# A New Tool for Benefit-Cost Analysis in Evaluating Transportation Alternatives

Patrick DeCorla-Souza, Michael Culp, and James Hunt, Federal Highway Administration; and Harry Cohen and Dan Haling, Cambridge Systematics, Inc.

**Abstract**

The Intermodal Surface Transportation Efficiency Act (ISTEA) emphasizes assessment of multimodal alternatives and demand management strategies. This emphasis has increased the need for planners to provide good comparative information to decision-makers. Benefit-cost analysis is a useful tool to compare the economic worth of alternatives and evaluate trade-offs between economic benefits and non-monetizable social and environmental impacts. In 1995, the Federal Highway Administration (FHWA) developed a sketch planning tool called the Sketch Planning Analysis Spreadsheet Model (SPASM) to assist planners in developing the type of economic efficiency and other evaluative information needed to compare across modes and demand management strategies, at a sketch planning level of analysis for corridor studies. When more detailed analysis is required, however, SPASM cannot be used directly, owing to several simplifying assumptions. (For example, all trips are assumed to be of an average trip length, made between the two ends of the corridor.) Also, it is difficult to use SPASM for systemwide analysis. (Note: We presented a paper on use of SPASM at the Small and Medium-Sized Urban Area Conference in October, 1996).

To allow more *detailed* analysis at both the system and corridor levels, FHWA has developed an enhanced version of SPASM. There are several significant improvements. First, the software accepts input directly from the four step travel demand modeling process or from off-model software such as FHWA's TDM software. Second, it post-processes outputs from conventional four-step planning models, in order to get more accurate highway travel speeds, especially under congested conditions. Third, it performs risk analysis to clearly describe the level of uncertainty in the results of the analysis, so that the debate can shift from unproductive technical controversy to compromise and action.

The software is based on the principles of economic analysis, and allows development of monetized impact estimates for a wide range of transportation investments and policies, including major capital projects, pricing and travel demand management (TDM). Impact measures are monetized to the extent feasible, but quantitative estimates of natural resource usage (i.e. energy consumption) and environmental impact (e.g. emissions) are also provided. Net monetary benefits (or costs) of alternatives can then be used to evaluate trade-offs against non-monetizable benefits, including sustainability and community livability.

This paper provides a case study application of the enhanced software in evaluation of corridor alternatives and system plan alternatives for Toledo, Ohio. The case study demonstrates that the new software can be a useful tool in providing information of interest to decision-makers.

The Intermodal Surface Transportation Efficiency Act (ISTEA) emphasizes assessment of multimodal alternatives and demand management strategies. This emphasis has increased the need for planners to provide good comparative information to decisionmakers. Benefit-cost analysis is a useful tool to compare the economic worth of alternatives and evaluate trade-offs between economic benefits and non- monetizable social and environmental impacts.

In 1995, the Federal Highway Administration (FHWA) developed a corridor sketch planning tool called the Sketch Planning Analysis Spreadsheet Model (SPASM) to assist planners in developing the type of economic efficiency and other evaluative information needed for comparing cross-modal and demand management strategies (DeCorla-Souza, Cohen & Bhatt 1996). When more detailed analysis is required, however, SPASM cannot be used directly, owing to several simplifying assumptions. For example, all trips are assumed to be of an average trip length, made between the two ends of the corridor. Also, it is difficult to use SPASM for systemwide analysis. To allow more *detailed* analysis, FHWA has developed an enhanced version of SPASM, called the Surface Transportation Efficiency Analysis Model (STEAM). The software is currently undergoing field testing.

## Overview Of STEAM

There are several significant improvements in STEAM. First, the software accepts input directly from the four-step travel demand modeling process or from off-model software such as FHWA's TDM software (Comsis 1993). Second, it post-processes traffic assignment outputs from conventional four- step planning models, in order to more accurately estimate highway travel speeds, especially under congested conditions. Third, it performs risk analysis to clearly describe the level of uncertainty in the results of the analysis, so that unproductive technical controversy over unit values or demand estimates can be avoided. Finally, its impact estimates are systemwide, not limited to the improvement corridor.

