Use of *STEAM* in Evaluating Transportation Alternatives

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1.0 INTRODUCTION

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 useful comparative information to decision makers with regard to proposed alternative transportation solutions. 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 (1). 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* corridor analysis and to facilitate systemwide analysis, FHWA has developed an enhanced version of SPASM, called the Surface Transportation Efficiency Analysis Model (STEAM).

2.0 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 FHWAэs Travel Demand Management (TDM) software (2). Second, it post-processes traffic assignment outputs from conventional four-step planning models in order to more accurately estimate highway travel speeds under congested conditions. Third, it performs risk analysis to clearly describe the level of uncertainty in the analysis results, thereby minimizing the potential for unproductive technical controversy over unit monetary values or impact estimates. Finally, STEAM produces estimates of *systemwide* impact; i.e., impact estimation is 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, and quantitative estimates of natural resource usage (e.g., energy consumption) and environmental impacts (e.g., pollutant emissions) are also provided. Decision makers can then use net monetary benefits (or costs) of alternatives as computed by STEAM to evaluate trade-offs against non-monetizable impacts.

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 accommodate special circumstances or new modes by modifying these parameters. Different trip purposes can be analyzed separately by the model. Also, STEAM can be applied using average weekday travel inputs or, alternatively, using separate peak and off-peak travel inputs.

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.

2. A *Network Analysis Module*, which reads a file containing highway traffic 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.

3. A *Trip Table Analysis Module*, which produces estimates of user benefits based on a comparison of Base Case and Improvement Case travel times and out-of-pocket costs for each zone-to-zone trip interchange for a given forecast year. It also produces estimates of pollutant 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, and probability distributions of several performance measures based on a risk analysis.

