



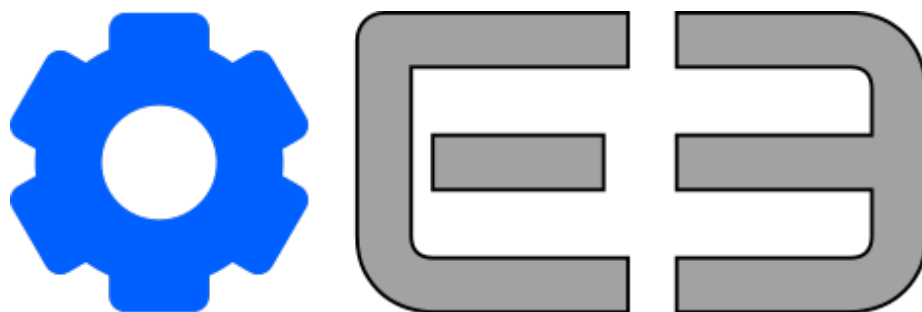
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Economic Evaluation Engine (E3)

Technical Manual

Joshua Kneifel
David Webb
Luke Donmoyer

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National Institute of Standards and Technology
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Abstract

The Engineering Laboratory (EL) of the National Institute of Standards and Technology (NIST) has developed a variety of tools that provide some level of economic analysis, many of which have been developed by EL's Applied Economics Office (AEO). AEO-developed tools range across topic areas and economic metrics. Each tool is targeting government agencies and organizations that fall under NIST's mission. Stakeholders need different levels of details and functionality because of the diverse backgrounds across stakeholders. As a result, AEO has developed these software tools in a "one-off" approach on an as needed basis. As a result, each software has its own unique set of code even though these tools have some key underlying components that are common across tools, including methodology documented in standards.

To improve the efficiency of the tools developed by AEO and its stakeholders, AEO has developed an economic service/engine with an associated Application Programming Interface (API) that provides consistent, standardized, transparent, reproducible economic analysis calculations should be developed, maintained, and made publicly available for internal and external researchers, analysts, and software developers called the Economic Evaluation Engine (E3). E3 provides economic evaluation capabilities based on ASTM building economic standards including life-cycle cost analysis, benefit-cost analysis, profit maximization / cost-minimization, and risk-cost analysis. E3 could be leveraged by NIST as well as other federal agencies and national laboratories, state and local governments, academia, and the private sector to improve their tool development by using a federally developed and validated calculations to provide standard-consistent analysis.

E3 is publicly accessible on a NIST server as well as on GitHub for anyone to use for economic analysis, whether it's through a basic script calling on the E3 API, online interface that connects to the E3 API, or an executable program that is built on E3's capabilities. Additionally, users of E3 could provide expansions to the capabilities by developing the code and submitting it to NIST for review and incorporation.

This technical manual describes E3, including the underlying standards on which its based, the data flow through the tool, details on the code libraries, classes, and file structure, development tools used, guidance on how to use the tool, limitations, planned release, and the development of its future capabilities.

Keywords

Benefit-cost analysis; building economics; building standards; life-cycle cost analysis; resilience; software; sustainability.

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Preface

This documentation was developed by the Applied Economics Office (AEO) in the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST). The document explains how the E3 software has been developed. The intended audience are researchers and software developers completing economic analysis, such as life cycle cost analysis and benefit-cost analysis.

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1. Introduction and Background

1.1. AEO's Software Tool Development

The Engineering Laboratory (EL) of the National Institute of Standards and Technology (NIST) has developed a variety of tools that provide some level of economic analysis, many of which have been developed by EL's Applied Economics Office (AEO). AEO-developed tools (both legacy and active described in Tab. 1-1) range across topic areas and economic metrics: life cycle cost analysis (LCCA), benefit-cost analysis (BCA), sensitivity and uncertainty analysis, risk assessment, and profit maximization / cost minimization.

Table 1-1 AEO-Developed Software

Software Name	Acronym	Topic Area	Analysis
Economic Decision Guide Software	EDGE\$	Community Resilience	BCA
Building for Environmental and Economic Sustainability^a	BEES	Building Product Sustainability	LCCA
Building Industry Reporting and Design for Sustainability^a	BIRDS	Whole Building Sustainability	LCCA
Building Life Cycle Cost	BLCC	Building economics (energy efficiency, sustainability)	LCCA
Bridge Life Cycle Cost	BridgeLCC	Bridge Economics	LCCA
Cost-Effectiveness Tool for Capital Asset Protection^a	CET	Building Risk Mitigation	LCCA; Uncertainty analysis; Risk assessment
Sprinkler Use Decisioning^a	SpUD	Residential Sprinklers	BCA
Turnout Gear Selector^a	ToGS	Firefighter Protection	Risk Assessment
LCCA Tool for Chem/Bio Protection of Building^a		Facility Chem/Bio protection strategies	LCCA; Rick Assessment
Manufacturing Cost Guide		Manufacturing	Cost Minimization; Profit Maximization; life cycle impact assessment (LCIA)
Monte Carlo Tool		Manufacturing	Uncertainty Analysis
Smart Investment Tool		Manufacturing	LCCA, Uncertainty Analysis

^aLegacy Software; no longer supported

Each tool targets the needs of government agencies and organizations that fall under NIST's mission. Stakeholders need different levels of details and functionality because of the diverse backgrounds across stakeholders. As a result, AEO has developed these software tools in a "one-off" approach on an as needed basis. Each tool is developed from scratch, commonly completed by different principal investigators and software developers (some of which are no longer employed at NIST) as different types of software (e.g., Excel Macro-based spreadsheet¹,

¹ Certain equipment, instruments, software, or materials, commercial or non-commercial, are identified in this paper in order to specify the experimental procedure adequately. Such identification does not imply recommendation or endorsement of any product or service by NIST, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose

desktop application, web application) using different programming languages (e.g., Java, C#, Python) and development tools (e.g., .NET, Django, JavaScript).

As a result, each software has its own unique set of code even though these tools have some key underlying components that are common across tools, including methodology documented in standards. The duplication of efforts has led to ever increasing maintenance costs and/or placing tools into a legacy status with no additional support or development. Additionally, there has been increasing interest in redevelopment and expansion of existing tools (e.g., BLCC) as well as potential new tools targeting other research areas at NIST (e.g., cost-effectiveness of seismic retrofits, prioritization of Border Patrol facility maintenance and improvements). Further software development would continue to stress EL's limited software development resources.

To improve the efficiency of the tools developed by AEO and its stakeholders, an economic service/engine with an associated Application Programming Interface (API) that provides consistent, standardized, transparent, reproducible economic analysis calculations should be developed, maintained, and made publicly available for internal and external researchers, analysts, and software developers. Economic evaluation capabilities should be able to provide life-cycle cost analysis, benefit-cost analysis, profit maximization / cost-minimization, and risk-cost analysis.

The requirements for the tool include that it should be consistent with federal legislation (e.g., EPA 2005, RFA, UMRA, NEPA, PRA), federal regulations (e.g., 10 CFR 436, Circular A-4, Circular A-94), guidance (e.g., Handbook 135, Tri-Services Memorandum of Agreement (MOA)), and executive orders (e.g., EO 12866, 13693, 13123, 13563, and 13579) that define the methodology and necessitate the use of LCCA and/or BCA in decision-making. Additionally, the tool should also be consistent with industry consensus standards (e.g., ASTM) across as many topics as possible, including:

- (1) Buildings (e.g., co-benefits and trade-offs from net-zero energy designs)
- (2) Infrastructure (e.g., life-cycle costs of alternative designs)
- (3) Resilience (e.g., community risk and benefit-cost analysis; seismic and wind building code adoption)
- (4) Manufacturing (e.g., economic assessment of adoption of new technology)
- (5) Smart Grid (benefit-cost analysis of interoperability)
- (6) Cybersecurity (risk-cost analysis)
- (7) Safety & Security (e.g., risk assessment)
- (8) Fire (e.g., economic impact of fire building code adoption)

Not only could such a tool be used to improve NIST-funded tool development, it could also be leveraged by other federal agencies and national laboratories, state and local governments, academia, and the private sector to improve their tool development by using a federally

developed and validated calculations to provide standard-consistent analysis.² A few examples of existing economic analysis tools, both developed and maintained by NIST and other federal agencies, that could leverage such a tool include the following:

- LCCA
 - Department of Energy (DOE) BLCC software (maintained by NIST) for building energy efficiency, water conservation, and renewable energy projects
 - Federal Highway Administration (FHWA) Real Cost (excel-based tool) for highway LCCA
- BCA
 - NIST's EDGe\$ web application for Community Resilience
 - Federal Emergency Management Agency (FEMA) Benefit Cost Toolkit 5.2.1
 - State of Connecticut's Cost/Benefit Analysis Forms
 - FHWA Tool for Operations Benefit-Cost Analysis (TOPS-BC)

1.2. Economic Evaluation Engine (E3)

To address this need, a new software tool has been developed, called the Economic Evaluation Engine (E3). E3 is publicly accessible on a NIST server as well as on GitHub for anyone to use for economic analysis, whether it's through a basic script calling on the E3 API, online interface that connects to the E3 API, or an executable program that is built on E3's capabilities. Additionally, users of E3 could provide expansions to the capabilities by developing the code and submitting it to NIST for review and incorporation.

The potential impacts of successful completion of an all-purpose economic analysis API (E3) would be broad, benefiting every division and office in EL as well as other government agencies (federal and state) that desire economic analysis but do not have the capabilities and/or funding available to develop and continually support similar tools internally. By leveraging E3, NIST researchers will have improved capabilities to evaluate the economic benefits and costs of new technologies and potential changes to or development of new standards and codes, leading to improved design and greater adoption of these standards, codes, and technologies. Additionally, industry could leverage the standards-based API for tool development that could either be used for internal evaluations or provided as a service to other companies, leading to more standardized economic analysis that will better inform decision-making throughout an industry.