The software is based on the principles of economic analysis, and allows development of monetized impact estimates for a wide range of transportation investments and policies, including major capital projects, pricing and travel demand management (TDM). Impact measures are monetized to the extent feasible, but quantitative estimates of natural resource usage (e.g., energy consumption) and environmental impact (e.g., emissions) are also provided. Net monetary benefits (or costs) of alternatives can then be used to evaluate trade-offs against non-monetizable benefits.

STEAM is highly flexible in terms of the transportation modes, trip purposes, and time periods analyzed. It provides default analysis parameters for seven modes (auto, truck, carpool, local bus, express bus, light rail, and heavy rail) and allows the user to deal with special circumstances or new modes by modifying these parameters. The user can also provide trip tables for different trip purposes, which will be analyzed separately by the model. STEAM can be applied to average weekday traffic or to peak and off-peak traffic.

## Case Study Analysis

We performed a real-world test of the software, using a case study evaluation of transportation alternatives for the I-15 corridor in Salt Lake City, Utah. In this section, we describe the alternatives analyzed, and procedures used to develop the needed input data. In section 4.0, we discuss impact analysis procedures embedded in the software, and present results of STEAM's impact analysis. In section 5.0, we discuss STEAM's economic efficiency analysis procedures, and results from the case study analysis.

### *Corridor Alternatives*

The limits of the case study corridor are defined by the interchanges of I-15 with the I-215 loop north and south of the city. The corridor is about 12 miles in length. Significant growth is expected in the Salt Lake City region, and in the corridor in particular. Population in the corridor is anticipated to increase by more than 100% while employment is estimated to increase by more than 140% over the next 20 years. This growth is expected to significantly affect traffic flow in the corridor. Traffic on I-15 in the southern portion of the corridor is expected to double.

In a 1995 study (USDOT 1995), four transportation alternatives were proposed for the corridor. For this case study demonstration, we used two of these alternatives (i.e., "No-Build" and "Full Build"), and designed a third alternative, i.e., a "Travel Demand Management (TDM)" alternative, for the purpose of demonstrating the application of the software in TDM analysis. The three alternatives are as described below.

- Do-Nothing or "No-Build" alternative: This alternative included all new capacity projects in the region's Long Range Transportation Plan, except for I-15 improvements. A planned light rail line in the I-15 corridor was included.
- "Build" alternative: This alternative involved the widening of I-15 to include two additional mixed- flow travel lanes in each direction. The section of the I-15 freeway to be expanded currently has 6 lanes, 3 in each direction.
- "TDM/Tolls" alternative: This alternative primarily involved introduction of a $1.00 toll to be collected on I-15 through automated collection techniques at both ends of the corridor (i.e., at each of the two I-215 interchanges), and at all entrance ramps within the corridor. No highway capacity improvements were included. A 25% increase in both bus and light rail service was included, to handle increases in transit demand due to "tolled off" auto users.

*Developing STEAM Inputs from Demand Models*

STEAM uses as input the following output from the four-step travel demand modeling process: (1) person and vehicle trip tables; (2) travel time and cost matrices skimmed from transit and highway networks; and (3) loaded highway network output from traffic assignment.

Travel demand model outputs for the two action alternatives and the No-Build alternative were obtained from runs of the four-step travel demand models developed by the Wasatch Front Regional Council (WFRC). The models were run using WFRC's 2015 Transportation Plan and its 2015 socio-economic forecasts for the WFRC region. For the TDM alternative, we re-coded the highway network to reflect an in-vehicle time penalty equivalent to the toll. The demand modeling procedures are presented graphically on the left side of Figure 1. Both trip table and loaded highway network outputs were obtained for a 24-hour time period. The transit time and cost skims reflected peak period service.