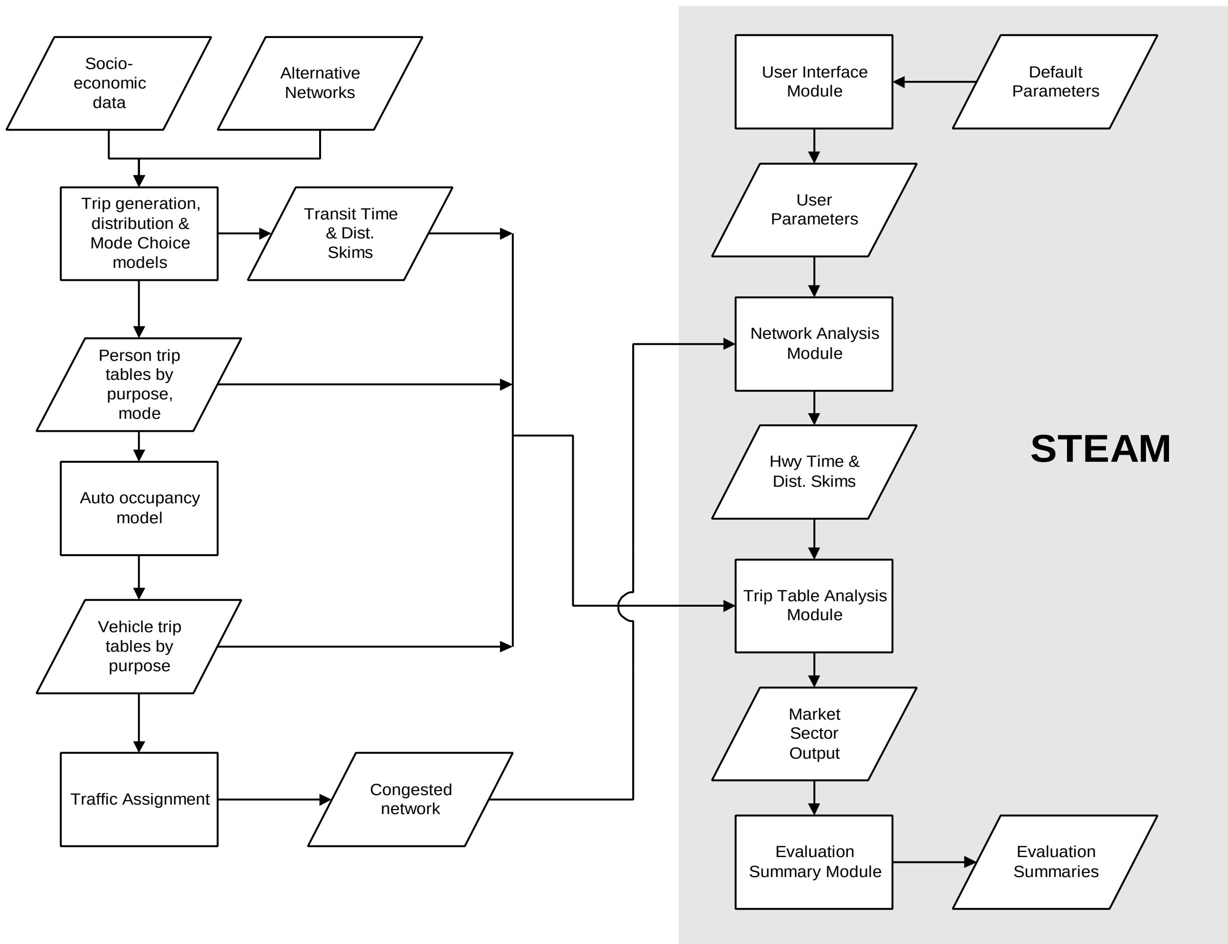
3.0 CASE STUDY ANALYSIS

A real-world test of the software was performed using case study data from a western U.S. urban area, which is being called Any City in this paper to maintain its anonymity. An evaluation of transportation alternatives was performed for the Central Freeway corridor in Any City. In this section, the alternatives and procedures used to develop the needed input data for STEAM are described. In section 4.0, impact analysis procedures embedded in the software are discussed, and results of STEAM's impact analysis are presented. In section 5.0, STEAMɘs economic efficiency analysis procedures are discussed, and results from the economic efficiency analysis are presented. Section 6.0 discusses current limitations of the software and planned enhancements.

3.1 Corridor Alternatives

The limits of the case study corridor were defined by the interchanges of Central Freeway with the beltway loop north and south of the city. The corridor is about 12 miles in length. Currently, traffic in the corridor exceeds capacities in many locations, causing significant peak period delays. Significant growth is expected in the Any 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. Traffic on Central Freeway in the southern portion of the corridor is expected to double.

Figure 1. Overview of Analysis Procedures



For the purpose of demonstrating the application of the software, three corridor alternatives were analyzed:

- *ANo-Build alternative*: This alternative included all new capacity projects in the region's Long Range Transportation Plan, except for Central Freeway improvements. A planned light rail line in the Central Freeway corridor was included.

- *ABuild alternative*: This alternative involved the widening of Central Freeway to include two additional mixed-flow travel lanes in each direction. The section of Central Freeway to be expanded currently has 6 lanes, 3 in each direction.

- *ATDM/Tolls alternative*: This alternative primarily involved introduction of a $1.00 toll to be collected on Central Freeway through automated collection techniques at both ends of the corridor (i.e., at each of the two beltway 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 auto users tolled off the freeway.

3.2 Developing STEAM Inputs from Demand Models

STEAM accepts as input the following output from the four-step travel demand modeling process: (1) person trip tables for passenger travel and vehicle trip tables for truck travel; (2) travel time and cost matrices skimmed from transit networks and (optionally) from 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 Any City planners. The models were run using Any City's 2015 Transportation Plan and its 2015 socio-economic forecasts for the region. For the TDM alternative, the No-Build highway network was re-coded 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.

3.3 Defining Market Sectors

Market sectors for use in STEAM analysis may be defined by trip mode, purpose, and time of day. Since the Any City models produced daily demand estimates, market sectors were defined only by trip mode and purpose. The travel demand models provided *person trip tables by mode* (auto, bus, walk-accessed light rail and drive-accessed light rail) for the following four internal trip purposes: Home-based (HB) work, HB non-work, HB college, and Non-HB. For HB work person trips, an additional mode, i.e. Carpool was estimated by the models. Additionally, *vehicle trip tables* were provided by the models for the following three trip purposes: internal truck, internal-external, and through. Since internal-external and through trips include both passenger and truck travel, the first step would be to break down trip tables for each of these two purposes into auto and truck modes. For Any City, the truck share of these trips was unknown, so all trips were assumed to be auto mode trips.