E3 will allow AEO to focus its collective resources on maintaining and expanding the API functionality and capabilities to keep it up-to-date and relevant instead of duplicating maintenance efforts across a range of software tools. Tools that leverage the API could be

² Such a tool could be useful for GSA, EPA, Commerce, DHS, NIH, Park Service, VA, DoD, DOE, NASA, State Dept., Smithsonian, USDA, USACE, USAF AFCEC, Army-COE, Navy – NAVFAC, Air National Guard, FEMA, Federal Railroad Admin., Individual States, National Labs, Labor Dept., Dept. of Transportation, US Access Board, US Courts, HHS, Federal Facilities Council, Green Seal, HUD, NIBS, NIST MEP, State Governments, Local Governments.

developed by AEO (including transition of existing tools), other EL or NIST researchers, federal and state government agencies, academics, or the private sector (industry groups and individual companies) based on their analysis needs at lower costs because much of the back-end development would already be completed. AEO and ELDST have received positive feedback from leadership across multiple EL research programs. External contacts that have shown an interest in such a tool will also be solicited, including Border Patrol, GSA, DOE FEMP, FHWA, and DHS.

1.2.1. Concept

To put the E3 products into perspective with other related (potential) products, a block diagram has been generated in Fig. 1-1. The E3 object library will be built into the API. The E3 API will be maintained on GitHub for 3rd party download, to be used locally with 3rd party scripts, or executable programs developed based on the API as well as be hosted on a NIST server to provide both NIST and 3rd party interfaces web-access. The E3 Interface will be a use case demonstrating the capabilities of the E3 function library and API (specific design to be discussed in Sec. 3). E3 will be designed to allow for expansion through modules that can provide items such as default data, calculation functions based on specific guidance, or more expansive environmental assessments.

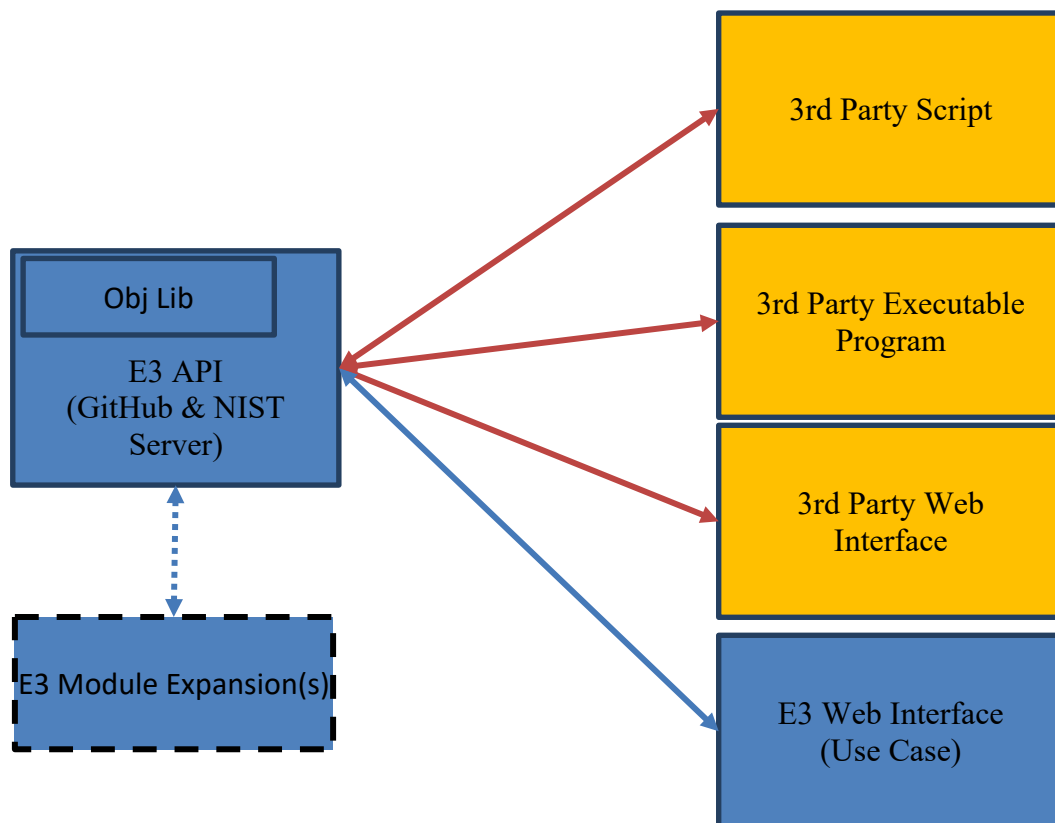


Figure 1-1 Block Diagram of E3 Product Interconnections

At this point in time, there does not exist such a set of products that provide the public with standards-based calculations that are generalized enough to be non-topic specific.

The intended users of the E3 products may include:

- AEO researchers completing economic calculations for internal research
- AEO researchers developing software to complete economic calculations for internal research and/or external parties
- Other NIST researchers wanting to complete economic calculations or develop software to complete economic calculations for internal research and/or external parties
- 3rd party researchers wanting to complete economic calculations or develop software to complete economic calculations

The users will have technical expertise in computer programming and/or software development allowing them to use the products (function library and/or API) without much assistance, primarily met by the support documents provided by AEO/ELDST with minimal technical support from AEO/ELDST staff.

The users will need a conceptual understanding of the economic analysis of interest. Since the users may not have in depth knowledge of economic analysis, the design will need to validate the data submission to ensure reasonableness and provide user's clear feedback on inconsistencies, concerns, or errors (e.g., check object tags for misspelled words that are similar that the user wanted to match).

The general process for a deterministic (single point estimate) analysis within E3 is as follows:

- Receive Request from User
- Authenticate, Validate, and Read the Request
- Calculate the cash flows for each BCN
- Aggregate cash flows for each standard category (i.e., "required" flows)
- Aggregate cash flows for each user-provided, customizable "tag" category ("optional" flows)
- Aggregate BCN flows for each Alternative by standard and tag categories
- Create Measure Summary for each Alternative by comparing to the Baseline Alternative
- Calculate Non-Deterministic Results (Optional)
 - If there are one or more Sensitivity Analyses included in the request, E3 replaces the value in the sensitivity analysis request and replicates the deterministic process. This is replicated for each value in the sensitivity analysis.
 - If there are one or more Uncertainty Analyses included in the request, E3 uses random selection of values that have uncertainty and replicate the deterministic

process. This is replicated until the analysis converges or the maximum number of simulations is met. Due to the amount of data, the cash flows generated in an uncertainty analysis are not saved or reportable.

- Generate E3 Output
- Return Output to the User

A user can customize the categorization (i.e., tags), and output objects (e.g., summaries, cash flows by category) to include in the output file. This provides the user the ability to customize the results returned. For example, the user may want to exclude some tags from LCCA results, such as externalities. In this case, the user can call on the cash flow objects and then generate their own results. Details of the data flow, code, libraries, and classes will be discussed in detail in Sec. 2 and Sec. 3.

1.2.2. Progress/Status

Development of E3 has been a multiyear process. In FY2020, the software requirements specifications document was finalized for designing E3 and examples files for validating the E3 API were created. In FY2021, the initial version of the E3 API was developed, internally beta tested, and published on GitHub and a NIST internal web server. In FY2022, the first E3 use case was released, a front-end interface that completes a LCCA of residential solar photovoltaic systems called Present Value for PhotoVoltaics - [PV]². Activities in FY2023 included transitioning E3 from Python to Java, including sensitivity and uncertainty analysis, continuous discounting, and non-monetary measures, and releasing E3 Version 2 (E3 V2). Additionally, the first use case for expanding E3 was developed, an E3 module that provides the capabilities in EDGe\$. Four key deliverables will be provided in FY2024: (1) a use case for researchers will be developed in Jupiter Notebook or similar (i.e., IPYNB file format), (2) a version of E3 that can be run locally, (3) release of a capital investment tool for manufacturers (SITEpress) based on AEO's Smart Investment Tool, and (4) development of a beta version of a web based BLCC.

1.3. ASTM Standards-Based Methodology

E3 is designed to be consistent with numerous standards from ASTM International, which can define test methods, specifications, classifications, practices, guides, and terminology. The primary focus in the initial development of E3 has been the suite of ASTM Standards developed by Subcommittee E06.81 on Building Economics. However, additional standards have been recently developed that use the same economic methods and apply them to additional topic areas, including community resilience and sustainable manufacturing. Although the focus may not be the same and some terminology may be different, the fundamental calculations are consistent across these standards. The standards that are the basis for the E3 design are discussed in the remainder of this chapter.

1.3.1. Building Economics (ASTM E06.81)

ASTM Committee E06 on Performance of Buildings was created to “promote knowledge, stimulation of research, development and maintenance of standards and related documents for performance of buildings, their elements, components, including means and methods of fabrication and assembly; and the description, measurement, prediction, improvement, and management of the overall performance of buildings and building-related facilities” [1]. Subcommittee E06.81 on Building Economics have developed standards for evaluating the potential economic performance of investments in buildings, providing industry standardized approaches for accepting or rejecting an investment, designing and sizing building systems, and establishing priorities. These standards include defining terminology for building economics (E833 Ref. [2]), guides for selecting the appropriate economic method (E1185 Ref. [3]) and how to summarize economic analysis results (E2204 Ref. [4]), and practices that show how to complete analysis using the selected economic methods. The practices will be discussed below by topic area.

1.3.1.1. LCCA and BCA

E06 Standard Practices for Building Economics provide the methods for calculating Life Cycle Cost Analysis (LCCA), Net Savings (NS) and Net Benefits (NB), and supplemental measures of Benefit-Cost Ratio (BCR) and Savings-to-Investment Ratio (SIR), Internal Rate of Return (IRR) and Adjusted Internal Rate of Return (AIRR), and Payback Period. Each of these measures is summarized below, including their appropriate use in decision making.

E917 is the Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems [5]. The LCC method sums all relevant costs associated with an entire building or building system over a specified time period.³ Mutually exclusive alternatives for a given functional requirement can be compared based on their LCCs to determine which is the least-cost option over the study period.

