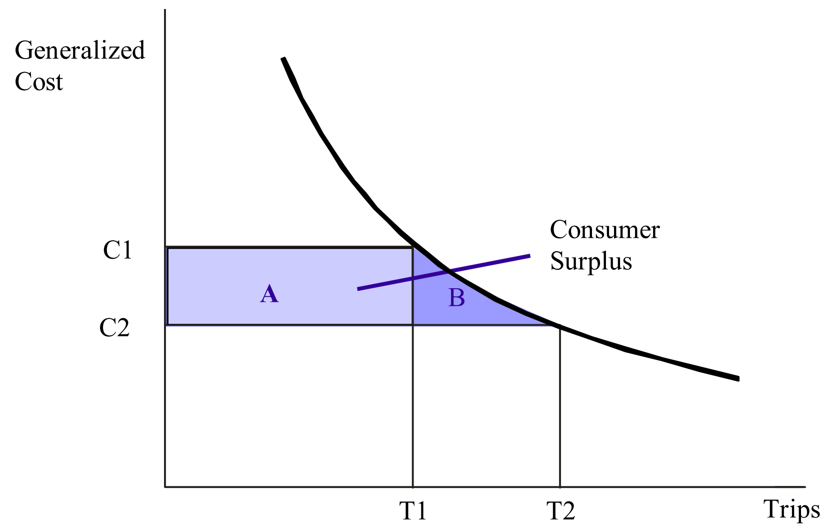
It should be noted that passenger rail fares used in this analysis are those used for development of the Ohio Hub financial projections and operating ratios. As a rule, these fares are slightly lower than the average optimal fares derived from the revenue-maximization analysis that was performed for each Ohio Hub corridor. Charging slightly less

[9] Note that inclusion of rail revenue is equitable, since rail operating costs are also included as a cost of the system. Therefore a positive operating ratio (where rail revenues exceed operating costs) tends to improve the cost benefits ratio, whereas a requirement for an operating subsidy would tend to reduce it.

than the revenue-maximizing fare, greatly increases the ridership and consumer surplus associated with the system without reducing the revenues by very much.

Exhibit 3.4 presents a typical demand curve in which Area A represents the improvement in consumer surplus resulting from generalized cost savings for existing rail users, while Area B represents the consumer surplus resulting from induced traffic and trips diverted to rail.

Exhibit 3.4: Consumer Surplus Concept




The formula for consumer surplus is as follows:
Consumer Surplus = $(C_1 - C_2)*T_1 + ((C_1 - C_2)*(T_2 - T_1))/2$ (3)

Where:

- $C_1$= Generalized Cost users incur before the implementation of the system;
- $C_2$= Generalized Cost users incur after the implementation of the system;
- $T_1$= Number of trips before operation of the system;
- $T_2$= Number of trips during operation of the system.

**Other Mode Benefits:** In addition to rail-user benefits, travelers by auto or air will also benefit from the Ohio Hub, as the system will contribute to highway congestion relief and reduced travel times for users of these other modes. For purposes of this analysis, these benefits will be measured by identifying the estimated number of air and auto passenger trips diverted to rail and multiplying each by the benefit levels used in the FRA/USDOT study[10].

• ***Airport Congestion***: Using projections from the COMPASS™ Model[11], benefits to air travelers resulting from reduced air congestion are to be identified by estimating the

[10] High Speed Ground Transportation for America. US DOT FRA. September 1997.

[11] Compass-R™ Strategic Transportation Planning Model. User Guide Version 2.1 Transportation Economics & Management Systems, Inc. 1995

number of passenger air trips diverted to rail in Ohio Hub study area in 2020 (the comparable year for the FRA study).

The FRA estimated travel time saved by air passengers (those not diverted to rail) due to reduced congestion, deviations from scheduled flight arrival and departure times, and additional time spent on the taxiway or en route. For each major airport, average delays were capped at 15 minutes per operation. The FRA calculated the Net Present Value (NPV) of this benefit for diverted air trips throughout the study period.

• ***Highway Congestion***: There will be reduced congestion and delays on highways due to auto travelers diverting to the Ohio Hub. The FRA methodology calculated the travel time saved when traffic volumes are reduced on major highways between city pairs.

**Resources Benefits:** The implementation of any transportation project has an impact on the resources used by travelers. Ohio Hub service and the consequent reduction in airport congestion will result in resource savings to airline operators and reduced emissions of air pollutants for all non-rail modes.