Executing STEAM using Any City trip tables could potentially require running (for the "daily" time period) each of 22 purpose/mode market sectors identified by an "X" in the upper part of Table 1. To reduce the number of market sectors to be analyzed, the seven trip purposes (shown in the first column of the table) were collapsed into two: (1) a passenger travel purpose and (2) a commercial (truck) purpose; i.e., all non-truck trip purposes were combined into a single Apassenger travel category, for which the same values of time and other STEAM parameters could be applied irrespective of the actual trip purpose. The resulting market sectors are indicated by an "X" in the lower part of Table 1.

TABLE 1   Market Sectors for Any City

A. Potential Market Sectors

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

B. Combined Market Sectors

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

3.4 Developing Market Sector Inputs

Highway Mode Inputs: Auto-occupancies needed as input into STEAM for the passenger travel auto and carpool modes were obtained by dividing the sum of regionwide person trips by the sum of vehicle trips for each mode (using output from the four-step demand models). While STEAM can estimate vehicle operating costs based on internally generated zone-to-zone highway distance skims, the user must provide "out-of-pocket cost" skims reflecting tolls for zone-to-zone travel. For the TDM alternative, toll skims were obtained using the demand modeling software. First, a select-link analysis was done to identify zone-to-zone vehicle trip interchanges subjected to tolls, and the number of vehicle trips for each zone-to-zone interchange actually choosing the toll route. For each trip interchange, these trips were divided by trips from the total vehicle trip table to get the proportion of zone-to-zone vehicle trips actually paying tolls. Average out-of-pocket cost per vehicle for each zone-to-zone interchange was obtained by multiplying the vehicle toll by the proportion of vehicle trips paying the toll. The average out-of-pocket cost per vehicle was then divided by auto-occupancy in order to generate a skim table of average out-of-pocket cost per person for input into STEAM.

Non-Highway Mode Inputs: For the non-highway passenger travel modes (bus and rail), STEAM inputs for average occupancies were estimated from passenger count data. STEAM cannot generate travel time skims for non-highway modes. Travel time skim tables as well as out-of-pocket cost tables must be obtained for input into STEAM using output from the demand models. For Any City, the in-vehicle travel time skims generated by the demand models were used directly as input into STEAM. The Any City models also generated walk time skims and wait time skims. These were summed by origin-destination pair to get "out-of-vehicle" travel time skims needed for input into STEAM. Additionally, the Any City models generated out-of-pocket cost skims (in cents) based on transit fares. These were directly input into STEAM.

4.0 IMPACT ANALYSIS PROCEDURES

This section discusses the speed estimation procedures used in the Network Analysis Module, procedures used in the Trip Table Analysis Module to estimate emissions and energy consumption impacts, and the analysis results produced by STEAM for the Central Freeway corridor in Any City.

4.1 Estimating Travel Speed

Users can format input network files to include link speeds which STEAM can use directly. As an option, STEAM can estimate travel speeds based on procedures which relate average weekday traffic-to-capacity ratios (AWDT/C) to average hourly delay and speed (3). The procedures incorporate the dynamic effects of queuing and peak-spreading which are not considered when conventional Highway Capacity Manual (HCM) procedures are used with assigned traffic volumes. Additionally, the procedures account for day-to-day variations in traffic. The relationship between delays due to congestion and traffic volumes are highly non-linear, especially when demand volume-to-capacity is close to 1.0. Hence, by explicitly accounting for a day-to-day variation in traffic volumes, the model estimates speeds more accurately than if uniform daily volumes are assumed. The procedures also take into account delays due to incidents, using data on the frequency, severity, and duration of incidents compiled by Ball State Engineering (4). Accounting for incident delays in economic analysis of transportation actions is important because incidents account for a large share of total travel delays due to congestion, especially on freeways. Failure to include the effects of incidents could grossly understate the benefits of transportation actions that reduce congestion.

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. Monte Carlo simulation of traffic volumes was used to reflect day-to-day variations in traffic volumes. 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 (5). The speed relationships thus account for spreading of traffic from congested time periods to uncongested time periods, queuing impacts on traffic speeds in successive hours, day-to-day variations in traffic volumes, and incidents.

4.2 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. STEAM therefore uses a trip based approach to estimate emissions (6). 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; national defaults are provided from recent research (7).

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.

4.3 Fuel Consumption and Greenhouse Gas Emissions

Increases or decreases in use of motor fuel are estimated by STEAM by vehicle type (auto and truck) as a function of average speed for each trip interchange, using fleet average fuel consumption rates (8). STEAM calculates changes in greenhouse gas emissions using carbon dioxide (CO_2) emission rates per gallon of motor fuel consumed (9).