The following is the general formula for the LCC present value model:

$$LCC = \sum_{t=0}^N \frac{C_t}{(1+d)^t}$$

Where:

- LCC = Total LCC in present-value dollars of a given alternative
- C_t = Sum of all relevant costs, including initial and future costs, less any positive cash flows, occurring in year t ,
- N = Number of years in the study period
- d = Discount rate used to adjust cash flows to present value

³ E917 allows for providing LCC on an annualized value basis. E3 only reports results in present value terms. The user could use the present value results provided by E3 to provide the annualized values allowed in E917.

E1074 is the Standard Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems [6]. The Net Benefits (NB) method calculates the difference between discounted benefits and discounted costs while the Net Savings (NS) method calculates the difference between LCCs as a measure of the cost-effectiveness of a project, also called the net present value method.

The NB for a project alternative, relative to a designated base case, can be calculated comparing the difference in total benefits and total costs for each alternative (*A/t*) against the base alternative (*Base*):

$$NB = (Benefit_{Alt} - Benefit_{Base}) - (Cost_{Alt} - Cost_{Base})$$

Net Benefits can be calculated using individual benefit and cost differences by applying the following general formula:

$$\begin{aligned} NB_{A:BC} &= \sum_{t=0}^N \frac{\Delta B_t}{(1+d)^t} - \sum_{t=0}^N \frac{\Delta C_t}{(1+d)^t} \\ &= \sum_{t=0}^N \frac{\Delta B_t}{(1+d)^t} - \sum_{t=0}^N \frac{\Delta NI_t}{(1+d)^t} - \sum_{t=0}^N \frac{\Delta I_t}{(1+d)^t} = \sum_{t=0}^N \frac{(\Delta B_t - \Delta NI_t - \Delta I_t)}{(1+d)^t} \end{aligned}$$

Where:

- $NB_{A:BC}$ = NB, in PV dollars, of alternative (A), relative to base case (BC)
- ΔB_t = Benefit difference in year t associated with the alternative relative to the base case
- ΔC_t = Cost difference in year t associated with the alternative relative to the base case
- ΔNI_t = Non-investment cost difference in year t associated with the alternative relative to the base case
- ΔI_t = Investment cost difference in year t associated with the alternative relative to the base case
- t = Year of occurrence (where 0 is the base date)
- d = Discount rate
- N = Number of years in study period

The NS for a project alternative, relative to a designated base case, can be calculated by simply subtracting the LCC of the alternative from the LCC of the base case:

$$NS = LCC_{Base} - LCC_{Alt}$$

Net Savings can also be calculated using individual cost differences by applying the following general formula:

$$NS_{A:BC} = \sum_{t=0}^N \frac{S_t}{(1+d)^t} - \sum_{t=0}^N \frac{\Delta I_t}{(1+d)^t}$$

Where:

- $NS_{A:BC}$ = NS, in PV dollars, of alternative (A), relative to base case (BC)
- S_t = Savings in year t in costs associated with the alternative
- ΔI_t = Additional investment-related costs in year t associated with the alternative
- T = Year of occurrence (where 0 is the base date)
- D = Discount rate
- N = Number of years in study period

When considering a single project alternative, a project is cost effective if net benefits or net savings are greater than zero. If multiple sizes or design alternatives competing for a given purpose are being considered, the alternative with the greatest net benefits or net savings is the most cost effective.

E964 is the Standard Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems [7]. The BCR is used when the focus is on (monetizable) benefits relative to project investment costs and compares the combination of benefits and non-investment costs (net benefits excluding investment costs) relative to investment costs. The SIR, a variation of the BCR, is used when the focus is on project savings (i.e., cost reductions) relative to project costs.

The general formula for the BCR rearranges the terms used for NB as a ratio and separates costs into investment costs and non-investment costs:

$$BCR_{A:BC} = \sum_{t=0}^N \frac{(\Delta B_t - \Delta NI_t)}{(1+d)^t} \bigg/ \sum_{t=0}^N \frac{\Delta I_t}{(1+d)^t}$$

Where:

- $BCR_{A:BC}$ = BCR of alternative (A) relative to base case (BC)
- ΔB_t = Benefit difference in year t associated with the alternative relative to the base case
- ΔNI_t = Non-investment cost difference in year t associated with the alternative relative to the base case
- ΔI_t = Investment cost difference in year t associated with the alternative relative to the base case
- t = Year of occurrence (where 0 is the base date)
- d = Discount rate

N = Number of years in study period

Alternatively, the BCR can be calculated using the NB and net present value of the total investment costs (I):

$$BCR = \frac{(NB + I)}{I}$$

The general formula for the SIR rearranges the two terms for NS as a ratio:

$$SIR_{A:BC} = \sum_{t=0}^N \frac{S_t}{(1+d)^t} \bigg/ \sum_{t=0}^N \frac{\Delta I_t}{(1+d)^t}$$

Where:

$SIR_{A:BC}$ = SIR of alternative (A) relative to base case (BC)

S_t = Savings in year t in costs associated with the alternative

ΔI_t = Additional investment-related costs in year t associated with the alternative

t = Year of occurrence (where 0 is the base date)

d = Discount rate

N = Number of years in study period

A BCR or SIR greater than 1.0 indicates a project is economical because the benefits (benefits minus non-investment costs) or savings (reduction in non-investment costs) are greater than the investment costs. Attention must be taken to correctly define and interpret ratios when using them to choose among multiple alternative designs and sizes of a project or prioritize projects competing for limited funds.

E1057 is the Standard Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems [8]. The IRR and AIRR methods measure economic performance as a compound yield on investment. The IRR is the discount rate at which the net present value of future cash flows is equal to the initial investment:

$$\begin{aligned} NB_{A:BC} &= \sum_{t=0}^N \frac{\Delta B_{A,t} - \Delta C_{A,t}}{(1+i^*)^t} = \sum_{t=0}^N \frac{(\Delta B_{A,t} - \Delta NI_{A,t} - \Delta I_{A,t})}{(1+i^*)^t} \\ &= \sum_{t=0}^N \frac{(\Delta B_t - \Delta NI_t)}{(1+i^*)^t} - \sum_{t=0}^N \frac{\Delta I_t}{(1+i^*)^t} = 0 \end{aligned}$$

Where:

$NB_{A:BC}$ = NB of alternative (A) relative to base case (BC)

ΔB_t = Benefit difference in year t associated with the alternative relative to the base case

- ΔC_t = Cost difference in year t associated with the alternative relative to the base case
- i^* = IRR
- N = Number of years in study period

The same formula can be used for calculating the IRR using NS:

$$NS_{A:BC} = \sum_{t=0}^N \frac{S_t}{(1+i^*)^t} - \sum_{t=0}^N \frac{\Delta I_t}{(1+i^*)^t} = 0$$

- $NS_{A:BC}$ = NS, in PV dollars, of alternative (A), relative to base case (BC)
- S_t = Savings (negative change in non-investment costs) in year t in costs associated with the alternative
- ΔI_t = Additional investment-related costs in year t associated with the alternative
- T = Year of occurrence (where 0 is the base date)
- i^* = IRR
- N = Number of years in study period

The IRR calculation requires the use of a root-finding algorithm due to the nonlinear nature of the IRR formula. Ridders' Method was selected due to its use of bracketing in conjunction with the false-position method. The method attempts to use the false-position method to produce a faster convergence to the root while relying on bracketing if the false position method produces a less optimal estimate. By using the bracketing method as a secondary method, Ridders' method can conditionally guarantee convergence to a root, although at the cost of convergence time (order $\sqrt{2}$ instead of order 2) due to the additional calculations. The condition required for convergence is that the signs of the initial left and right bracketing values must be opposite. This means if there are an even number of roots in the initial bracket (0 to 1) the algorithm will fail. Furthermore, if an even number of roots is present, the algorithm will only converge to one without preference.

The AIRR is the discount rate at which the net present value of future cash flows is equal to the initial investment including earnings on reinvested savings to the end of the study period. The IRR formula is modified by introducing the reinvestment returns for the NB or NS for each period assuming a constant reinvestment rate (r) compounded for the remainder of the study period:

$$NB_{A:BC} = \sum_{t=0}^N \frac{(\Delta B_t - \Delta NI_t)(1+r)^{N-t}}{(1+i^*)^N} - \sum_{t=0}^N \frac{\Delta I_t}{(1+r)^t} = 0$$

$$NS_{A:BC} = \sum_{t=0}^N \frac{(S_t)(1+r)^{N-t}}{(1+i^{**})^N} - \sum_{t=0}^N \frac{\Delta I_t}{(1+r)^t} = 0$$

Where:

- i^{**} = AIRR
- r = reinvestment rate
- N = Number of years in study period

If the reinvestment rate is not equal to the discount rate, then the same approach as implemented for calculating the IRR is implemented with the same root-finding algorithm approach.

The most straightforward method of calculating the AIRR requires the calculated BCR for a BCA or SIR for a LCCA for a project (relative to its base case) and assumes the reinvestment rate (r) equals the discount rate. The AIRR can then be computed using the following formulas for BCA and LCCA, respectively:

$$\begin{aligned} AIRR_{BCA} &= (1+r) \cdot \left(1 + \frac{\sum_{t=0}^N \frac{(\Delta B_t - \Delta NI_t)}{(1+r)^N} - \sum_{t=0}^N \frac{\Delta I_t}{(1+r)^t}}{\sum_{t=0}^N \frac{\Delta I_t}{(1+r)^t}} \right)^{\frac{1}{N}} - 1 \\ &= (1+r) \cdot \left(1 + \frac{NB}{I} \right)^{\frac{1}{N}} - 1 = (1+r) \cdot \left(\frac{NB + I}{I} \right)^{\frac{1}{N}} - 1 = (1+r) \cdot (BCR)^{\frac{1}{N}} - 1 \\ AIRR_{LCCA} &= (1+r) \cdot \left(1 + \frac{\sum_{t=0}^N \frac{(S_t)}{(1+r)^N} - \sum_{t=0}^N \frac{\Delta I_t}{(1+r)^t}}{\sum_{t=0}^N \frac{\Delta I_t}{(1+r)^t}} \right)^{\frac{1}{N}} - 1 \\ &= (1+r) \cdot \left(1 + \frac{NS}{I} \right)^{\frac{1}{N}} - 1 = (1+r) \cdot \left(\frac{NS + I}{I} \right)^{\frac{1}{N}} - 1 \\ &= (1+r) \cdot (SIR)^{\frac{1}{N}} - 1 \end{aligned}$$

Note that in the case where the change in benefits (ΔB_t) for all times t are zero (i.e., LCCA), the benefits only include reductions in non-investment costs (i.e., cost savings) and the BCR equals the SIR. The reinvestment rate is assumed to be equal to the discount rate. The appropriate value of the reinvestment rate (r) is typically best approximated using the discount rate because a rate higher (or lower) than the discount rate suggests that the discount rate is too low (or too high) because it does not adequately reflect the next best investment opportunity in which you would invest additional cash flows.