• ***Air-Carrier Operating Costs***: Benefits to air carriers in terms of operating costs savings resulting from reduced congestion at airports are calculated in much the same way as the time savings benefits to air travelers. For its study corridors, the FRA study estimated the benefits to air carriers by multiplying the projected reduction in the number of aircraft hours of delay by the average cost to the airlines for each hour of delay. As noted above, average delays were capped at 15 minutes per operation. The NPV of air carrier benefits was estimated at $623 million for the 110-mph scenario, or the equivalent of $28.13 per diverted passenger air trip. A discounted 30-year air carrier benefit is estimated over the life of the Ohio Hub project.

• ***Emissions***: The diversion of travelers to rail from the auto and air modes generates emissions savings. The Emissions methodology used in the Ohio Hub study follows closely the methodological framework that was established by the 1997 FRA Study. The FRA calculated emissions savings based on changes in energy use with and without the proposed rail service[12]. The FRA developed region-specific factors that accounted for the status of compliance with air quality regulations in the counties through which each route passes, and the projection year. Access and egress modes were considered in addition to the line-haul portions of trips. The valuation of emissions savings calculated by the FRA study recognized the attainment status of the impacted counties for all emissions except carbon dioxide (CO2) and sulfur oxides (SOx.) CO2 was valued at $15 per ton based on CO2's impact on the global greenhouse effect, while SOx was valued at $600 per ton based on estimates for the value of emission allowances traded on the commodities market at the time of the 1997 study. For other emissions, the value reflected control costs in non-attainment counties, with no value assigned for emissions within attainment counties.

As a result, the Emissions component of the Ohio Hub benefits assessment is based on the projected dollar value of emissions savings only in non-attainment areas. The 1997 Commercial Feasibility Study did not report the exact emissions tonnage nor did the study report the detail on the imputed value calculation that was applied to that tonnage in each county. As well, the 1997 study reported results only for a three-route Chicago Hub system,

[12] High Speed Ground Transportation for America. US DOT FRA. September 1997, pp. 6.8-6.9

which was taken as the most representative available system for estimation of Ohio Hub factors. These 1997 study results, expressed in dollars, were directly scaled on a passenger-mile basis to the Ohio Hub and adjusted for inflation, but the underlying calculation of emissions tonnages is not available.

In addition, a number of changes have occurred in development of both highway and rail vehicle technology since the 1997 FRA study was performed. Initially, there was a trend towards larger SUV highway vehicles with poorer gas mileage but presumably better emissions controls. More recently because of higher gasoline prices and introduction of hybrid vehicle technology, there is a trend back towards smaller highway vehicles. In rail, new EPA regulations have required the development of more efficient diesel locomotive technology with direct application of emissions controls in both running and idling modes[13]. These new technologies will improve the emissions performance of any new trainsets that may be deployed on the Ohio Hub system.

As a result, the level of emissions benefit reflected in the current Ohio Hub study reflects the value of savings that occur in CMAQ non-compliance areas only and ignores savings in other areas. Furthermore, the calculations themselves, although consistent with 1997 FRA results, do not reflect the most recent trends in the efficiency of both highway and rail vehicles. Although the current estimate of the value of emissions savings is reasonable for planning at a feasibility level, it is recommended that a more detailed calculation be undertaken as a part of the Ohio Hub EIS process.

For the Ohio Hub, it was assumed that emissions savings would be proportional to the number of diverted auto vehicle miles. The resulting auto vehicle miles saved was divided by the estimate of emissions benefit, yielding a FRA estimated benefit of $0.02 per vehicle mile. This value, multiplied by the number of vehicle miles saved by implementation of the Ohio Hub, yields an estimate of total emission benefit.

• ***Fuel Savings***: Appendix F details an estimation of the fuel savings attributable to the Ohio Hub. The calculation was done in three steps –

- Step 1: Estimate Fuel Rates per Passenger-Mile for each mode;
- Step 2: Estimate Passenger-Mile Diversion from Each Mode, along with Induced Demand;
- Step 3: Calculate Net of Fuel Savings: Savings of each mode, minus Projected Rail Fuel Consumption.

Between 1970 and 1990, auto average fuel efficiency improved; but since then, in spite of the continued improvement in automotive technology, consumers have preferred to purchase larger and more powerful, instead of more fuel-efficient cars. However, in the past two years, the average fleet efficiency is starting to improve again as higher fuel prices have forced consumers to start choosing more economical models.

Airline fuel efficiency has shown a continuing improvement; as a result not only of improved aircraft design but also airline revenue management techniques which have improved average aircraft load factors. However, rail tends to divert trips away from short-distance air routes, which because of the high proportion of fuel consumed in take-off and landing, are the least fuel-efficient air routes. Accordingly the fuel savings from air to rail diversion can still be substantial.