4.4 Impacts of Case Study Alternatives

Table 2 summarizes travel demand estimates by mode for the entire region, obtained from Any City 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 analysis used STEAM-estimated speeds rather than travel model output speeds. Table 2 provides estimates from STEAM of resulting average regionwide vehicular travel speeds, and total regionwide emissions and fuel consumption. Note that average speeds estimated by STEAM are lower than those typically estimated by travel demand models or even by HCM procedures. This is because, as discussed in Section 4.1, STEAM϶s speed relationships take into account delays due to queues carried over from one hour to the next, as well as delays due to incidents and the effects of day-to-day variations in traffic when volume-to-capacity ratios are close to 1.0.

5.0 ECONOMIC ANALYSIS PROCEDURES

All benefits are computed by STEAM϶s Trip Table Analysis Module based on weekday travel estimates by market sector for a specific analysis year. Weekday benefits for each market sector are annualized assuming a default value of 250 working days per year. This annualization factor may be modified by the user. The analysis year may be selected by the user to be representative of benefits over the analysis period, which is normally the life of the investment. Alternatively, the user may run STEAM separately with data for several different analysis years, and estimate the stream of benefits over the analysis period.

5.1 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), fuel taxes, and tolls. User benefits also include the portion of accident costs that are perceived by the traveler and taken into account in travel decisions. As discussed in Section 5.3 below, a substantial portion of accident costs is not perceived by travelers. STEAM treats the portion of accident cost savings not perceived by travelers as "external" costs, i.e., costs not considered in the decision to drive. The user may specify the breakdown between "internal" (i.e., perceived) and "external" (i.e., unperceived) accident costs. User benefits estimated by STEAM may differ depending on the extent to which such costs are considered to be perceived.

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 to the government (i.e., not a net increase in the resource cost of transportation to society as a whole), it is necessary to account for these revenue transfers as "benefits" to government agencies in the estimation of total societal benefits of the actions under consideration.

TABLE 2 Impacts Of Alternatives: Year 2015

	No-Build	Build	TDM/Tolls
Weekday Person Trips (in millions)			
Auto	5.719	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 millior	**27.767**	**27.958**	**27.452**
Avg. Auto Speed (mph)	18.24	18.98	18.32
Annual Emissions (tons)			
Hydrocarbons (HC)	7,723	7,622	7,578
Carbon Monoxide (CO)	166,075	162,417	162,662
Nitrogen Oxides (NOx)	8,853	8,913	8,743
PM 10	310.0	312.0	305.6
Annual Fuel Use (million gallons	246.06	241.72	241.29

Travel cost changes for vehicle operation are computed by STEAM based on VMT changes and on fuel consumption changes. At the user's option, vehicle operating and fuel cost changes can be treated by STEAM as external costs, i.e., costs not perceived by travelers and therefore not taken into consideration in travel decisions. STEAM uses a defaults for variable vehicle operating cost (excluding fuel costs) amounting to 3.4 cents per mile for autos (10) and 10 cents per mile for trucks. It is assumed that fixed costs such as vehicle depreciation or garaging costs will not vary by alternative, but if they do, the differences with respect to the No-Build can be provided as an input to STEAM in the "non-mileage costs" category discussed in Section 5.3. The defaults for fuel cost are $1.21 per gallon of auto fuel and $1.15 per gallon of truck fuel *inclusive of fuel taxes*. Therefore, changes in fuel tax revenues resulting from changes in fuel consumption need to be considered as benefits or losses 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 passenger travel time per hour provided by the user. STEAMэs default is $8.90 per person hour for in-vehicle time (11). The default value for out-of-vehicle travel time is $17.00 (9). For commercial truck traffic, STEAMэs default is $16.50 per hour for in-vehicle time (11), and $17.00 for out-of-vehicle travel time.

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 (12), 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 base case (i.e., No-Build scenario). New users are those users attracted to the mode, or to a new destination, due to facility or service improvements. For users who shift *away* from a mode or destination, disbenefits are computed similarly.

5.2 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, as discussed in Section 5.1, 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.

STEAM calculates changes in revenues occurring as a result of *changes* in fares, tolls and other out-of-pocket costs paid by transportation system users. The transfers are calculated at the zonal interchange level. Revenue increases due to increased transit ridership or revenue losses due to a decrease in ridership must be computed by the user off-line, and combined appropriately with estimates of changes in revenues estimated by STEAM.

