Appendix P

Benefit-Cost Analysis

Appendix Contents

Benefit-Cost Analysis

Introduction and Summary

To compare the potential benefits of San Diego Forward: The 2019 Federal Regional Transportation Plan (2019 Federal RTP) with the projected costs we use transportation modeling to compare the benefits of the transportation investments with the costs of the projects (i.e., benefit-cost analysis or BCA).

The **benefit-cost analysis (BCA)** uses the output of the SANDAG activity-based travel demand forecasting model (ABM) to monetize and aggregate the benefits of the plan. This analysis tells us things such as how much time and money drivers and transit riders will save, and how much safer, healthier, and cleaner our system becomes as the 2019 Federal RTP is implemented. We can then compare those monetized benefits to the cost of the plan to get a "benefit-cost (B-C) ratio." The results indicate that the benefits of the proposed 2019 Federal RTP are somewhat less than the costs, with a benefit/cost ratio of 0.61. But the BCA cannot capture the entirety of the economic benefit from transportation improvements, as it captures just those metrics that can be modeled. The economic value of expanding access to jobs, education, and recreation for residents is not fully captured, nor is the economic value to businesses of expanded access to customers, suppliers, and employees. The economic development potential of an expanded system is not captured, as the land-use and economic forecast used is static. A B-C ratio below one suggests that these investments are not worth making, but that would be an oversimplification. The primary driver of these benefits is the time savings, which represent 80 percent of the benefits, followed by reduced operating costs, and the rest of the benefits categories.

The costs of the plan are primarily capital (72%), with about 28 percent for both operations/maintenance and financing costs. The net present value (NPV) (benefits minus costs) is -$13.9 billion. Detailed results and methodology are available in Section I of this report.

I. The Regional Transportation Plan Benefit-Cost Analysis

I.1 Summary and Results

The BCA tool used to evaluate the transportation scenarios for the 2019 Federal RTP was created specifically to take advantage of the output from the SANDAG ABM. The BCA tool uses estimates of trips, travel times, travel costs, auto ownership and other indicators output by the activity-based model (ABM) and assigns monetary values to these outputs to create a stream of benefits that result from the transportation investments in the scenario. This stream of benefits is compared with the stream of costs (including capital costs, operations and maintenance costs, and financing costs) that results from the projects included in the scenario to get a B-C ratio. A B-C ratio greater than one indicates that the measurable benefits of the scenario are greater than the total costs, and thus provide a net benefit to society.

Because the BCA relies on the outputs of the ABM, only transportation projects that can be modeled using ABM are included in it. For that reason, projects such as the new mobility hubs, which may influence travel behavior but are not modeled in ABM, are not included in either the costs or benefits of the BCA.

Another factor of the BCA is the discount rate chosen. Future costs and benefits are "discounted" in recognition of the "time value of money," the fact that a dollar next year is worth less than a dollar today.[1] The higher the discount rate, the less future benefits and costs affect the outcome of the analysis. The discount rate used in this BCA is 4 percent.

Benefits for the BCA were calculated for the following types of benefits:

1. Time Savings (residential and commercial)
2. Operating Cost Savings
3. Accident Cost Savings
4. Emissions Savings
5. Reliability Savings
6. Physical Activity Benefits
7. Vehicle Ownership Cost Savings

- Time savings compares the time of travel for all travelers for each scenario versus a no-build scenario. For example, by adding capacity to roads and transit, the time spent traveling is reduced. This time savings for personal travel has an economic value to people that is assumed to be roughly one-half of the average wage rate. The value of time for personal travel (calculated by ABM as an average of all trips) is $15.40 per hour. Higher values are assigned for truck travel ($29.70 per hour for light truck, $43.20 per hour for heavy truck) as it is work-related and assumed to include a factor for the time value of the freight in the truck. Higher values are also assumed for “out-of-vehicle” time, such as time spent waiting for transit (approx. $34 per hour), which is assumed to be roughly twice as burdensome as travel time.

- Vehicle operating costs are simply the avoided costs from not operating a vehicle, which may be due to a mode switch (e.g., from auto to transit), or from changes in destinations or overall trip-making. The operating cost is calculated on a per-mile basis and is based on the assumed operating costs used in the ABM. In 2050, the assumed operating cost of personal vehicles is roughly $0.19 per mile. This operating cost is assumed to remain roughly the same throughout the analysis period and is significantly lower than in previous analyses; this a key factor in the results of the model, as driver behavior is heavily influenced by price.