*Defining Market Sectors*

Market sectors for use in STEAM analysis are defined by trip mode, purpose, and time of day. Since the Salt Lake City models produced daily demand estimates, market sectors were defined only by trip mode and purpose. The travel demand models produced person trip tables by mode (auto, bus, walk-accessed light rail and drive-accessed light rail) and vehicle trip tables, for the following four internal trip purposes: Home-based (HB) work, HB non-work, HB college, and Non-HB. Additionally, vehicle trip tables were generated for the following three trip purposes: internal truck, internal-external, and through. For HB work person trips, an additional mode, i.e. "Carpool" was estimated by the models.

Since internal-external and through trips include both passenger and truck travel, the first step would be to break down these two trip tables into auto and truck modes. For Salt Lake City, the truck share of these trips was unknown, so all trips were assumed to be auto mode trips. To run STEAM with Salt Lake City trip tables could potentially require running each of the market sectors shown below:

| Trip Purpose | Auto mode | Carpool | Bus | Walk to Light Rail | Drive to Light Rail | Truck |
|---|---|---|---|---|---|---|
| HB work | X | X | X | X | X | |
| HB college | X | | X | X | X | |
| HB non-work | X | | X | X | X | |
| NHB | X | | X | X | X | |
| Internal truck | | | | | | X |
| Internal-external | X | | | | | potential |
| Through | X | | | | | potential |

To reduce the number of market sectors to be analyzed, the seven trip purposes were collapsed into two: (1) a personal travel purpose and (2) a commercial (truck) purpose; i.e., all non-truck trip purposes were combined into a single "personal travel" purpose, since we planned to use the same values of time and other user benefits irrespective of trip purpose. The resulting market sectors are displayed below:

| Trip Purpose | Auto mode | Carpool | Bus | Walk to Light Rail | Drive to Light Rail | Truck |
|---|---|---|---|---|---|---|
| Personal travel | X | X | X | X | X | |
| Internal truck | | | | | | X |

*Developing Market Sector Inputs*

Auto-occupancies for the personal travel auto and carpool modes were obtained by dividing the sum of regionwide person trips by the sum of vehicle trips for each mode. For the non-highway personal travel modes (bus and rail), average occupancies were estimated from passenger count information. For these modes, travel time "skim" tables and out-of-pocket cost tables were additionally needed. The demand models generated the in-vehicle travel time skims. The models also generated walk skims and wait skims, which were summed by origin-destination pair to get out-of-vehicle travel time skims. The models directly generated out-of-pocket cost skims (in cents) based on transit fares.

**Impact Analysis Procedures**

As shown on the right side of Figure 1, STEAM consists of four modules:

1. A *User Interface Module*, which includes on-line help files and tutorials.
2. A *Network Analysis Module*, which reads a file containing volumes, segment lengths, capacities, and other link data and produces zone-to-zone travel times and distances based on minimum time paths through the highway network.