The IRR or AIRR is compared against the investor's minimum acceptable rate of return (MARR), and the investment is considered economical if the value is greater than the MARR. The IRR and

AIRR will be equal if there is only an initial investment cost and the benefits/savings are realized at the end of the study period or if the reinvestment rate (r) equals the IRR. If r is less than the IRR, then the AIRR will be less than the IRR; and if r is greater than the IRR, the AIRR is greater than the IRR. Examples where the IRR and AIRR are both reported as provided in Sec. 4.5. The AIRR is recommended for most applications in which a return-on-investment measure is desired because it is more reliable than IRR for maximizing NB or NS. Caution is recommended in applying either measure, as problems may arise under certain conditions, for instance the root finding algorithm (Ridder's method) may fail to find the IRR if it is out of the initial bounds or if the initial bounds contain two roots.

E1121 is the Standard Practice for Measuring Payback for Investments in Buildings and Building Systems [9]. The payback method determines the number of periods required for the benefits or savings to offset the initial investment costs and is used for determining whether the investment is recovered within the project's service life or some maximum acceptable payback period (MAPP). The simple payback period (excluding discounting) is the minimum number of years, y , for which:

$$\sum_{t=1}^y ((\Delta B_t - \Delta NI_t) - \Delta I_t) \geq \Delta I_0 \text{ or } \sum_{t=1}^y (S_t - \Delta I_t) \geq \Delta I_0$$

Where:

- y = Minimum length of time over which future net cash flows have to be accumulated in order to offset initial investment costs
- S_t = Savings in year t in non-investment costs associated with the alternative
- ΔB_t = Additional benefits in year t associated with a given alternative
- ΔNI_t = Additional non-investment costs in year t associated with a given alternative
- ΔI_0 = Initial investment costs associated with a given alternative
- ΔI_t = Additional investment-related costs in year t , other than initial investment costs

The discounted payback period is the minimum number of years, y , for which:

$$\sum_{t=1}^y \frac{(\Delta B_t - \Delta NI_t) - \Delta I_t}{(1 + d)^t} \geq \Delta I_0 \text{ or } \sum_{t=1}^y \frac{S_t - \Delta I_t}{(1 + d)^t} \geq \Delta I_0$$

Where:

- y = Minimum length of time over which future net cash flows have to be accumulated in order to offset initial investment costs
- S_t = Savings in year t in operational costs associated with the alternative

ΔB_t	=	Additional benefits in year t associated with a given alternative
ΔNI_t	=	Additional non-investment costs in year t associated with a given alternative
ΔI_0	=	Initial investment costs associated with a given alternative
ΔI_t	=	Additional investment-related costs in year t, other than initial investment costs
d	=	Discount rate

There are numerous reasons why the payback method is widely used. It is easy for a layperson to calculate and understand. It helps to identify projects that will be unusually profitable or unprofitable early in their life. Investors often want to be assured of short-term paybacks along with high rates of return before investing. However, it is important to note that the decision to use the payback method should be made with care because it is an incomplete measure of economic performance. The primary function of the payback remains as a supplementary method of economic evaluation, not as a means by which to make decisions across alternatives. Payback is particularly useful as a screening tool for narrowing the feasible set of projects to which additional economic methods should be applied. The payback method excludes all benefits and costs that occur after the payback period is reached, creating a bias against projects with longer paybacks even if the long-term returns are greater than projects with shorter paybacks. Additionally, payback is not an indication of economic efficiency for a design or size of a project.

1.3.1.2. Uncertainty and Risk

Standards on Building Economics also address how to handle uncertainty, including selecting a technique and developing and evaluating cost risk and risk mitigation strategies.

E1369 is the Standard Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems [10]. This guide:

- describes when measuring uncertainty and risk may be helpful
- defines uncertainty, risk exposure, and risk attitude
- presents techniques for measuring uncertainty and risk exposure
- discusses how to select the appropriate technique for a particular problem
- describes how risk exposure can be measured
- describes how risk attitude can be incorporated using utility theory and other approaches

E1946 is the Standard Practice for Measuring Cost Risk of Buildings and Building Systems and Other Constructed Projects [11], which provides a “procedure for measuring cost risk...using the Monte Carlo simulation technique as described in Guide E1369.” Cost risk analysis (CRA) can

help answer questions related to uncertainty and risk to the costs of a capital project, such as the likelihood of costs exceeding a target cost level or identifying the aspects of the project that are most impactful on the uncertainty or risk.

E2506 is the Standard Guide for Developing a Cost-Effective Risk Mitigation Plan for New and Existing Constructed Facilities [12]. This guide describes a “generic framework for developing a cost-effective risk mitigation plan for new and existing constructed facilities—buildings, industrial facilities, and other critical infrastructure” and “provides an approach for formulating and evaluating combinations of risk mitigation strategies.” Using this guide in conjunction with the ASTM Practices discussed in Sec. 1.3.1.1 ensures the inclusion of uncertainty for input parameters in the economic analysis and results reporting.

1.3.1.3. Analytical Hierarchy Process (AHP)

Thus far, the discussion on standards has revolved around monetizable benefits and costs. However, there are often non-monetary benefits and costs that should be considered in the decision-making process, such as location, security, aesthetic environment, image to the public, and environmental externalities. E1765 is the Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Projects, Products, and Processes, which specifies how to apply the AHP to numerous evaluation criteria with different units of measures to develop a more comprehensive method of evaluation [13]. AHP considers non-monetary criteria for evaluations, potentially qualitative or quantitative, along with common economic criteria to evaluate a project. This practice provides a procedure for calculating and interpreting results from an AHP analysis.

AHP is not explicitly included in E3. However, E3 can develop the different monetary and non-monetary measures necessary as inputs into the AHP approach for post-processing.

1.3.1.4. Applicability of Building Economic Standards

The ASTM Building Economics Standards have been the basis for federal LCCA requirements [14] and guidance for decades, most recently published in the revision to Handbook 135 – Life Cycle Costing Manual for Federal Energy Management Program [15]. Handbook 135 provides examples of evaluating the cost-effectiveness of building projects related to energy efficiency, water conservation, renewable energy, sustainability, and resilience.

Although these standards are written explicitly for evaluating buildings and related engineered systems, the methodologies can be practical for other applications. In fact, many of these standards are referenced or mentioned in standards covering other topic areas, such as community resilience and manufacturing.

1.3.2. Community Resilience

The first standard guide for cost-effective community resilience strategy decisions, E3130 - Standard Guide for Developing Cost-Effective Community Resilience Strategies, was published in 2018 [16]. E3130 provides guidance for evaluating the economic performance of community

resilience-related investment strategies that improve responding, withstanding, and recovering from disruptive events. The guide assists in identifying relevant benefits and costs, including investment costs, future cost savings, and damage loss avoidance, from capital investment into resilience strategies relative to the status-quo. Procedures are provided for defining and satisfying the functions of a project, product, or process. The focus of the cost-effectiveness analysis is on benefit-cost analysis over life-cycle cost analysis because of the important role high-impact, low-probability events have on expected benefits and costs for resilience, including externalities and non-market considerations.

Although the standard takes a slightly different analysis perspective, the analysis methodology is consistent with the Building Economics Standards. The economic evaluations are based on the same standard practices (with the addition of E1699):

- E917 (life-cycle costs)
- E964 (benefit-to-cost and savings-to-investment ratios)
- E1057 (internal rate of return and adjusted internal rate of return)
- E1074 (net benefits and net savings)
- E1121 (payback)
- E1765 (analytical hierarchy process for multi-attribute decision analysis)
- E1699 (value engineering/value analysis) [17]
- E1369 (treatment of uncertainty)
- E2204 (summarizing results of economic evaluations)
- E2506 (cost-effective risk mitigation plan)

E3 provides all the necessary capabilities, including benefit, cost, and non-monetary analysis using the same methodologies defined in E3130.

1.3.3. Sustainable Manufacturing (E60.13)

A new ASTM standard, E3200 - Standard Guide for Investment Analysis in Environmentally Sustainable Manufacturing, covers techniques for evaluating manufacturing investments from the perspective of environmentally sustainable manufacturing by pairing economic methods of investment analysis with environmental aspects of manufacturing [18]. The analysis is focused on trade-offs (or synergies) between (non-monetary) environmental impacts and economic performance.

The economic analysis is based on the same economic methods in the Building Economics Standards for selecting the right economic method and quantifying the economic assessment of an alternative. The metrics included in the standard are net present value, IRR, payback period, and hurdle rate (equivalent to the MARR in E1057). The standard also addresses sensitivity analysis in a consistent manner as the Building Economics Standards in Sec. 1.3.1.2 on uncertainty and risk.

The environmental assessment requires the quantification of the environmental impact(s) of interest, which are typically in non-monetary units (e.g., carbon dioxide equivalent emissions), for each alternative investment option. The metric can either be total change or percentage change in the unit of measure from the investment relative to the baseline alternative.

The economic assessment and environmental assessment(s) are combined to determine if there is a trade-off and, if so, evaluate the trade-off to determine whether the trade-off in the investment is favorable to the baseline alternative. The appropriate metric depends on the decision type (accept/reject, decision, size, ranking/priority), but each metric is based on relative net present value or IRR and total or percentage changes in the environmental impact value.