- Accident costs savings simply result from an estimated net reduction in the number of accidents for automobiles versus the no-build scenario. The number of accidents is based on the estimated difference in vehicle miles travelled (VMT) between the base and the build scenario. The BCA analysis and the ABM do not reflect the effect of potentially safer roadway types, or of the potential safety gains from autonomous cars. Accident values are based on the most recent federal guidelines and vary from roughly $4,000 for a property damage only (non-injury) accident to over $9 million for a fatality.

- Emissions reductions results from fewer VMT, reductions in congestion that improve vehicle efficiency, and overall assumptions about future year fleet efficiency. Emissions are modeled using EMFAC, based on outputs from the ABM. Emissions values are based on the health effects of pollutants.

- Reliability savings are time savings that result from having more consistent travel times over the same trip. For example, if variable congestion or poor transit performance require a traveler to add five extra minutes onto their travel time to ensure timely arrival, this is a cost. Reliability savings are largely a function of congestion and are valued as time savings.

- Physical activity benefits result from the increase in active transportation in the plan scenarios over the no-build and are calculated on a per-minute basis using recreational values of time.

- Vehicle ownership cost savings are the result of reductions in the number of vehicles that households in the county opt to own. Ownership costs for a private automobile are roughly $6,000 annually.

The costs for this analysis were estimated by SANDAG project managers, engineers, and other experts.

The horizon year for the B-C analysis is 2070, which allows the projects completed in 2050 to accrue benefits over the typical 20-year lifespan.

The results of the BCA are summarized in Table P.1:

Table P.1

Benefit-Cost Analysis Results (2019$ Billion)

Benefits by Category	
Time Savings	$17.04
Emissions Cost Savings	$0.15
Safety Benefits	$0.52
Reliability Benefits	$0.06
Auto Operating Costs Savings	$1.11
Auto Ownership Costs Savings	$2.69
Physical Activity Benefits	$0.01
Total Benefits	$22.14
Costs by Category	
Capital Costs	$25.94
O&M Costs	$10.12
Total Costs	$36.06
Net Present Value	-$13.92
Benefit/Cost Ratio	0.61

In summary, these results indicate that the benefits of the proposed 2019 Federal RTP are smaller than the costs, with a B-C ratio of 0.61. This contrasts to a B-C ratio of 1.86 when essentially the same plan was analyzed in 2015. The dramatic decline can be several factors: (1) Decline in benefits due to modeling changes; (2) increase in costs; and (3) change in extrapolation procedure for 2050-2070 period.

By far the most important factor is the decline in benefits due to changes in the modeling assumptions, primarily the auto operating costs per mile which have a dramatic impact on traveler behavior. In the 2015 Regional Plan auto operating costs per mile were significantly higher ($0.289/mile vs. $0.187/mile in 2050), resulting in both lower VMT in the 2015 Regional Plan (94 million vs. 100 million per day), and a much greater reduction in VMT (3.5% vs. 1.6% in 2050) versus the no-build scenario. This also results in a lower increase in transit use versus the no-build scenario (1.21% to 1.02% in 2050). More importantly, the increased VMT means more congestion and less delay reduction; in the 2015 Regional Plan drivers saved an average of 3.54 minutes per-capita daily in 2050, in the 2019 Federal RTP they save 1.06 minutes. That metric alone helps account for the huge decrease in “mobility benefits” (largely time savings). Similar reductions are seen in auto operating cost savings ($10.2 billion vs. $1.1 billion) due to this factor, and to other metrics, like truck mobility (average 2050 truck/commercial travel times declined by 0.59 minutes build vs. no-build in the 2015 Regional Plan and declined by only 0.02 minutes in the 2019 Federal RTP).

The increase in costs is less massive, but still important. In 2019$, NPV of 2015 Regional Plan costs were $34.2 billion over 35 years; for the 2019 Federal RTP discounted costs are $36.1 billion over 30 years. In addition, the federal guidance (Benefit-Cost Analysis Guidance for Discretionary Grant Programs, December 2018) which was used to monetize benefits included much lower values for several types of benefits. For example, the avoided cost of a property damage only accident declined from almost $10,000 to roughly $4,000, and the value of emission reductions were reduced as well.