If additional motor fuel is consumed in an improvement case, the additional user costs for the motor fuel include fuel taxes which are simply a revenue transfer from users to the government. STEAM calculates the amount of revenue transfer based on an average combined State and Federal fuel tax rate of 37.48 cents/gallon for gasoline and 42.6 cents/gallon for diesel.   The user will need to make appropriate adjustments to STEAM϶s estimates of fuel tax revenue changes if actual combined fuel tax rates differ from these averages.

5.3 External Cost Changes

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. Four types of external costs which *can* be quantified by STEAM are: accident costs, noise damage, pollution, and greenhouse gas emissions.

Accidents: 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). Moreover, even the portion of accident costs that are actually incident upon drivers may not be taken into account by them in making a decision to drive. In STEAM, these unperceived portions of accident costs may be treated as external costs. STEAM provides default estimates of fatality, injury and property damage only (PDO) accident rates by facility class. (The rates do not vary by congestion levels or speed.) Also, STEAM provides default estimates of the breakdown between "internal" (i.e., user-perceived) and "external" accident costs per accident (13), based on the assumption that all costs *borne* by the highway user are taken into consideration in the decision to drive.   Therefore, the STEAM user may wish to adjust the breakdown of costs if the urban area's travel models reveal that accident costs borne by highway users are underestimated by them and are not fully taken into account in driving decisions.

Air pollutant emissions, greenhouse gas (CO_2) emissions, and noise: STEAM permits the user to specify emission costs per ton of pollutant and per ton of CO_2, and noise costs per VMT. STEAM provides default monetary values for HC, NOx and CO emission costs per ton based on Denver (14), PM 10 costs per ton based on nationwide estimates (15), and noise damage cost per VMT and global warming cost per ton of CO_2 based on an FHWA study (11,16).

Other external costs: These include other external costs which are not *specifically* computed by STEAM. The user may provide estimates of these costs per VMT by facility class and mode for mileage-based external costs (e.g., indirectly borne highway patrol and safety costs).   Annual non-mileage based external costs (e.g., indirectly borne parking cost changes) can be provided by mode as a lump-sum user input. Any changes in vehicle fixed costs may be included here. External costs during construction (such as travel delay and environmental impacts) may also be provided separately as a user input.

5.4 Public Agency Costs

Included in this category are all costs borne by highway and transit agencies. Capital costs and annual highway operation and maintenance (O&M) costs must be input directly by the user. For construction costs, STEAM projects out to the year of opening of the facility the value of capital costs assumed to be incurred at the mid-point of construction, and then annualizes this cost based on the facility life. A default discount rate of 7%, as recommended by the Federal Office of Management & Budget (OMB) is used to annualize capital costs (17). 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 the user provides as input to STEAM.

5.5 Net Annual Worth

Net annual worth is calculated by STEAM by subtracting annualized costs to public agencies from the total annual benefits (i.e., the sum of user benefits, revenue transfers, and changes 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.

5.6 Risk Analysis

STEAM includes a risk analysis component. There will always be considerable uncertainty about appropriate values for unit costs or impact rates used as input. For parameters subject to uncertainty, the risk analysis feature in STEAM allows the user to input the median value and the upper limit of a 90% confidence interval. STEAM uses these values to generate a statistical probability distribution. STEAM then uses Monte Carlo simulation techniques to calculate probability distributions for each result metric such as the benefit-cost ratio. Such estimates are useful to decision-makers in selecting the level of risk within which they are willing to make commitments. The results are also useful in forging consensus among diverse groups, each desiring that their own values of input parameters be used in the analysis (18).

5.7 Case Study Benefits and Costs

User Benefits: Table 3 summarizes the annualized costs and benefits of the two action alternatives. User cost savings of $191 million make up most of the benefits for the Build alternative. For the TDM alternative, the large user disbenefits perceived -- $31 million -- reflect a combination of the monetary "losses" to users who continue to use Central Freeway and pay tolls, travel time benefits to these users due to reduced congestion, the consumer surplus losses of former Central Freeway users who are disinduced from using Central Freeway, and the travel time disbenefits to other travelers who are faced with increased congestion when former Central Freeway users who are disinduced from using Central Freeway divert to other facilities.