There are four metrics for considering a tradeoff where the investment is not environmentally favorable. Maximum impact is the largest acceptable increase in environmental impact, either in percent or total units. Net present value per percent change in environmental impact (NPVP) is the average increase or decrease in income brought about by each percentage point change (or unit change) in environmental impact. Environmental hurdle rate is a value selected by the decision-maker and represents the net present value of income or cost savings needed to compel a 1 % percent increase (or one-unit increase) in environmental impact. The maximum environmental expenditure is the total amount the user is willing to pay to reduce environmental impact after all other financial benefits are considered. Net present value elasticity (NPVE) is the percent increase in net present value per 1 % increase in environmental impact.

There are four metrics for considering a tradeoff where the investment is not financially economical but is environmentally favorable. The maximum environmental expenditure is the total amount the user is willing to pay to reduce environmental impact after all other financial benefits are considered. The maximum environmental expenditure rate (MEER) a value selected by the decision-maker to represent the maximum they are willing to pay to decrease the environmental impact by 1 % (or one unit). The other two metrics are NPVP and NPVE.

The interpretation of NPVP and NPVE is different depending on the trade-off that occurs. For investments that are financially economical but not environmentally favorable, a higher NPVE is considered better. For investments that are environmentally favorable, but not financially economical, a lower NPVE is better. The NPVE can be compared among investments, but the NPVE for investments that are financially economical, but not environmentally favorable should not be compared with the NPVE for investments that are environmentally favorable, but not financially economical.

Although the standard includes metrics that are not currently calculated in E3, the results from E3 use a consistent methodology and can provide results for both the economic and non-economic (non-monetary) measures if the user submits the necessary information. These results will include total net present value, IRR, hurdle rate/MARR, and payback period as well as non-monetary values (total value and total change in value). These results would be straightforward to post-process into the desired metrics discussed above. An example of economic-environmental trade-off analysis is provided in Sec. 4.4.4.

2. Data Flow Through the API

This chapter expands on Sec. 1.2.1 by providing details on the object classes in E3 as well as a walk-through of the workflow logic (pseudocode/actual code). Figure 2-1 shows the information workflow of E3, which can be categorized into user defined classes, main and validation classes, libraries, and API-created classes. Section 2 and Sec. 3 are meant to be introductions to the code for those interested in understanding and possibly modifying the API files. This section will serve as a guide to the basics of the flow of data through the calculations. Figure 2-1 presents the general steps that information will go through when flowing through the API. Note that object creation (object directory files) and the stream, util and web directories are not included in the flow diagram to preserve clarity. Input object generation occurs in “MainPipeline.java,” while output generation occurs in the respective Pipeline file. “stream”, “util” and “web” directories are called as needed. Section 3.2 provides specifics on the libraries themselves, including their dependencies, their functions, and their classes. These are meant to work in tandem with the publicly available code and variable dictionary available in the E3 GitHub repository, or Sec. 3, to allow a user to easily follow the process from start to finish.

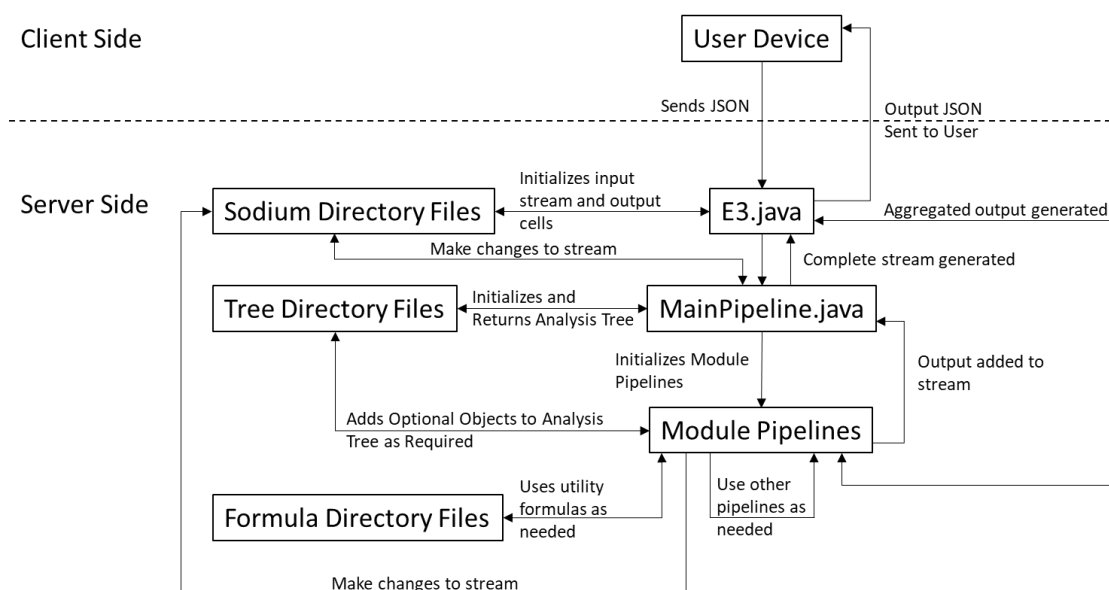


Figure 2-1 E3 Information Workflow

Before fully exploring the flow through Fig. 2-1, the individual libraries and classes involved need to be defined. Section 2.3, Sec. 2.4 and Sec. 3.2 provide the required background. Non-calculation libraries are omitted from the current discussion for brevity.

2.1. Reactive Programming

At the core of E3 is the use of reactive programming and reactive programming relies on the use of event streams. An event stream is any flow of data that can be modified in a discrete

manner based on elements within the data. Furthermore, these updates can occur anywhere in the calculation chain and be handled asynchronously, allowing for optimized concurrent actions. A good analogy of a reactive stream is a spreadsheet formula that calculates the sum of a column of other cells. If a cell in the referenced column is changed then the sum updates automatically. Streams operate on the same principle. If an element in the stream is defined by a function that operates on a value in the stream, then updating the value updates the element without any additional commands.

Along with streams there are mutable cells within the program. In FRP it is generally assumed that every expression is a function, however programming needs might require that certain operations be mutable. In E3 this requires the use of a cell, a value or operation that is not reactive but is known to the reactive code portion, allowing a non-reactive element to trigger reactive updates if the mutable cell is altered.

The primary motivation for the use of reactive programming in E3 was the inclusion of Monte Carlo simulation. Monte Carlo requires the repeated updating of the same data set it made sense to view the collection of uncertain inputs as an event stream where the discrete updates were the alteration of inputs because of a new simulation cycle. This approach was then extended to the case of deterministic inputs.

2.2. Directory Structure for Files Mentioned in Fig. 2-1

The source code for V2 is currently found in the java branch on GitHub. This section will briefly cover the organization, an in depth look at certain aspects of the code will follow. The main directory contains two directories, “gradle/wrapper” and “src”, as well as numerous files required to build the app. Gradle is used to compile and package the app while Docker allows for quick deployment and testing.

The “src” directory contains the source code for the app and is split into the “main” and “test” directories. “test” is used for internal testing of the code prior to server pushes while “main” contains the current version of the source code. Within “main” there are the “java”, “resources” and “web/WEB-INF” directories. “java” is the primary source code and the focus of this section. “resources” contains the files required to build the front end for the API and “web/WEB-INF” contains the “web.XML” file.

2.2.1. java/nz/sodium directory

Version 2 of E3 uses the sodium library [19], allowing for functional reactive programming (FRP) to optimize the calculation code. FRP combines reactive programming, which focuses on the manipulation and processing of real-time data and events and functional programming, which attempts to reduce the programming problem into individual functions that, ideally, only perform one task. The files in this directory don’t directly run any calculations, but instead define multiple classes and libraries that allow the calculation code to function properly.

2.2.2. java/gov/nist/e3

The “e3” directory contains the calculation implementation as well as other supporting files. “compute” contains the calculations themselves while “formula” contains generic formulas that are common to numerous functions in the computation, as well as the formulas for calculating the present value of a cash flow. “objects” contains the class definitions for all input and output objects. “stream” contains the files required to create and manipulate a sodium stream (a collection of events containing a set of values that can be manipulated). “tree” contains the code that defines the elements that create the overall calculation structure. E3 uses a tree data structure based on a dependency graph to set up the flow of the code, defining the basic logic required for the reactive programming elements to operate appropriately. The tree data structure is common and numerous sources are available for reference (i.e. Ref. [20]). “util” contains various utility functions. These include the files required to construct the dependency graph for the calculations, definitions of the various tuples among others. “web” contains the code required for the front-end to operate as well as the required functions to parse the user input for calculation on the back end and receive output on the front end.

“Config” and “E3” perform the basic operations of building the tree using the dependency graph and initializing the calculation code, respectively.

2.3. Input Classes (User-Defined Classes)

Input Classes are the objects (located in *objects* directories) provided by the user in the E3 input file converted from JSON to JAVA objects. The user must provide an analysis-level set of information (Analysis Class), details on each benefit, cost, and non-monetary value for each “project” alternative including the baseline alternative (Benefit/Cost/Non-monetary (BCN) Class), and any required sensitivity (Sensitivity Class) and/or uncertainty (Uncertainty Class) analysis the user desires to be completed. Each is described below along with the variable definitions a user should be aware of.

2.3.1. Analysis

The analysis class serves to store all inputs that are consistent across all aspects of the analysis. These include values such as the discount rate, study period, and whether real or nominal discounting is used. It also contains descriptive aspects of the analysis that, at present, are not used in the analysis itself. Information like the physical address of the project, what the project is and what type of project is being analyzed (Building, Energy, etc.). Input validation is also performed within the class. The type of output desired is also defined in the Analysis class. Table 2-1 contains the attribute details for the Analysis Object.