The change in extrapolation method is intended to improve consistency with federal guidance. The previous method was to use a linear extrapolation of the rate from the last two analysis years to extrapolate benefits, which assumed that additional transportation improvements accounted for in this analysis will come on line at the same rate as between the last two analysis years, which is not the case. Holding the benefits constant in the 2050 to 2070 time period is a conservative assumption, but without a 2070 build/no-build ABM run, it is like the most prudent method, as we have little information about how benefits would behave over time.

The primary driver of benefits is the time savings, which represent 80 percent of the benefits, followed by reduced operating costs and the rest of the benefits categories.

The costs of the plan are primarily capital (72%), with about 28 percent for operations/maintenance. The NPV (benefits minus costs) is -$13.9 billion.

I.2 Detailed Benefit-Cost Analysis Methodology

I.2.1 Purpose

The SANDAG BCA tool was developed to measure the benefits and costs of the SANDAG investments in transportation infrastructure and operations as well as other policy objectives such as the Smart Growth Incentive Program. The tool was designed to consider a wide range of factors such as regional resident, commercial vehicle and truck mobility benefits, emissions savings, and safety savings, and to consider the effects of these and other factors over a multiyear time horizon. It provides users with the opportunity to select specific multiyear start and end analysis years in order to account for transit and other late-stage benefits. A distinguishing feature of the BCA tool is that it uses the SANDAG disaggregate ABM outputs, which mitigates aggregation biases, and allows for more detailed analyses of social equity concerns.

The first stage in the tool development was to inventory the existing data produced by the SANDAG ABM system and other analysis tools (such as EMFAC), and to identify the critical types of benefits measures that could be produced using the available data. Ultimately, a set of eight types of benefits were included in the tool design:

- Regional resident mobility
- Truck and commercial vehicle mobility
- Vehicle operating costs
- Auto ownership
- Vehicle operating costs
- Reliability
- Safety
- Emissions

A detailed design specification was then developed that outlined the functional logic for calculating the required B-C metrics using the available data. In conjunction with the development of the design specification, it was also necessary to identify appropriate economic assumptions, such as values-of-time, operating costs, accident rates and costs, and capital, operating and financing costs. The tool was implemented in SQL Server in order to allow the tool to interact directly with the database in which SANDAG stores all ABM inputs and outputs for all scenarios.

I.2.2 Activity-Based Model

All of the BCA metrics are based on two primary data sources. Benefits (and disbenefits) are calculated using information extracted directly from the SANDAG ABM system, or using information derived from ABM post processing tools, such as EMFAC. The benefits are derived primarily from estimates of travel demand and associated metrics. Travel demand includes both personal travel made by regional residents, as well as travel demand associated with truck and commercial vehicles and external travel. The ABM includes a network supply model component which interacts with the demand components and produces indicators for network performance, such as link volumes and speeds by time-of-day. The second primary type of data source, costs, were prepared by SANDAG regional planning staff to represent the capital, operating and maintenance, and financing associated with different alternatives.

Activity-Based Model Sensitivities

CT-RAMP is the ABM component of the SANDAG integrated model system. ABMs are used to predict the detailed travel patterns of regional residents as they travel within the region on a typical weekday. These estimates of travel demand are highly spatially and temporally detailed and reflect the complex relationships amongst the trips that individuals make, as well as the interrelated travel of members of the same household. The ABM is complemented by a number of additional models that address other important travel demand market segments, including a truck and commercial vehicle model that estimates travel demand for these vehicle types.

There are three primary types of inputs to the ABM system, and a number of other inputs associated with specific auxiliary models. The first primary input is a geographic input file containing information on employment by sector, housing, households, persons, enrollment, urban form, parking, and open space. This file incorporates dynamic information derived from upstream integrated model system components and tools such as PECAS and UDM, as well as fixed information from exogenous sources. The second primary input is a synthetic population created by the upstream PopSyn component. The third primary input to the ABM is measures of network performance created by prior runs of the downstream network model. Outputs from the ABM system include detailed estimates of travel demand used by the downstream network model, as well as accessibility measures and travel time and cost “skims” used by the upstream model components.

ABM Database

The BCA tool operates directly on information included in the SANDAG ABM database. The ABM requires as input, and produces as output, significant amounts of data. In order to systematically analyze and archive these data, SANDAG established an ABM database which includes both ABM inputs and outputs. These inputs and outputs provide fundamental information required for the BCA.