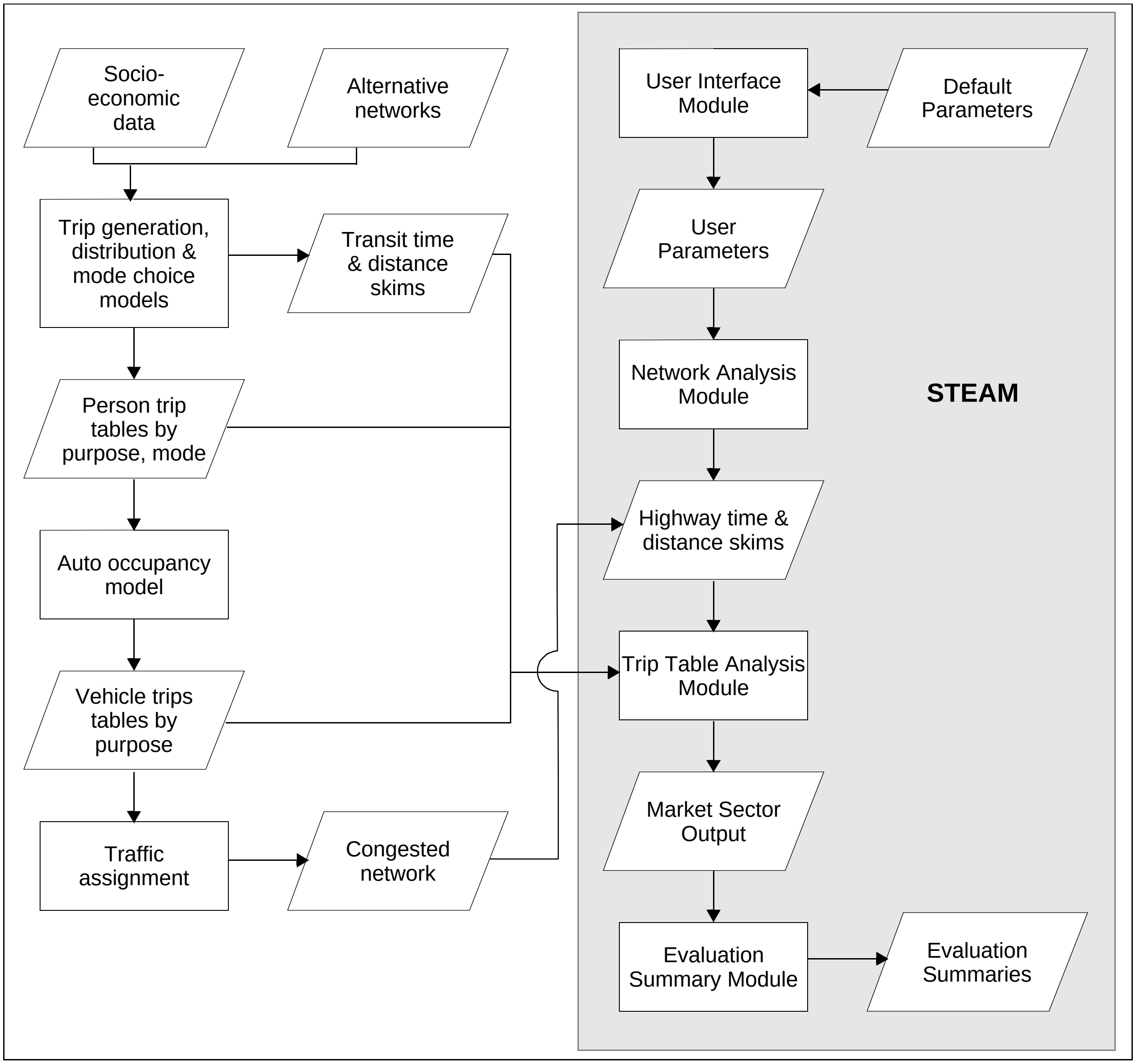


**Figure 1: Overview of analysis procedures**

3. A *Trip Table Analysis Module*, which produces estimates of user benefits based on a comparison of Base Case and Improvement Case conditions. It also produces estimates of emissions, noise costs, accident costs, energy consumption, and other external costs associated with highway use.

4. An *Evaluation Summary Module*, which calculates net present worth and a benefit-cost ratio for the improvement under consideration. It also provides summary information on individual benefit and cost items.

In this section we discuss the speed estimation procedures used in the Network Analysis Module, and procedures used in the Trip Table Analysis Module to estimate emissions and energy consumption.

*Estimating Travel Speed*

As a user option, STEAM estimates travel speeds based on procedures which relate average weekday traffic-to-capacity ratios (AWDT/C) to average hourly delay and speed (Margiotta et al. 1996). The procedures incorporate the dynamic effects of queuing and peak-spreading which are not considered when conventional Highway Capacity Manual (HCM) procedures (TRB 1994) are used with assigned traffic volumes.