Table 2-1 Analysis Variable Details

Variable	Var Name	Var Type	Format/Values	Req
Analysis Type	type	String	LCCA, BCA, Cost-Loss, Profit Maximization, Other	X
Project Type	projectType	String		
Objects To Report	objToReport	List of Strings	[required, optional, measure, sensitivity, sensitivity, uncertainty]	X
Study Period	studyPeriod	Int	Integer	X
Timestep Value	timestepValue	String	Year, Quarter, Month, Day	X
TimestepCompound	timestepComp	String	END_OF_YEAR, MID_YEAR, CONTINUOUS	X
Output in Nominal or Real Dollars	outputReal	Boolean	false, True, 0,1	X
Interest Rate (Nominal)	interestRate	Float	in decimals	
Real Discount Rate	discountRateReal	Float	in decimals	X ^a
Nominal Discount Rate	discountRateNom	Float		X ^a
Inflation Rate	inflationRate	Float	in decimals	
MARR (Real or Nominal)	marr	Float	in decimals	X
Reinvestment Return Rate (Real or Nominal)	reinvestRate	Float	in decimals	X
Income Tax Rate	federalIncomeRate	Float	Federal	
	otherIncomeRate	Float	State/Local	
Location	location	Subdictionary	{country, region, division, state, county, city, zipcode, address}	
Number of Alternatives	numberOfAlternatives	Int	whole digits	X
Baseline Alternative Number	baseAlternative	Int	whole digits	X

^aA real or nominal rate is required but not both

2.3.2. Alternative

The Alternative class stores information related to a specific alternative. It doesn't serve a role in the calculations themselves but is instead meant to allow users to organize and quickly pull information for a specific alternative. Input validation is also performed within the class. Table 2-2 contains the attribute details for the Alternative Object.

Table 2-2 Alternative Variable Details

Variable	Var Name	Var Type	Format/Values	Req
Alternative ID	id	int	N/A	X
Alternative Name	name	String	N/A	
Alternative BCN List	bcns	List of ints	N/A	X

2.3.3. Benefit / Cost / Non-Monetary

Benefit/Cost/Non-monetary (BCN) objects store all information required to determine the cash flow (and quantity flow) for a specific cost, benefit, or non-monetary account item. It also relates how a BCN links to alternatives. Input validation is performed within the class. Some calculations are performed as well, including the generation of BCN level cash flows, quantity flows, discounting, and residual value. Table 2-3 contains the attribute details for the BCN Object.

Table 2-3 BCN Variable Details

Variable	VarName	VarType	Type
Alternative IDs	altIds	List of Int	Whole digit array; object can apply to more than 1 alternative
BCN ID	id	Int	Whole Digit
Type	type	String	Benefit, Cost or Non_Monetary: revenue treated as negative cost
SubType	subType	String	Direct, Indirect or Externality
Name	name	String	String
Tag (Custom Category)	tags	String	List of Strings
DateofOccurrence	initialOccurrence	Int	Whole digit
NominalorReal	real	Boolean	true, false, 0 or 1
Investment	invest	Boolean	true, false, 0 or 1
InvestmentServiceLife	life	Int	Digit
ResidualValueBoolean	residualValue	Bool	true, false, 0 or 1; true means to calculate a residual value associated with this object.
ResidualValueOnly	residualValue Only	Bool	true, false, 0 or 1; true means the object is a residual value object and is calculated as a negative investment cost; false means that the object should be used to generate both an investment cost value and a residual value at the end of study period using Linear Depreciation
Recurrence (optional) ^a	recur	Sub-dictionary	{interval, end, varRate, varValue}
ValuePerQ	quantityValue	Float	Float
Quantity	quantity	Float	Float
Quantity Escalation Rate	quantityVarRate	String	"PERCENT_DELTA" or "YEAR_BY_YEAR"
Quantity Escalation Values	quantityVarValue	Float or List of Floats	Float or List of Floats
Quantity Unit	quantityUnit	String	String

^aSee Sec. 4 for analysis examples and Appendix B for formatted JSON strings.

2.3.4. Sensitivity

Sensitivity Objects store information related to any sensitivity analysis a user may wish to run. Sensitivity is the standard "one at a time" analysis. The object keeps information on the BCN object to be altered as well as the specific variable being changed, the type of change (gross or percentage), and the value of the change. Table 2-4 contains the attribute details for the Sensitivity Object.

Table 2-4 Sensitivity Object Details

Variable	Var Name	Var Type	Required
Sensitivity ID	id	int	X
List of impacted alternatives by ID	altIds	List of Ints	X
Variable being altered	variable	String presenting the altered object and the associated variable in "object.variable" form	X
Nature of the alteration to the BCN value	diffType	String	Valid entries are: "Gross", "Percent"
Amount the BCN value is changed	diffValue	Float	Can be negative or positive

2.3.5. Uncertainty

Uncertainty Objects store input information related to any uncertainty analysis being performed by the user. Basic Monte Carlo simulation is used in running the analysis and E3 allows for the most commonly used distributions to be selected. These include Gaussian (Normal), Uniform (Rectangular), Triangular, and Discrete. Table 2-5 contains the attribute details for the Uncertainty Object. Table 2-6 contains further details on the "Variables with Uncertainty" attribute from Tab. 2-5.

Table 2-5 Uncertainty Object Details

Variable	Var Name	Var Type	Req
ID	id	Integer	X
Random Number Generator Seed	seed	Integer	X
Variables with Uncertainty	variables	List (Curly Brackets). See Table 2-6 for the format for an element in the variables list.	X

Table 2-6 Variables with Uncertainty Details

Variable	Var Name	Var Type	Req
Variable with Uncertainty	variable	String	X
Distribution	distribution	String. Valid Inputs: "Normal" or "Gaussian", "Rectangular" or "Uniform", "Discrete" or "Enumerated", "Triangular", "Weibull" or "Extreme_Value_Type_III", "Beta", "Log_Normal", "Binomial"	X
Distribution Arguments	distributionArgs ^a	List	X

^aE3 uses the Apache Commons math3 distributions library. See the Apache Commons website for a full description of input formatting for the relevant distributions [21].

2.3.6. Input

The input class takes the user defined inputs and collects them in a single object. Table 2-7 contains the attribute details for the Input Object.

Table 2-7 Input Object Details

Variable	Var Name	Var Type	Format/Values	Req
Analysis Object	analysisObject	Object	N/A	X
Alternative Objects	alternativeObjects	List of Objects	N/A	X
BCN Objects	bcnObjects	List of Objects	N/A	X
Sensitivity Object	sensitivityObjects	List of Objects	N/A	
Uncertainty Objects	uncertainty	List of Objects	N/A	

2.4. Output Classes

Output Classes are used to store the results of calculations as Java objects (located in *objects* directories). After all calculations are complete the output classes are converted to a single output object and converted into a JSON format to be sent back to the user.

2.4.1. Measure Summary

The MeasureSummary output object contains all the measure output for a single alternative. Table 2-8 contains the details on the attributes of the MeasureSummary object.

Table 2-8 Measure Summary Variable Details

Variable	Var Name	Var Type	Format/Values
Alternative ID	altId	Int	N/A
Total Benefits Flow	totalBenefits	Float	N/A
Total Costs Flow	totalCosts	Float	N/A
Total Investment Costs	totalCostsInvest	Float	N/A
Total Non-Investment Costs	totalCostsNonInvest	Float	N/A
Total Tag Flows	totalTagFlows	List of Floats	N/A
Net Benefits	netBenefits	Float	N/A
Net Savings	netSavings	Float	N/A
Savings to Investment Ratio	sir	Float	N/A
Internal Rate of Return	irr	Float	N/A
Adjusted Internal Rate of Return	airr	Float	N/A
Simple Payback Period	spp	Float	N/A
Discounted Payback Period	dpp	Float	N/A
Benefit cost Ratio	bcr	Float	N/A
Quantity Sum	quantitySum	List of Floats	N/A
Quantity Units	quantityUnits	List of Floats	N/A
MARR	marr	Float	N/A
Change in Quantity	deltaQuantity	List of Floats	N/A
Net savings per change in quantity	nsPercentQuantity	List of Floats	N/A
Net savings per change in percent quantity	nsDeltaQuantity	List of Floats	N/A
Net savings elasticity	nsElasticityQuantity	List of Floats	N/A

2.4.2. RequiredCashFlow

RequiredCashflow stores the sums of all cash flows of interest for use both as pure output and as input into measure calculations. Table 2-9 contains the details on the attributes of the RequiredCashflow object.

Table 2-9 Required Cash Flow Variable Details

Variable	Var Name	Var Type	Format /Values
Alternative ID	altId	Int	N/A
Total Non-Discounted Costs	totalCostsNonDiscounted	List of floats	N/A
Total Discounted Costs	totalCostsDiscounted	List of floats	N/A
Total Non-Discounted Benefits	totalBenefitsNonDiscounted	List of floats	N/A
Total Discounted Benefits	totalBenefitsDiscounted	List of floats	N/A
Total Non-Discounted Investment Costs	totalCostsNonDiscountedInvest	List of floats	N/A
Total Discounted Investment Costs	totalCostsDiscountedInvest	List of floats	N/A
Total Non-Discounted Investment Benefits	totalBenefitsNonDiscountedInvest	List of floats	N/A
Total Discounted Investment Benefits	totalBenefitsDiscountedInvest	List of floats	N/A
Total Non-Discounted Non-Investment Costs	totalCostsNonDiscountedNonInvest	List of floats	N/A
Total Discounted Non-Investment Costs	totalCostsDiscountedNonInvest	List of floats	N/A
Total Non-Discounted Non-Investment Benefits	totalBenefitsNonDiscountedNonInvest	List of floats	N/A
Total Discounted Non-Investment Benefits	totalBenefitsDiscountedNonInvest	List of floats	N/A
Total Non-Discounted Direct Costs	totalCostsNonDiscountedDirect	List of floats	N/A
Total Discounted Direct Costs	totalCostsDiscountedDirect	List of floats	N/A
Total Direct Non-Discounted Benefits	totalBenefitsNonDiscountedDirect	List of floats	N/A
Total Discounted Direct Benefits	totalBenefitsDiscountedDirect	List of floats	N/A
Total Non-Discounted Indirect Costs	totalCostsNonDiscountedIndirect	List of floats	N/A
Total Discounted Indirect Costs	totalCostsDiscountedIndirect	List of floats	N/A
Total Indirect Non-Discounted Benefits	totalBenefitsNonDiscountedIndirect	List of floats	N/A
Total Discounted Indirect Benefits	totalBenefitsDiscountedIndirect	List of floats	N/A
Total Non-Discounted Externality Costs	totalCostsNonDiscountedExternality	List of floats	N/A
Total Discounted Externality Costs	totalCostsDiscountedExternal	List of floats	N/A
Total Non-Discounted Externality Benefits	totalBenefitsNonDiscountedExt	List of floats	N/A
Total Discounted Externality Benefits	totalBenefitsDiscountedExternality	List of floats	N/A

2.4.3. OptionalCashFlow

OptionalCashflow stores the sums of all cash flows of interest for use both as pure output and as input into measure calculations. Table 2-10 contains the details on the attributes of the RequiredCashflow object.