Key ABM input data used by the BCA tool includes:

- *Synthetic population*: A detailed representation of all regional households and persons, including critical demographic information such as age, income, and employment status.
- *Land use data*: Spatial data describing base year and future year employment by industrial sector, enrollment, and other variables is available at two primary geographic levels – MGRAs (which are comparable to Census block groups), and TAZs (which are larger aggregations of MGRAs).
- *Multimodal Network Information*: Data describing network attributes.

Key ABM output data used by the BCA tool include:

- *Trip demand lists*: Detailed lists of trips for all regional residents.
- *Tour lists*: Detailed lists of tours, or chains of linked trips that start and end at the home or workplace, for all regional residents.
- *Synthetic population*: The ABM updates synthetic information during the model run process. Some of this updated information, such as the number of vehicles each household chooses to own, is used by the BCA tool.
- *Multimodal Network Impedances*: Data representing travel times, costs and volumes by different modes (such as drive alone vehicles, local buses, etc.) and time-of-day (for five broad time periods which combined represent the 24 hours of the day).

Two additions to the ABM database were required to implement the BCA tool. First, it was necessary to add a table that contains the emissions information produced by EMFAC. Second, it was necessary to add some indices to the TAZSKIM table in order to support more rapid data access. Note that while the BCA tool operates directly on the data stored within the SANDAG ABM database, the BCA tool stores B-C input assumptions and output results in a separate, parallel BCA database.

I.2.3 Benefit-Cost Analysis Tool

Capabilities

The BCA tool provides estimates for eight types of benefits. The following sections describe each of these benefit types, as well as the key data items in the ABM database used to calculate these benefits.

Residential Mobility Benefits

Residential mobility benefits are the travel time benefits that accrue to regional residents. These benefits are calculated for each individual trip by monetizing the differences between base and build travel time impedances. These impedances are either at the spatial detail level of either MGRAs or TAZs, depending on the travel mode.
In order to monetize these travel time benefits, value-of-time (VOT) assumptions were calculated and applied based on an analysis of trips by purpose, household income, and vehicle occupancy levels. Note that for some transit trips, it was necessary to impute a base impedance to compare to the build impedance because no transit service existed in the base networks. Telecommuting benefits are also included in this category of benefits (see details on telecommuting assumptions below).

Truck Mobility Benefits

Truck mobility benefits are the travel time benefits that accrue to truck trips and commercial vehicle trips. These benefits are calculated at an aggregate TAZ-level by monetizing the differences between base and build impedances. The monetization is was based on ABM assumptions and varied by vehicle type, and the impedances are TAZ-level.

Emissions Benefits

Emissions benefits are due to changes in emissions by pollutant type. Estimates of emissions are derived from the California Air Resources Board's EMFAC model, California's emissions factors modeling software. EMFAC uses ABM network supply model outputs, calculated at an aggregate level. The monetization factors used to calculate the benefits are based on regional and Federal guidance.

Safety Benefits

Safety benefits are due to reductions in vehicle accidents by accident type. Accident types include fatal, injury, and property damage only. Accidents by type estimated using San Diego-specific information about accidents by type per VMT. These VMT estimates are produced by the ABM network supply model. Monetization factors used to calculate the benefits are based on Federal guidance regarding the value of a statistical life.

Reliability

Reliability benefits are due to reductions based on the concept of "total equivalent delay" resulting from unreliable travel times, which can be thought of as the amount of "schedule buffer time" (in minutes) that travelers require in order to ensure they arrive at their activities on time. Estimates of total equivalent delay pivot off of estimates of free-flow and congested travel times derived from the ABM network supply model. The "value-of-reliability" used to monetize this time is assumed to be equivalent to the VOT used to monetize travel time benefits.

Vehicle Operating Benefits

Vehicle operating benefits are due to reductions in vehicle operating costs. Vehicle operating costs are calculated separately for autos and trucks (by type), on a per mile basis. These costs are derived from the ABM's network supply model, and the monetization factors based on per mile operating costs used in ABM.

Auto Ownership Benefits

Auto ownership benefits are due to reductions in the number of vehicles that regional households choose to own, as forecast directly by the ABM. Ownership costs include costs such as insurance and financing, but exclude costs associated with vehicle usage such as fuel and maintenance costs. The factors used to monetize these changes are based on federal and private industry research on annual per vehicle ownership.

Physical Activity Benefits

Physical activity benefits are due to increases in the amount of transportation-related physical activity that regional residents get. The monetization factors used to calculate these benefits are based on review and adjustment of numerous exogenous sources.