Transfers: STEAM estimated the fuel tax revenue reductions (due to reduced fuel consumption as a result of average speed improvements) at $1.6 million for the Build and $1.8 million for the TDM alternative. STEAM does not currently estimate fare revenue changes due to changes in transit ridership. Fare revenue changes were estimated "off-line" as a $0.25 million loss for the Build and a $2.75 million gain for the TDM alternative, based on transit ridership changes.

TABLE 3 Annualized Benefits And Costs

	Build	TDM
Annual Benefits		
User Benefits:	191.40	(30.92)
Revenues to Public Agency (change):		
Fuel taxes	(1.64)	(1.80)
Fares	(0.25)	2.75
Tolls	0.00	75.50
Sub-total	(1.89)	76.45
External Benefits/Disbenefits:		
Accidents	(0.22)	(0.58)
Noise	(0.06)	0.06
Emissions	14.16	13.85
Global warming	0.15	0.01
Other non-mileage	(0.16)	2.01
Sub-total	13.87	15.35
TOTAL ANNUAL BENEFITS	203.38	60.88
Total Annual Public Agency Costs		
Capital	73.74	0.04
Operating	0.89	14.53
TOTAL ANNUALIZED COSTS	74.63	14.57
Economic Efficiency Measures		
Net Annual Worth	128.76	46.31
Benefit/Cost Ratio	2.73	4.18

Toll revenues for the TDM alternative were estimated at $75.5 million by STEAM based on input out-of-pocket cost changes for auto, carpool and truck trips as discussed in Section 3.4. The tolls paid are more than total losses suffered by users because of travel time savings due to faster speeds on Central Freeway.

External costs and benefits: The increase in VMT in the Build alternative causes external accident and noise disbenefits. In the case of the TDM alternative, reductions in VMT reduce noise costs, but not accident costs, because a significant amount of VMT shifts to arterials, which have higher accident rates.

For the Build alternative, higher speeds result in net cost reductions of $14 million in emissions costs and $0.15 million in global warming costs. For the TDM alternative, cost reductions are similar, but result from both speed improvements as well as VMT reductions. Emission reduction estimates and resulting monetary benefit estimates by STEAM tend to be higher than conventional approaches because the average speeds estimated by STEAM tend to be lower than those estimated by conventional approaches (as discussed in Section 4.4), and tend to be in the range where emission rates are much more sensitive to differences in speed (i.e., below 25 mph).

For the Build alternative, an increase in other non-mileage based external costs amounting to $0.16 was estimated (off-line) and was provided as an input to STEAM. The cost changes were based on parking cost increases as a result of the higher number of vehicle trips. For the TDM alternative, there are parking cost savings (i.e., non-mileage based cost savings) due to reductions in vehicle trips. When the need for parking spaces at business locations is reduced, there is a saving in resource costs in the long term, because fewer new spaces will need to be provided to accommodate growth, or existing spaces can be redeveloped for other uses.

Public agency costs: Agency cost estimates are presented in Table 3 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 were included in total R-O-W capital costs. A discount rate of 7% was used to annualize capital costs. Costs for operation and maintenance of added freeway mixed-flow lanes were estimated based on national data (10). Transit operating cost increases (above the No-Build) were also estimated based on average costs per vehicle mile from national data (10).

Economic Efficiency: Table 3 also presents estimates of net annual worth (i.e., benefits minus costs) and benefit/cost (B/C) ratios. B/C ratios are useful in prioritizing investments from a list of candidates for a limited budget. However, in comparing mutually exclusive alternative investments, (i.e., alternatives proposed to address the same problem), *net worth* should be the criterion used in economic comparisons.

The Build alternative shows a net annual worth of $129 million, while the TDM alternative shows a net annual worth of only $46 million. The Build alternative is therefore superior when only monetized benefits are considered. These net worth estimates provide the decision maker with useful measures for comparative evaluation of alternatives, *along with measures or clear descriptions of non-monetized social and environmental impacts,* such as community livability and pride, neighborhood cohesion, aesthetics, energy security, social equity and environmental justice. The net worth of an alternative can be used by decision makers to assess whether other non-monetized disbenefits (or benefits) are worth the estimated net *monetized* 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.