Table 2-10 Optional Cash Flow Variable Details

Variable	Var Name	Var Type	Format/Values
Alternative ID	altId	Int	N/A
Tag	tag	String	N/A
Total Monetary Flow for Tag	totalTagCashflowDiscounted	List of Floats	N/A
Total Non-monetary flow for Tag	totalTagQuantity	List of Floats	N/A
Units for the Tag	units	String	N/A

2.4.4. SensitivitySummary

The SensitivitySummary object stores the information from a sensitivity analysis. Its attributes are similar to those of a measure summary, but instead include the output for all alternatives as key:value pairs in a list. Table 2-11 contains the details for the SensitivitySummary object.

Table 2-11 SensitivitySummary Variable Details

Variable	Var Name	Var Type	Format/Values
Sensitivity ID	id	int	N/A
Alternative ID	altID	int	N/A
Total Benefits Flow	totalBenefits	List of Floats	N/A
Total Costs Flow	totalCosts	List of Floats	N/A
Total Investment Costs	totalCostsInvest	List of Floats	N/A
Total Non-Investment Costs	totalCostsNonInvest	List of Floats	N/A
Total Subtype Flows	totalTagFlows	List of List of Floats	N/A
Net Benefits	netBenefits	List of Floats	N/A
Net Savings	netSavings	List of Floats	N/A
Savings to Investment Ratio	sir	List of Floats	N/A
Internal Rate of Return	irr	List of Floats	N/A
Adjusted Internal Rate of Return	airr	List of Floats	N/A
Simple Payback Period	spp	List of Floats	N/A
Discounted Payback Period	dpp	List of Floats	N/A
Benefit cost Ratio	bcr	List of Floats	N/A
Quantity Sum	quantitySum	List of List of Floats	N/A
Quantity Units	quantityUnits	List of List of Floats	N/A
MARR	marr	Float	N/A
Change in Quantity	deltaQuantity	List of List of Floats	N/A
Net savings per change in quantity	nsPercentQuantity	List of List of Floats	N/A
Net savings per change in percent quantity	nsDeltaQuantity	List of List of Floats	N/A
Net savings elasticity	nsElasticityQuantity	List of List of Floats	N/A

2.4.5. UncertaintyMeasureSummary

The Uncertainty results are treated differently than the rest of the outputs. Table 2-12 displays the variables in UncertaintySummary; however, other files are required to construct them: UncertaintyMeasureSummary, UncertaintyStats and UncertaintySummaryBuilder. The output received by the user will appear similar to the Measure Summary output, but it will be in the form of a key:value pair where the key is the alternative ID, and the associated pair is the MeasureSummary list. Furthermore, each item in the MeasureSummary will now be a key:value pair where the key is the MeasureSummary variable and the value is a set of two key:value pairs, mean and standard deviation.

Table 2-12 Uncertainty Summary

Variable	Var Name	Var Type	Format/Values
Uncertainty ID	id	int	N/A
Total Benefits Flow	totalBenefits	List of Floats	N/A
Total Costs Flow	totalCosts	List of Floats	N/A
Total Investment Costs	totalCostsInvest	List of Floats	N/A
Total Non-Investment Costs	totalCostsNonInvest	List of Floats	N/A
Total Subtype Flows	totalTagFlows	List of List of Floats	N/A
Net Benefits	netBenefits	List of Floats	N/A
Net Savings	netSavings	List of Floats	N/A
Savings to Investment Ratio	sir	List of Floats	N/A
Internal Rate of Return	irr	List of Floats	N/A
Adjusted Internal Rate of Return	airr	List of Floats	N/A
Simple Payback Period	spp	List of Floats	N/A
Discounted Payback Period	dpp	List of Floats	N/A
Benefit cost Ratio	bcr	List of Floats	N/A
Quantity Sum	quantitySum	List of List of Floats	N/A
Quantity Units	quantityUnits	List of List of Floats	N/A
MARR	marr	Float	N/A
Change in Quantity	deltaQuantity	List of List of Floats	N/A
Net savings per change in quantity	nsPercentQuantity	List of List of Floats	N/A
Net savings per change in percent quantity	nsDeltaQuantity	List of List of Floats	N/A
Net savings elasticity	nsElasticityQuantity	List of List of Floats	N/A

2.4.6. Output

The Output object aggregates all pertinent output into a single object for conversion to JSON and return to the user. Table 2-13 contains the details for the Output Object.

Table 2-13 Output Object Details

Variable	Var Name	Var Type
Required Cash Flows	requiredCashFlows	Object
Optional Cash Flows	optionalCashFlows	List of Objects
Measure Summaries	measureSummaries	List of Objects
Sensitivity Summaries	sensitivitySummaries	Object
Uncertainty Summaries	uncertaintySummaries	List of Objects

3. Code Development and Library

3.1. Development Tools

3.1.1. Programming – Java and Sodium

Java is a compiled, class-based, object-oriented programming language originally developed by Sun Microsystems, now owned by Oracle. It is a write once, run anywhere language which makes it possible for the compiled code to run on any machine that supports it. This feature makes the code usable across numerous devices with little additional work on the coding side due to Java's avoidance of implementation dependencies.

Sodium is a multilanguage library written by Stephen Blackheath and Anthony Jones that comes with pre-built functions and classes to allow FRP [19]. It has complete functionality for C++, C#, F#, Java, Kotlin, Scala and Typescript/Javascript. More information on the specific Sodium files can be found in Sec. 3.2.

3.1.1.1. JavaScript Submission Library

Additionally, a JavaScript library has been developed that will simplify the building and sending of analysis requests to an E3 instance. This library is not strictly necessary to use E3 since REST requests can still be manually constructed and sent. However, it can break up requests into easily understandable and re-usable parts that can aid in application development. A builder pattern is used to store information until an analysis is requested, which then triggers the library to take the stored information, infer any information it can (e.g., IDs), send constructed JSON request to E3, and return the result.

This library is intended to be used to create web applications, but similar libraries could be made for use in desktop applications as well.

3.1.2. Framework – Spring

The Spring framework is an open-source toolset designed for Java that allows for deployment on any platform [22]. Spring allows for individual modules of its framework to be selected as needed, however the key modules for using Spring are those in the core container, which provides vital functions such as the configuration model and a dependency injection mechanism.

3.1.3. Deployment – Gradle, PostgreSQL, Docker, AWS

Gradle is a build tool for software development. As a build tool, it organizes and executes tasks such as compilation and packaging of an application, as well as deployment and publishing [23]. A key feature of Gradle is the ability to run build tasks in serial or parallel, as well as allowing for incremental builds. In the event of an update the full build tree is examined and only those tasks that are altered, as well as those that are dependent on them, are executed.

“PostgreSQL is a powerful, open-source, highly extensible object-relational database system” [24]. It is ACID compliant and is widely used due to its reliability. Its primary use in E3 is for managing the databases for API-key creation and storage.

“Docker is an open platform for developing, shipping, and running applications.” [25] Docker is widely used in app development to “package and run [applications] in a loosely isolated environment called a container.” [25] Containers simplify app development by making the app agnostic to what is installed on the host.

AWS offers information technology infrastructure services to businesses in the form of web services (i.e., cloud computing). The E3 Docker Container is hosted on an AWS instance.

3.1.4. Input/Output Format

The input for the E3 API is expected as a JSON string. A JSON string organizes input into a collection of key names, and values defined for those key names. Utilizing JSON strings allows for a simple means of standardizing input/output objects creation and ensures that data is received in a usable format. For additional, more detailed examples see Sec. 4.5 and formatted JSON input strings in Appendix B.

3.2. E3 Files

This section provides details on the files defining the E3 API. The goal of this section is not to cover every possible conditional or track every variable in the code, but instead is meant to provide a guide to the libraries, functions, and classes available in the code base. Coupling Sec. 2 and Sec. 3 with the code itself should provide the user with sufficient information to work with the calculation code effectively. Section 4.2 provides basic guidance on sending requests to the E3 API server.

The list that follows is organized by directory. Each directory heading contains a list of files within and that file’s general purpose. Annotation within the code itself provides the remainder of the information. The general purpose of this section is to allow a searchable aggregation of the source code files by name and purpose.

3.2.1. E3/src/main/java/nz/sodium and E3/src/main/java/nz/sodium/time

This directory contains code specific to the Sodium library implementation of FRP. **These are unaltered implementations from the Sodium project GitHub [19].** See Functional Reactive Programming for more information [26]. For specifics on the nature of the contained libraries and classes please see the Sodium GitHub page [19].

3.2.2. E3/src/main/java/gov/nist/e3

This directory contains the code to support and implement the E3 calculations, excluding those used to set up the Sodium FRP implementation. The e3 directory contains the following

subdirectories: compute, formula, objects, stream, tree, util, web. Each of the preceding will be discussed separately. The e3 directory also contains two files.

Config.java – Configures the E3 app for the current run. Defines preset variables such as MAX_DIGITS and UNCERTAINTY_TOLERANCE, as well as initializing the dependency graph.