To develop these speed relationships, hour-by-hour traffic for typical facilities was first estimated based on the flattening of the diurnal distribution of traffic that occurs in response to increasing levels of congestion at higher AWDT/C ratios. The hour-by-hour traffic estimates were then used to obtain hour- by-hour estimates of congestion delay using the traffic microsimulation models FRESIM and NETSIM (Makemson et al. 1993). The speed relationships thus developed account for spreading of traffic from congested time periods to uncongested time periods, as well as queuing impacts on traffic speeds in successive hours. The procedures thus provide a simple and straightforward method to estimate speeds with greater accuracy, without having to resort to complex peak-spreading and microsimulation models.

*Emissions Analysis*

The conventional link-based emissions analysis approach cannot easily be used to estimate the changes in cold start emissions that may result from demand management actions (DeCorla-Souza et al. 1994). STEAM therefore uses a trip based approach to estimate emissions. In STEAM, emissions for autos, trucks and carpools are calculated as the sum of: (1) emissions due to vehicle miles of travel (VMT), calculated under the assumption that vehicles are already warmed up, i.e., in either the hot-start mode or hot-stabilized mode; and (2) added emissions due to cold starts.

Non-cold start emissions are calculated using emission rates as a function of speed. The added emissions due to cold starts are calculated on a per vehicle trip basis. STEAM allows the user to specify the fraction of vehicle trips starting cold for the peak and off-peak periods; national defaults are provided from recent research (Venigalla, Miller and Chatterjee 1995).

Default emission rates in STEAM for non-cold-start operations were calculated using MOBILE5A by setting the cold start VMT fraction equal to zero, the hot start VMT fraction equal to 0.479 and the stabilized VMT fraction equal to 0.521. The default emission rate due to each cold start in STEAM was calculated by subtracting the gram per mile value (at 26 mph) under hot start conditions from the gram per mile value (also at 26 mph) under cold start conditions, and multiplying the result by 3.59 miles.

*Fuel Consumption Analysis*

Increases or decreases in use of motor fuel are estimated by STEAM by vehicle type (auto and truck) as a function of speed, using fleet average fuel consumption rates (Cohn et al. 1992).

*Impacts of Case Study Alternatives*

Table 1 summarizes travel demand estimates by mode for the whole region, obtained from WFRC travel demand models. Auto person trips include both solo-driver and carpool trips; and transit person trips include both bus and light rail trips. The table also provides estimates from STEAM of average regionwide vehicular travel speeds, emissions, and fuel consumption.

## Economic Analysis Procedures

All benefits are computed by STEAM's Trip Table Analysis Module based on weekday travel estimates for a specific analysis year. Weekday benefits are annualized assuming 250 working days per year. (This may be modified by the user). The analysis year may be selected by the user to be representative of benefits over the analysis period, i.e., the life of the investment. Alternatively, the user may run STEAM with data for several different analysis years, and estimate the stream of benefits over the life of the investment. STEAM analyzes the benefits of transportation actions by market segment.

**Table 1: Travel demand, emissions, and average speeds**

| | No-Build | Build | TDM/Tolls |
|---|---|---|---|
| Weekday Person Trips (in millions) | | | |
| Auto | 5.721 | 5.721 | 5.708 |
| Transit | 0.091 | 0.090 | 0.102 |
| Truck | 0.018 | 0.018 | 0.018 |
| Total | 5.828 | 5.828 | 5.828 |
| Weekday Vehicle Trips (in millions) | | | |
| Auto | 4.231 | 4.231 | 4.224 |
| Truck | 0.018 | 0.018 | 0.018 |
| Total | 4.249 | 4.248 | 4.242 |
| Weekday Vehicle Miles (in millions) | 27.767 | 27.958 | 27.452 |
| Avg. Auto Speed (mph) | 18.24 | 18.98 | 18.32 |
| Annual Emissions (tons) | | | |
| Hydrocarbons (HC) | 23,388 | 22,865 | 22,648 |
| Carbon Monoxide (CO) | 194,765 | 190,225 | 181,746 |
| Nitrogen Oxides ($NO_x$) | 15,417 | 15,535 | 14,695 |
| Annual Fuel Use (million gallons) | 410.42 | 406.30 | 402.81 |