Risk Analysis: STEAMɜs default 90% confidence intervals for the various input impact rates and monetary values were used to generate probability distributions of benefits, costs and the benefit-cost ratio. Figure 2 provides STEAMɜs output cumulative probability distributions for the B/C ratios of the Build and TDM alternatives respectively. The probability distributions suggest that there is a 10% probability that the Build's B/C ratio will be less than 1.0, while there is a 27% probability that the B/C ratio of the TDM alternative will be below 1.0 (i.e., that the net worth will be $0.0). In other words, the TDM alternative is "riskier". These risks can be used by decision makers along with median (i.e., 50% probability) estimates of net worth shown in Table 3 and other non-monetized impacts to judge acceptability of risks relative to potential rewards.

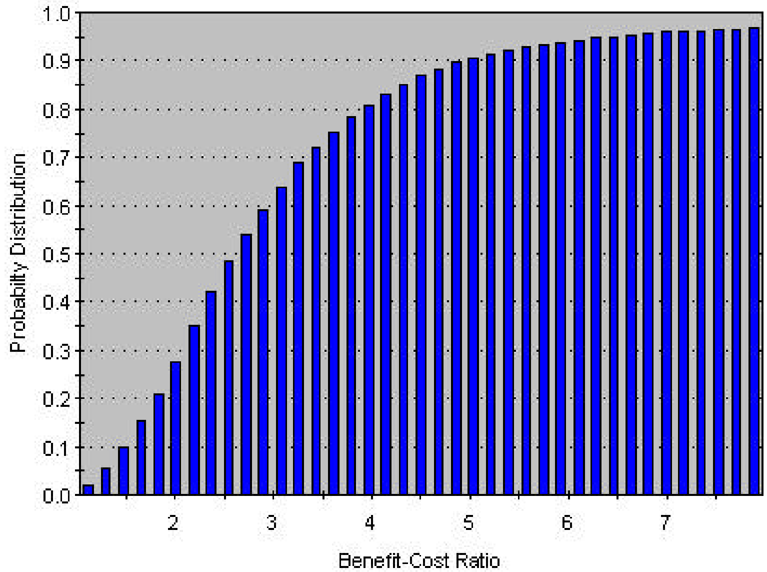
6.0 CONCLUSIONS AND FURTHER RESEARCH

This paper has demonstrated a benefit-cost assessment at a detailed level of analysis for two action alternatives in a major travel corridor of a case study urban area, using FHWAɜs new software STEAM. Benefit-cost assessment was done on a multi-modal basis using output from the four-step travel demand modeling process. The case study demonstration shows that STEAM can be a useful tool for system planning and corridor planning in metropolitan areas. However, the current version of STEAM has some limitations. These are discussed below, along with FHWA plans to enhance STEAM to address them.

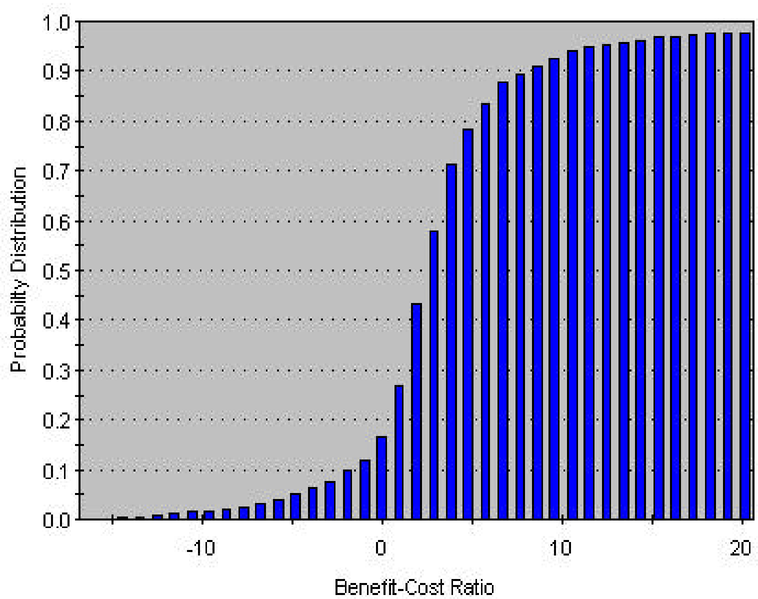
Benefit Streams: Currently, travel related benefits and costs computed by STEAM are provided for a single forecast year. It is difficult to account for the effects of varying rates of growth in travel demand over time, unless the forecast year chosen for providing input demand estimates is representative of the entire analysis period. A multi-year analysis capability will be developed for the enhanced STEAM, so that the stream of benefits over the life of the investment may be more precisely computed. The STEAM user will be able to provide as input travel demand model outputs for several analysis years to account for the change in demand over time.