Multiyear Processing

The multiyear BCA metrics are calculated in two stages. In the first stage, a comparison of base and build alternative ABM model results is performed for each alternative scenario year. This produces a set of single year estimates of benefits by type. In the second stage, a multiyear benefit stream is calculated by interpolating and extrapolating benefits and costs between start year, scenario years, and end year. The multiyear benefit stream calculation also incorporates inflation and discount rates, animalization factors, and produces summary B-C metrics.

User Controls

This section describes the list of controls or information that the user must provide, such as analysis years, VOT assumptions, animalization factors, and other key inputs.

The BCA tool is implemented in the BCA database. The BCA database includes stored procedures that implement the logic required to calculate each of the seven types of benefits and calculate the multiyear B-C stream, as well as tables that contain the BCA input assumptions and the BCA output results.

Implementation

The BCA tool is implemented in the SQL Server. The tool is comprised of a set of stored procedures, a set of input assumption tables, and a set of output results tables. There are three primary types of stored procedures. The first type of stored procedures calculates the benefits by benefit type. For each benefit type, there are two or three component stored procedures that are executed in sequence. The second type of stored procedure summarizes the demographics for each analysis year. The third type of stored procedure performs the multiyear analysis and produces estimates of benefits and costs for each year, as well as summary metrics for the overall BCA.

I.2.4 Tool Components

I.2.4.1 Mobility Benefits

Mobility benefits represent the monetized value of travel time savings that accrue to regional travelers' trips and to commercial and truck vehicle trips. The travel time savings are calculated by comparing the travel times that are experienced by travelers or trucks under a "build" scenario to the travel times that they would have experienced under a "no-build" or "base" scenario, for the same origin-destination pair, mode, and time-of-day. These savings are then monetized using market segment specific values-of-time. The following sections describe the calculation of these mobility benefits for resident travel, and for commercial and truck travel.

Travel Time Benefit Calculation

Resident Travel

Regional resident travel time savings are calculated at the individual trip level. The travel time savings are calculated by comparing the travel times that are experienced by travelers under a "build" scenario to the travel times that they would have experienced under a "no-build" or "base" scenario, for the same origin-destination pair, mode, and time-of-day. A set of table joins is performed to define existing, new, and dropped trips. All these different types of trips are included in the analysis. The travel time calculations include both in-vehicle and out-of-vehicle travel time components. In some cases where transit service did not exist in the base scenario, but did exist in the build scenario, it was necessary to impute a no-build transit travel time. This imputation was based on a statistical analysis of the relationship between auto distance and walk-to-transit generalized cost, and auto distance and drive-to-transit generalized cost.

$\text{Time}_{\text{walk-to-transit}} = \text{Time}_{\text{drive alone auto}} * (19.700 * \text{Distance}_{\text{drive alone auto}}\text{\^{}}{-0.362})$

$\text{Time}_{\text{drive-to-transit}} = \text{Time}_{\text{drive alone auto}} * (12.653 * \text{Distance}_{\text{drive alone auto}}\text{\^{}}{-0.358})$

Trucks and Commercial Vehicles

Truck and commercial vehicle trip travel time savings are calculated at the zone pair level. The travel time savings are calculated by comparing the commercial vehicle and truck travel times experienced under a "build" scenario to the travel times they would have experienced under a "base" scenario. Travel time difference calculations were segmented by mode and payment status.

Mobility Benefit Monetization

After calculating travel time differences, these benefits are monetized by using assumed VOT. These VOT vary by market segment, with different values for regional resident travel, commercial vehicle travel, and truck travel.

Value of Time: Resident Travel

For regional resident travel, in-vehicle travel time is monetized using the latest research regarding VOT derived from the relevant federal guidance (Benefit-Cost Analysis Guidance for Discretionary Grant Programs, December 2018).

Note that out-of-vehicle time is perceived by travelers to be more onerous than in-vehicle time. Out-of-vehicle time is considered only for transit trips and includes the amount of time spent walking to or from transit, waiting for transit, or transferring. Out-of-vehicle time is valued at 2.2 times in-vehicle time, based on guidance from the Federal Highway Administrations Surface Transportation Economic Analysis Model.

Value of Time: Truck / Commercial Travel

Truck and commercial vehicle VOT assumptions are calculated using the federal guidance (2018 BULD grant).