*User Benefits*

User benefits are calculated for each zone-to-zone trip interchange. Benefits include savings in user costs such as travel time costs, vehicle operating costs and out-of-pocket costs for fares, parking (if paid by the user) and tolls. User-perceived benefits are reduced as a result of increases in user costs. Since user payments for fares, fuel taxes and tolls represent monetary transfers (not a net increase in the resource cost of transportation to society as a whole), it is necessary to add these revenue transfers to total societal benefits of the actions under consideration.

User-perceived travel cost changes for vehicle operation are computed by STEAM based on VMT changes and on fuel consumption changes. STEAM uses a default variable vehicle operating cost of 3.4 cents for autos (CSI 1992) and 10 cents for trucks. The defaults for fuel cost are $1.20 per gallon of auto fuel and $1.10 per gallon of truck fuel. Note that these values include fuel taxes, which are transfers. Therefore, the tax revenues need to be considered as “benefits” to public agencies in the accounting for total societal benefits.

Travel time savings for personal travel (i.e. autos, HOV and transit) are monetized by STEAM using a value of personal travel time per hour provided by the user. STEAM's default is $6.00 per person hour, i.e., 50% of the national average wage rate (Miller 1989). The default value for out-of-vehicle travel time is $9.00, i.e., 1 ½ times the value of in-vehicle travel time. For commercial truck traffic, STEAM’s default is $24.60 per hour based on national data (NHI 1995).

For new users of a mode (for each trip interchange), savings are valued by STEAM at one-half the rate used for former users, as suggested by consumer surplus theory (NHI 1995), since new users do not really save the full amount saved by former users, but approximately half. Former users are those users who used the specified mode under the No-Build scenario. New users are those users attracted to the mode, or to a new destination, due to facility or service improvements. Similarly, disbenefits are computed for users discouraged from a mode or destination.

*Revenue Transfers*

Fares, tolls and taxes are transfers from users to the government, and are not normally relevant in evaluation of economic costs and benefits for society as a whole, even though they are extremely important in demand estimation. However, since the imposition of fares, tolls and taxes causes a reduction in the user-perceived benefit estimates computed by STEAM, any changes in these revenues to public agencies must be added back into the computation of total benefits to society.

*External Cost Changes*

Accident costs are considered to be “external” costs because drivers do not generally take these costs into consideration in making a decision to drive. Moreover, accidents cause many costs which are not borne by system users directly (e.g., costs for public services such as police, fire and court systems, health insurance coverage which may be paid by employers, and pain and suffering caused to non-users). STEAM uses default estimates of fatality, injury and property damage only (PDO) accident rates by facility class, and default estimates of user-perceived and societal accident costs per accident (Miller 1991).

Many social and environmental impacts (i.e., both benefits and costs) cannot be monetized or even quantified, and must be described qualitatively for consideration by decision makers. For example, it is difficult to monetize benefits such as community livability, and it is difficult to monetize costs such as loss of historical resources. STEAM does monetize two types of impacts which are quantifiable -- air pollutant emissions and noise. STEAM permits the user to specify emission costs per ton of pollutant, and noise costs per VMT. STEAM’s default monetary values for emission costs are based on recent research (Wang & Santini 1995). Default values of noise damage cost per VMT are based on FHWA research (Haling & Cohen 1996).

The user may provide estimates of other mileage-based external costs by facility class. These costs per VMT are multiplied by VMT to produce estimates of “other mileage-based” external costs. Non-mileage based external costs such as parking costs which are generally not directly borne by drivers (and therefore not taken into consideration in driving decisions) are not computed by STEAM, but must be provided as a lump-sum user input to STEAM called “other non-mileage based costs”. The user may also provide estimates of construction period costs such as travel delay costs separately.