[13] See: http://www.epa.gov/oms/locomotv.htm

Buses are the most fuel-efficient form of transportation, requiring even less fuel than rail because of their lighter vehicle weight and lower speeds. However bus diversion is small because the train ticket is priced higher than bus. Trains are better able than buses to divert riders away from the automobile, which is the least fuel-efficient form of transportation, resulting in a higher net fuel savings than a bus-only system could provide.

The Ohio Hub trains are themselves projected to consume 8.2 million gallons annually, as compared to 17.6 million gallons saved by other modes, resulting in a net fuel savings of 9.4 million gallons per year.

**Costs:** In the economic analysis, costs were separated into three primary components - infrastructure and rolling stock capital costs, capital track maintenance costs associated with the long-term infrastructure replacement and operating and maintenance costs.

• **Capital Costs**: Capital costs were based on the up-front costs for infrastructure improvements and the rolling stock required for the proposed Ohio Hub implementation plan. It was assumed that 80 percent of the capital costs would be funded by the federal government beginning in the year 2004. (GANs or GARVEE bonds would be used to address any temporary funding shortfalls due to the annual Federal funding budget cap.) Capital funds would be used on an as-needed basis in accordance with the implementation schedule. The NPV of the total infrastructure and rolling stock capital costs for the Ohio Hub can then be estimated.

• **Capital Track Maintenance Costs**: Capital track maintenance costs were not included in the operating ratio calculation, but they do enter into the costs benefit ratio. As compared to the ongoing operating costs for the system, the capital track maintenance costs (NPV) are quite small. This is because track capital maintenance costs are largely not incurred until the end of the project when the daily use of the system is beginning to wear out the track.

• **Operating Costs**: Operating costs were compiled for the Ohio Hub project, and they include the costs associated with the implementation period. The NPV of the operating costs over the 30 years lifespan of the project will be estimated to provide the total cost for the analysis.

**Measures of Economic Benefit:** Two measures of economic benefit were used to evaluate the alternative options – net present value (NPV) and cost/benefit ratio, which are defined as follows:

Net Present Value = Present Value of Total Benefits – Present Values of Total Costs

Cost Benefit Ratio = Present Value of Benefits / Present Value of Costs

$$\text{Cost Benefit Ratio} = \frac{\text{Present Value of Benefits}}{\text{Present Value of Costs}}$$

Where:

Present Value is defined as:[14]

$$PV = \sum C_t / (I + r)^t$$

[14] See [15] for details.

And where:

PV= Present value of all future cash flows;
$C_t$ = Cash flow for period *t;*
r = Opportunity cost of money;
t = Time.

**Discount Analysis:** For the purposes of the Ohio Hub Economic Impact Study a 30-year life was defined for the project. As a result all cash flows were estimated in Present Value terms by applying a discount rate to the 30-year cash flow.

**Discount Rates:** A Cost Benefit analysis requires that a discount rate is selected in order to identify the real cost of money for a project. GAO guidelines require that "real" (inflation-adjusted) rather than "nominal" interest rates be used in discounting calculations. In Investment Grade studies for Wall Street, TEMS, Inc. would use a 3.9 percent real discount rate that reflects the cost of long-term government bonds. This rate reflects the real cost of money for a project like the Ohio Hub and as such shows the real value of the project. This rate corresponds to the rate used in other recent studies[15]. Although FRA suggests using a seven percent real discount rate it also assumes the possibility of using a four percent rate[16]. Taking into account that current 30-year interest rates on treasury notes and bonds is 3.0[17], we see that the seven percent level of discount rate is in fact a "rationing" rate that sets the cost of money well above its real cost. This understates the value of a project like the Ohio Hub. However, to ensure that this analysis provides both a full understanding of the Ohio Hub project and a support of the FRA evaluation assumption, both sets of calculations are included.

Other theoretical issues in using Consumer Surplus are described in Appendix A.

[15] See Benefits of High Speed Trains. California High-Speed Rail Authority. http://www.cahighspeedrail.ca.gov/plan/pdf/Plan_4.pdf

[16] Benefits and Costs of Positive Train Control. Report in Response to Request of Appropriations Committees. August 2004, p. 24. (http://www.fra.dot.gov/downloads/safety/ptc_ben_cost_report.pdf).

[17] Office of Management and Budget. Circular # A-94. Revised January 2006. Appendix C. Discount Rate for Cost Effectiveness, Lease Purchase, and Related Analyses, http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html