Table P.2

Truck / Commercial Vehicle Values of Time (2019$)

Market Segment	Value-of-time ($ / hour)
Heavy duty trucks	$43.20
Medium duty trucks	$29.70
Light duty trucks	$29.70
Commercial vehicles	$29.70

Other Out-of-Pocket Costs

Parking costs are incorporated into the overall monetized regional travel mobility benefits.

Treatment of Transfers

Tolls and fares are treated distinctly from other out-of-pocket costs such as parking, and vehicle operating expenses. This is because, although they are paid out-of-pocket by travelers, they accrue as income to regional transportation agencies and thus help offset monetary costs associated with building and maintaining the transportation system. Consequently, these values represent both costs and benefits and as a result are treated as internal "transfers." These costs reduce the overall net benefit to travelers, but also reduce the overall net costs of developing and maintaining transportation infrastructure.

I.2.4.2 Vehicle Operating Cost Benefits

Vehicle operating costs represent the variable cost associated with operating a vehicle, such as fuel costs and maintenance. Vehicle operating costs do not include fixed costs associated with vehicle ownership, such as purchase, financing, and insurance costs.

Vehicle Operating Cost Calculation

Vehicle operating costs are calculated using ABM network link information on link distances and volumes by vehicle type market segment. A potential future enhancement to the BCA tool would be to calculate this at the individual trip level for regional resident travel, in order to support the assessment of equity impacts of changes in these operating costs.

Vehicle Operating Cost Monetization

For regional residents, the valuation of auto operating costs is based on assumed distance-based auto operating costs used in the SANDAG ABM system. Note that this valuation is assumed to change over time, in order to be consistent with the assumptions used in the ABM. Table P.3 shows the cost per mile assumed in various alternative analysis scenario years.

Table P.3

Vehicle Operating Costs (2019$)

YEAR	Auto Operating Cost ($ / mile)
2016 (base)	$0.163
2025	$0.203
2035	$0.185
2050	$0.187

It is critical to note that these operating costs are significantly lower than in previous analyses, leading to an increase in driving in the analysis period, and a corresponding reduction in benefits from the plan.

The current SANDAG model does not incorporate a truck-specific operating cost, so the valuation of truck operating costs is based on assumed distance-based auto operating costs used in Metropolitan Transportation Commission’s (MTC) ABM system. For all analysis years, the truck operating cost is assumed to be $0.346/mile.

I.2.4.3 Vehicle Ownership Cost Benefits

The valuation of annual auto ownership costs is intended to capture all the aspects of auto ownership not captured by the operating cost valuation. These costs would include factors such as purchase and depreciation, financing and insurance. Reductions in vehicle ownership are considered to be a net benefit or savings.

Vehicle Ownership Cost Calculation

The SANDAG ABM system incorporates a sub-component that forecasts the number of vehicles that each regional household chooses to own. Changes in auto ownership, predicted by the model, can be monetized using this information. The SANDAG auto ownership model is sensitive to changes in accessibility. For example, if transit services improve, this may induce households to own fewer vehicles.

Vehicle Ownership Cost Monetization

The valuation of annual auto ownership costs is intended to capture all the aspects of auto ownership not captured by the operating cost valuation. These costs would include factors such as purchase and depreciation, financing and insurance. The assumption of costs of $5,900 per vehicle is applied to the total number of vehicles maintained by regional households. This assumption is based on information from MTC and the California Automobile Club (AAA).

I.2.4.4 Emissions Benefits

The valuation of emissions is intended to capture the benefits and costs associated, respectively, with reductions or increases in emissions by pollutant type.

Emission Type Estimation

Emissions are not directly output or forecast by the SANDAG ABM. Rather, forecasts of regional network link volumes and speeds output by the ABM are used as inputs to the EMFAC, which is the California Air Resources Board's tool for estimating emissions from on-road vehicles. EMFAC outputs forecasts of emissions by pollutant type.