*Public Agency Costs*

Included in this category are all costs borne by highway and transit agencies. Capital costs and annual highway O & M costs must be input directly by the user. For construction costs, STEAM projects out to the year of opening to traffic the value of capital costs assumed to be incurred at the mid-point of construction, and then annualizes it based on the facility life. A default discount rate of 7%, as recommended by the Federal Office of Management & Budget (OMB) is used to

**Table 2: Annualized benefits and costs (millions of dollars)**

| | | Build |
|---|---|---|
| **Annual Benefits** | | |
| User Benefits | | 135.39 |
| Revenues to Public Agency (change) | Fuel taxes | -1.63 |
| | Fares | -0.25 |
| | Tolls | 0.00 |
| | Sub-total | -1.88 |
| External Benefits/ Disbenefits | Accidents | -0.21 |
| | Noise | -0.04 |
| | Emissions | 16.48 |
| | Other non-mileage | -0.16 |
| | Sub-total | 16.07 |
| Total Annual Benefits | | 149.58 |
| **Total Annual Public Agency Costs** | | |
| Capital | | 64.92 |
| Operating | | 0.89 |
| Total Annualized Costs | | 65.81 |
| **Economic Efficiency Measures** | | |
| Net Annual Worth | | 83.77 |
| Benefit/Cost Ratio | | 2.27 |

annualize capital costs (OMB 1992). STEAM permits the use of alternative discount rates.

Transit operating costs are calculated by STEAM by applying cost per vehicle mile, cost per vehicle hour and cost per peak vehicle (input by the user) to the changes in transit vehicle miles, vehicle hours and peak vehicles, which STEAM estimates based on changes in transit travel demand and transit vehicle occupancy provided by the user.

*Net Annual Worth*

Net worth is calculated by STEAM by subtracting costs to public agencies from the total benefits (i.e., the sum of user benefits, revenue transfers, and savings in external costs). Benefit/cost ratios are also calculated. The numerator of this ratio is the total benefits. The denominator is annualized costs to public agencies. Net worth and benefit-cost ratios are indicators of the economic efficiency of the alternatives.

*Case Study Benefits and Costs*

Table 2 summarizes the annualized costs and benefits of the Build alternative. (At the time of writing, STEAM results for the Tolls/TDM Alternative were not yet available. User cost savings make up most of the benefits for the Build alternative -- $135 million.

Fuel tax revenue changes were estimated based on annual gasoline consumption changes from Table 1. Fare revenue changes were estimated based on transit ridership changes from Table 1. The increase in VMT in the Build alternative causes disbenefits in VMT-based external costs (i.e., accidents and noise). However, higher speeds result in net savings in emission costs of $16.5 million. Other non-mileage costs increase due to parking cost increases as a result of higher numbers of vehicle trips.

Public agency cost estimates are presented in Table 2 as differences with respect to the No-Build alternative. Capital costs include costs borne by transportation agencies for construction, engineering and rights-of-way (R-O-W). Opportunity costs of R-O-W already owned by the public agency (Utah DOT) were included in total R-O-W capital costs. A discount rate of 7%, as recommended by the Federal Office of Management & Budget (OMB 1992) was used to annualize capital costs. Costs for operation and maintenance (O&M) of added freeway mixed-flow lanes were estimated based on the 1995 study (USDOT 1995).

Table 2 also presents estimates of net annual worth (i.e., benefits minus costs) and benefit/cost (B/C) ratios. The Build alternative shows a net annual worth of $84 million. Net worth provides a useful measure in comparative evaluation of alternatives, *along with measures or clear descrip-*

*tions of non- monetized social and environmental impacts*, such as community livability and pride, neighborhood cohesion, aesthetics, energy security, global climate change effects, social equity and environmental justice. The net worth can be used by decision makers to assess whether other non-monetized disbenefits (or benefits) are worth the estimated net *economic* gain (or loss) to society for the alternative under consideration. If net worth is negative, it provides "scale" as to how large non-monetized benefits should be in order to move a project alternative into the acceptable range.