Revenue Transfers: STEAM currently calculates the amount of revenue transfer based on an average combined State and Federal fuel tax rate of 37.48 cents/gallon for gasoline and 42.6 cents/gallon for diesel. The user cannot change these default inputs, which are embedded in the software. In the enhanced STEAM, fuel tax rates will be allowed as a separate user input, so that transfers can be properly calculated by STEAM for different metropolitan areas. Also, transit fare revenue changes resulting from changes in transit ridership will be computed directly by STEAM, instead of requiring off-line analysis.

FIGURE 2 Cumulative Probability Distributions of Benefit-Cost Ratios



A. Build Alternative



B. TDM/Tolls Alternative

Emissions analysis: Currently, STEAM users are permitted to provide only a single breakdown of cold vs. hot start trips for all market sectors, irrespective of mode, purpose, and time-of-day. To improve emissions estimates, the enhancements will allow users to specify the percentage of trips that occur in the cold start mode *by market sector* (e.g., work trip percentages and peak period percentages for cold starts would typically be higher than non-work and off-peak percentages). Also, currently STEAM users must estimate composite emission rates for an "auto" and "truck" mode, and these rates cannot vary by market sector. For example, a solo-driver market sector and a carpool market sector must both use the same composite "auto" emission rates, although the carpool market sector may include heavier vehicles such as vans. The enhanced STEAM will allow a market sector to have as many vehicle types as MOBILE5A, so that the user simply provides a percentage breakdown by vehicle type for each mode. For example, carpools may be 80% light duty gasoline (LDG) and 20% light duty truck (LDT).

Risk Analysis: Currently, probability distribution inputs can only be provided for monetary values and impact rates. Proposed STEAM enhancements will extend risk/uncertainty analysis to include uncertainty of travel demand inputs.

Monetary Values: Currently, all monetary values must be updated manually in order to ensure that they reflect current year dollars. The enhanced STEAM will provide capability for input of inflation adjustment factors, so that all monetary values can be updated automatically to current year dollars by the software. Also, STEAM currently assumes carpool and solo-driver values of time are the same, and they cannot be differentiated. The enhanced STEAM will allow value of time to differ for different categories of auto and transit travel.

Access VMT: STEAM currently ignores the access portion of transit and carpool trips, with consequent underestimation of vehicle miles and other impacts from park-and-ride or kiss-and-ride operations. The enhanced STEAM will allow for estimation of access mileage and impacts.

Interface with Demand Models: Perhaps the greatest effort in using the current version of STEAM involves converting the networks and matrices produced by travel demand modeling software packages to input formats required by STEAM. An automated process will be developed to allow STEAM to accept and directly convert data from the most commonly used travel modeling packages

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REFERENCES

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

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

3. Margiotta, Richard and Harry Cohen. "Improved Speed Estimation Procedures for the STEAM Model". Metropolitan Planning Technical Report No. 11. FHWA Metropolitan Planning Division. In process of publication.

4. Sullivan, Edward, Sam Taft and James Daly. A Methodology For Measurement and Reporting of Incidents and the Prediction of Incident Impacts on Freeways. Prepared for FHWA. Ball Systems Engineering. April 1995.

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

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

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

8. Cohn, Louis, Roger Wayson and Roswell, AEnvironmental and Energy Considerations. Transportation Planning Handbook. Institute of Transportation Engineers. 1992.

9. Federal Transit Administration. Technical Guidance on Section 5309 New Starts Criteria. September 1997.

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

11. USDOT. Memorandum on Departmental Guidance for Valuation of Travel Time in Economic Analysis. April 9, 1997

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

13. U.S. DOT. 1997 Federal Highway Cost Allocation Study. August 1997.

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

15. Delucchi, Mark. The Annualized Social Costs of Motor Vehicle Use in the U.S, 1990-1991: Summary of Theory, Data, Methods and Results. Institute of

Transportation Studies, Davis, CA. June 1997.

16. U.S. DOT. 1997 Federal Highway Cost Allocation Study. Appendix E. Feb 1997.

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

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