Emission Type Monetization

Each pollutant type is associated with a unique monetization factor, and all of the factors are from the federal guidance (Benefit-Cost Analysis Guidance for Discretionary Grant Programs, December 2018). In some cases, this monetization factor increases over time. Each pollutant type and associated unit cost is summarized below:

- *CO_2 PER METRIC TON*: The assumption of costs of $2.00 per metric ton is applied to estimates of tons of CO_2 emitted produced by EMFAC. Note that in previous analyses, the value of CO2 per ton was $21.18 in the base year, and rose to $51.81 in 2050.
- *$PM_{2.5}$ (FINE PARTICULATE MATTER) PER TON, BOTH DIRECT AND DIESEL*: The valuation per metric ton of fine particulate matter emissions of $392,584 per metric ton is applied to estimates of tons of fine particulate matter emitted produced by EMFAC.
- *PM_{10}*: The valuation per metric ton of PM_{10} particulate matter is $356,838 per ton.
- *NO_X PER TON*: The valuation per metric ton of NO_X emissions of $8,625 per metric ton is applied to estimates of tons of NOx emitted produced by EMFAC.
- *ROG (REACTIVE ORGANIC GASES) PER TON, ALL TYPES*: The valuation per metric ton of ROG emissions of $1,905 per metric ton is applied to estimates of tons of ROGs emitted produced by EMFAC.
- *SO_2 PER METRIC TON*: The valuation per metric ton of SO_2 emissions of $50,814 per metric ton is applied to estimates of tons of CO_2 emitted produced by EMFAC.

I.2.4.5 Safety Benefits

This valuation of safety is intended to capture the benefits and costs associated, respectively, with reductions or increases in vehicle accidents by severity. All cost factors for collisions are based on the federal guidance (Benefit-Cost Analysis Guidance for Discretionary Grant Programs, December 2018), converted to 2019$.

Collision Type Calculation

Vehicle accidents are not directly output or forecast by the SANDAG ABM. Rather, forecasts of regional network link volumes are used to generate estimates of vehicle miles travelled. These forecasts were used in conjunction with San Diego-specific VMT-based accident rates by severity prepared by SANDAG staff using California state Statewide Integrated Traffic Records System (SWITRS) data to produce estimates of accidents by severity.

Collision Type Monetization

Fatality Collisions

Fatality collisions are proposed to be calculated based on the recent U.S. Department of Transportation (U.S. DOT) "Guidance on Treatment of the Economic Value of a Statistical Life (VSL)," dated 2016. This valuation is based on extensive recent empirical studies, and is defined as the additional cost that individuals would be willing to bear for improvements in safety (that is, reductions in risks) that, in the aggregate, reduce the expected number of fatalities by one. The proposed valuation of fatality collisions is $9.98 million. This valuation is applied to an estimate of total fatality collisions derived from San Diego-specific collision rates and SANDAG ABM outputs.

Injury Collisions

The previously mentioned U.S. DOT "Guidance on Treatment of the Economic Value of a Statistical Life" is also a source for information about the valuations of injuries by severity level, using a factor that is applied to the VSL. The severity level used was code U – "Injured (Severity Unknown)". This results in a proposed valuation of injury collisions of $180,809. This valuation is applied to an estimate of total injury collisions derived from San Diego-specific collision rates and SANDAG ABM outputs.

Property Damage Only (PDO) Collisions

The valuation of property damage only collision is $4,468.

I.2.4.6 Reliability Benefits

The valuation of reliability is intended to capture the benefits associated with more predictable travel times, which reduces the need for travelers to include additional buffer time in their schedules. This additional buffer time is referred to as "Total Equivalent Delay."

Total Equivalent Delay Calculation

The formula for calculating Total Equivalent Delay is from the SHRP2 L05 research report "Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes: Technical Reference." Total Equivalent Delay is calculated using ABM network link outputs. The congested and free flow travel times for each link are the key inputs used to first calculate the 80th and 50th percentile travel time indices. These indices are then used to calculate travel time equivalents, which are in turn converted to total equivalent delay. The steps are as follows:

1. For each alternative, calculate recurring mean TTI (travel time index)
    a. Travel time index = t / t0
    b. t = average travel time per unit distance (hours / mile) - this can be calculated at the link level from loaded model networks
    c. t0 = free flow travel time per unit distance (hours / mile) - this can be calculated at the link level from free flow model networks
2. Calculate Adjusted recurring mean TTI (TTIm)
    a. TTIm = 1.0274 * TTI^1.2204
    b. Cap TTIm at value of 3.0
3. Calculate the 80th and 50th percentile TTI
    a. TTI80 = 1 + 2.1406 * ln(TTIm)
    b. TTI50 = TTIm^0.8601
4. Calculate travel time equivalents
    a. TTIe = TTI50 + a * (TTI80 - TTI50)
    b. a represents is the Reliability Ratio (VoR / VoT), which was conservatively set = 1.0 (meaning minutes of reliability are equivalent to minutes of travel time).
5. Compute total equivalent delay
    a. TotalEquivalentDelay = ((TTIe / Freeflowspeed) - (1 / free flow speed)) * VMT

Total Equivalent Delay Monetization

Total Equivalent Delay is a measure in minutes, and thus for consistency, this time is valued the same as travel time minutes. In the absence of other information, it is assumed that the value of this reliability measure is the same as the value of time.