**Conclusions**

This paper has demonstrated a benefit-cost assessment at a detailed level of analysis for the Build alternative for the I-15 corridor in Salt Lake City, using FHWA's new software STEAM. Benefit-cost assessment was done on a multi- modal basis using output easily available from the four-step travel demand modeling process.

We are continuing efforts to refine STEAM based on feedback from beta-testing by practitioners. Also, a risk analysis component is being added to the software. There will always be considerable uncertainty about the input cost parameters, e.g., value of time. The risk analysis feature in STEAM will allow the user to input these values as a probability distribution. STEAM will then use Monte Carlo simulation techniques to calculate the probability that Net Worth will exceed values specified by the user. Such estimates are useful in forging consensus among diverse groups, each desiring that their own values be used in the analysis (Lewis 1995).

Disclaimer: We wish to emphasize that the case study analysis described in this paper has been performed for demonstration purposes only, and *the results do not necessarily represent impacts of any of the alternatives tested by Salt Lake City planners*. The views we have expressed in the paper are ours alone, and do not necessarily represent the views or policies of the FHWA or the US DOT.

**References**

Cambridge Systematics, Inc.(CSI) et. al. Characteristics of Urban Transportation Systems. US DOT publication no. DOT-T-93-07. Revised Edition. September 1992.

Comsis. Users' Guide: Travel Demand Management Evaluation Model. FHWA. 1993.

Cohn, Louis, Roger Wayson and Roswell, "Environmental and Energy Considerations". Transportation Planning Handbook. ITE.

DeCorla-Souza, Patrick, H. Cohen & K. Bhatt. "Using Benefit-Cost Analysis to Evaluate Across Modes and Demand Management Strategies. Compendium of Technical Papers for the 66th ITE Annual Meeting. ITE. Sept. 1996.

DeCorla-Souza, Patrick et al. "Trip-Based Approach to Estimate Emissions with Environmental Protection Agency's MOBILE Model". TRR No.1444. TRB. 1994.

Haling, Daniel & Harry Cohen. Noise Damage Costs Caused by Motor Vehicles. Paper No. 960558. TRB. 1996.

Lewis, David. "The Future of Forecasting: Risk Analysis as a Philosophy of Transportation Planning". TR News 177. March-April 1995.

Makemson, James R et al. Traffic Models Overview Handbook. FHWA. June 1993.

Margiotta, Richard et al. Improved Speed Estimation Procedures for Air Quality Planning. Prepared for FHWA. August 1996.

Miller, Ted The Value of Time and the Benefit of Time Saving. The Urban Institute. 1989.

Miller, Ted et al. The Costs of Highway Crashes. Federal Highway Administration. October 1991.

National Highway Institute (NHI). Estimating the Impacts of Urban Transportation Alternatives. Course No. 15257. Participant's Notebook. December 1995.

OMB. Benefit-Cost Analysis of Federal Programs: Guidelines and Discounts Circular A-94 revised. In Federal Register, Nov 10, 1992.

TRB. Highway Capacity Manual (HCM) Special Report No. 209. Third Edition. 1994.

UDOT and FHWA. Interstate 15 Corridor. Supplemental Draft Environmental Impact Statement. FHWA-UT-EIS-90-02-DS. August 1995.

Venigalla, Mohan, Terry Miller and Arun Chatterjee, "Start Modes of Trips for Mobile Source Emissions Modeling". Transportation Research Record No. 1432. Transportation Research Board. 1995.

Wang, M. and Santini, D. Monetary Values of Air Pollution Emissions in Various U.S. Areas. TRB TRR 1475. 1995.