I.2.4.7 Physical Activity Benefits

Physical activity benefits represent health care cost savings and improved productivity associated with physical activity. The ABM can provide forecasts of transportation-related physical activity, such as time spent walking, biking, or walking to transit.

Physical Activity Calculation

The total amount of transportation-related physical activity is calculated for each individual person in the regional synthetic population by summarizing (for all trips made by the person) the total time spent walking, biking, and walking to transit.

Physical Activity Monetization

The valuation of the health care cost savings and improved productivity associated with physical activity on a per minute basis was based on value of time based on the associated value of time for all travel.

I.2.4.8 Costs of Transportation Investments

The preceding sections have described how the different types of benefits can be monetized. These benefits can then be compared against the monetary costs associated with transportation investments and policies. All of the B-C metrics produced by the BCA tool are based on the relationship between these benefits and costs. Monetary costs can be classified into: (1) capital costs; and (2) operating and maintenance costs. All costs were developed by SANDAG.

Capital Costs

Capital costs represent fixed expenses associated with the purchase of equipment, constructions costs, and other one-time expenses, although these expenses may be paid over time through the use of financing. For example, costs associated with purchasing transit vehicles, or expanding physical roadway capacity, are capital costs.

Operating and Maintenance (O&M) Costs

O&M costs represent expenses associated with the ongoing use of transportation investments. These costs typically endure for a longer period of time than capital costs or finance cost expenditures. For example, O&M costs may include costs associated with operating transit services or maintaining adequate pavement conditions.

I.2.4.9 Lifecycle Analysis and Benefit-Cost Analysis Output

The BCA tool allows the user to consider the entire lifecycle of transportation investments by calculating not only the benefits for a single analysis year, but by considering the multiyear stream of benefits and costs, and produces a variety of B-C metrics, including B-C ratios, network present value, and the internal rate of return.

Multi Year Analysis

A distinguishing feature of the BCA tool is that all B-C metrics reflect the multiyear stream of benefits and costs as well as the effects of inflation and discounting. The benefits are primarily derived directly from SANDAG ABM outputs although in some cases, such as emissions, the benefits pivot off of other analysis tools. The user identifies the start and end years for the analysis, as well as interim years. If users have ABM outputs for the start and end years, these may be specified, but they are not required. Start and end years can be earlier or later than any given model output years. However, the user must have ABM output for any interim years specified.

Interpolation and Extrapolation

The BCA tool produces B-C metrics for every individual year between the start and end years identified by the user. However, the tool does not require that the user have model outputs for every individual year. Instead, for any year for which no modeled data is available, the benefits and costs are extrapolated using available model data. For interim years that fall between any two modeled analysis years for which model data is available, results are interpolated between these two years. For interim years that fall between the analysis start year and the first modeled analysis year, results are interpolated between zero (i.e., the base and the build are the same) and this first modeled analysis year. For interim years that fall between the last modeled analysis year and the end year, results are assumed to stay flat at the level of the last modeled year.

Inflation and Discounting

Discounting provides a method for valuing a future sum of money in today's dollars. The discount rate reflects the "time value of money." Money that is invested, rather than spent, in the current year will be worth more in the future year – in the next year (assuming a positive return on investment). In contrast, inflation represents the fact that the currency values generally decline over time – a dollar today will purchase more than a dollar tomorrow. Both inflation and discounting must be considered when calculating a multiyear stream of benefits and costs, as both will influence the final output BCA metrics. The BCA tool allows the user to specify both inflation and discount rates. Note, however, that the ABM outputs are in constant base year dollars. The discount rate used in this analysis is 4 percent, though federal guidance prefers 7 percent. Four percent was used as it is consistent with previous analyses, and also because a 7 percent discount rate severely undervalues long-term investments, such as transportation infrastructure, which can last decades.

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Endnotes

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[1] The discount rate is often assumed to be similar to the real rate of return on investment, thus accounting for lost opportunity. This is not to be confused with the effect of inflation, as all costs and benefits in the BCA are "real" or "constant" dollars, eliminating the effects of inflation.