E3.java – Main object that contains the computational model and analyze method. Initializes the event stream and output, as well as the computational processes. Returns to output of a successful run.

3.2.3. E3/src/main/java/gov/nist/e3/compute

The compute directory uses the objects, formulas, utilities and FRP elements to perform the necessary economic calculations. Entries here list the purpose for the file, what other Pipelines call the file and what other Pipelines are called by the file. Dependencies are also defined if applicable. Note that any classes in these files represents an intermediate object i.e., one that does not store initial input or final output. For input/output objects see the output directory.

DiscountedPipeline.java – Defines class that is used to discount cash flows. Uses formulas from the presentvalue.java file and is called from OptionalCashFlowPipeline.java, RequiredCashFlowPipeline.java,

MainPipeline.java – Defines class that begins the full calculation process. Called from E3.java, it calls for other calculation object construction as necessary and defines the input stream as well as creating multiple pipelines for value/output storage. Calls MeasureSummaryPipeline.java, OptionalCashFlowPipeline.java, QuantityPipeline.java, RequiredCashflowPipeline.java, ResidualValuePipeline.java, SensitivityPipeline.java, UncertaintyPipeline.java and ValuePipeline.java.

MeasureSummaryPipeline.java – Defines class that contains the calculations to create measure summaries and stores them. Called in MainPipeline.java, SensitivityPipeline.java, and the UncertaintyPipeline.java files. RequiredCashFlowPipeline.java is required to have completed, OptionalCashFlowPipeline.java is not required but will be used if completed.

OptionalCashFlowPipeline.java – Defines class to calculate and store the tagged cash flows for a project. Calls DiscountedPipeline.java and QuantityPipeline.java. Called from MainPipeline.java. Optional input to MeasureSummaryPipeline.java.

QuantityPipeline.java – Defines class to calculate and store quantity flows (non-cash flows) and their calculations. Called by MainPipeline.java and OptionalCashFlowPipeline.java.

RequiredCashFlowPipeline.java – Defines class to calculate and store required cash flows. Called by MainPipeline.java. Calls on DiscountedPipeline.java, ResidualValuePipeline.java and ValuePipeline.java Required input for MeasureSummaryPipeline.java.

ResidualValuePipeline.java – Defines class to calculate and store residual value cash flows. Called by MainPipeline.java and RequiredCashFlowPipeline.java. Uses logger from QuantityPipeline.java.

SensitivityPipeline.java – Defines class to calculate and store sensitivity results. Called by MainPipeline.java. Calls on MeasureSummaryPipeline.java.

UncertaintyPipeline.java – Defines class to calculate and store uncertainty results. Called by MainPipeline.java. Calls on MeasureSummaryPipeline.java.

ValuePipeline.java – Defines class to calculate and store value flows (monetary flows). Called by MainPipeline.java and RequiredCashFlows.java.

3.2.4. E3/src/main/java/gov/nist/e3/formula

The “Formula” directory contains the subdirectory “presentvalue” and the file:

Formula.java – Defines class that contains miscellaneous calculations shared between multiple other classes. These include various timestep calculations and the internal rate of return solver.

3.2.5. E3/src/main/java/gov/nist/e3/formula/presentvalue

This directory contains the discounting formulas. While a file exists for each discounting type, they all only contain the discounting formula in question. These are ContinuousPresentValue.java for continuous discounting, EndOfYearPresentValue.java for end of year discounting, MidYearPresentValue.java for mid-year discounting and PresentValueFormula.java which uses the previous three files to calculate the present value of a cash flow.

3.2.6. E3/src/main/java/gov/nist/e3/objects

The objects directory stores input and output objects that the user either creates via their JSON requests or receives in JSON format upon completion of their run. The objects directory contains the subdirectories “input” and “output” as well as the file:

OptionalKey.java – Defines a record that stores which variables contain tagged/optional flows.

3.2.7. E3/src/main/java/gov/nist/e3/objects/input

The input directory contains the files required to properly define user input objects. Some inputs have multiple files associated with them. **Note:** Any file containing “Cell” is used to allow the event stream to properly account for the mutable nature of the input object, as such these will be omitted from the list that follows for brevity.

Alternative.java – Defines record to store user defined Alternative objects.

Analysis.java – Defines record to store and validate user defined Analysis objects.

AnalysisType.java – Defines valid inputs for the “AnalysisType” attribute of an Analysis object.

Bcn.java – Defines record to store and validate user defined BCN objects.

BcnSubType.java – Defines valid inputs for the “BcnSubType” attribute of a BCN object.

BcnType.java – Defines valid inputs for the “BcnType” attribute of a BCN object.

DistributionType.java – Defines valid inputs for the “DistributionType” attribute of a BCN object.

Input.java – Defines record that aggregates and validates all user defined objects into a single object.

Location.java – Defines record to store a user defined location object.

OutputType.java – Defines valid inputs for the “OutputType” attribute of an Analysis object.

ProjectType.java – Defines valid inputs for the “ProjectType” attribute of an Analysis object.

RecurOptions.java – Defines class that is attached to a BCN subtree which stores user defined values for recurring BCNs. Note that the associated “Cell” file for this object does not include the “s” in the file name.

Sensitivity.java – Defines record to store user defined Sensitivity objects.

SensitivityDiffType.java – Defines valid inputs for the “DiffType” attribute of a Sensitivity object.

TimestepComp.java – Defines valid inputs for the “TimestepComp” attribute of an Analysis object.

TimestepValue.java – Defines valid inputs for the “TimestepValue” attribute of an Analysis object.

Uncertainty.java – Defines record to store user defined Uncertainty objects.

VarRate.java – Defines valid inputs for the “varRate” attribute of a recurOptions object.

3.2.8. E3/src/main/java/gov/nist/e3/objects/output

The output directory contains the files required to construct output objects in a form that can easily be converted to a json string and sent to the user.

MeasureSummary.java – Defines record to store the summary measure results for a single alternative.

OptionalCashflow.java – Defines record to store the summary measure results for a single alternative’s optional cash flows.

Output.java – Defines record to aggregate all outputs into a single object.

RequiredCashFlow.java – Defines record to store the summary measure results for a single alternative’s required cash flows.

SensitivitySummary.java – Defines record to store the summary measure results for a sensitivity analysis.

UncertaintyMeasureSummary.java – Defines record to store the summary measure results for measure results under uncertainty.

UncertaintyStats.java – Defines a record to record the summary statistics for an uncertainty run.

UncertaintySummary.java – Defines record that aggregates the results of all uncertainty runs.

UncertaintySummaryBuilder.java – Defines class that contains the functions required to aggregate the uncertainty results.

3.2.9. E3/src/main/java/gov/nist/e3/stream

The stream directory contains files related to constructing specific event streams.

PercentDifferenceStream.java – Defines class that generates a stream that escalates the values in a stream by the percentage difference between successive entries.

RandomStream.java – Defines class that generates a stream that accepts the randomized values used in a simulation cycle.

3.2.10. E3/src/main/java/gov/nist/e3/tree

The tree directory contains files used to implement a tree data structure.

Leaf.java – Defines class and methods to create and manipulate a leaf on a data tree.

Node.java – Defines class and methods to create and manipulate a node on a data tree.

ToTree.java – Defines an interface used to convert an object into a tree.

Tree.java – Defines class and methods to create and manipulate a tree or subtree on a data tree.

3.2.11. E3/src/main/java/gov/nist/e3/util

The util directory contains files used to facilitate proper operation of the API and its calculations. It contains the “dependency” and “tuple” folders as well as the following files:

CellUtils.java – Defines class that provides utility operations on Sodium Cells.

Pool.java – Defines class that generates a reserve ArrayDeque.

ToCell.java – Defines an interface that adds an item to a cell.

Util.java – Defines class that contains various utility functions for E3 including elementwise operations and mapping operations and conversions.

3.2.12. E3/src/main/java/gov/nist/e3/util/dependency

The dependency directory contains the files required to generate the dependency graph which is used to generate the data tree.

DependencyGraph.java – Defines class which maps nodes to a hash map based on a set of dependencies.

Node.java – Defines class which defines and adds hierarchy to nodes based on dependencies.

3.2.13. E3/src/main/java/gov/nist/e3/util/tuple

The tuple directory contains multiple files of the type “tupleX” where X is a number from one to twelve. These all serve the same purpose, to quickly generate a tuple of the defined size.

3.2.14. E3/src/main/java/gov/nist/e3/web

The web directory contains the code required for API functionality. It contains the directories “api”, “config”, “exceptions”, “frontend”, “repository” and “validation”. As well as the following files:

E3Application.java – Defines class that boots the API.

E3Error.java – Defines record that stores error information.

E3ErrorType.java – Defines valid error types for the E3Error.java file.

ExceptionTranslator.java – Defines controller class that creates exception handlers for validation errors in user input parameters.

ExpandedDoubleSerializerConfig.java – Defines configuration class that ensures double values are output in expanded form and not scientific notation.

SpringUtils.java – Defines class that provides utilities related to authentication.

3.2.15. E3/src/main/java/gov/nist/e3/web/api

The api directory contains the following files:

ApiContriller.java – Defines class for the Spring Controller containing the API endpoints.

3.2.16. E3/src/main/java/gov/nist/e3/web/config

The config directory contains files related to various policy requirements.

CorsConfig.java – Defines class that provides configuration for CORS policy.

NonceFilter.java – Defines class that provides a filter for injecting a nonce value in the CSP header.

SecurityConfig.java – Defines class that provides additional security configuration.

3.2.17. E3/src/main/java/gov/nist/e3/web/exceptions

The exceptions directory contains the following files:

ApiTokenException.java – Defines class that catches API token exceptions.

3.2.18. E3/src/main/java/gov/nist/e3/web/frontend

The frontend directory contains the controllers for various aspects of the API frontend.

AddTokenController.java – Defines controller class that allows for the creation of new user tokens, as well as their revocation and deletion.

DashboardController.java – Defines controller class that allow for the display of the user dashboard and other account actions.

DocumentationController.java – Defines controller class that serves the documentation page.

IndexController.java – Defines controller class that returns the index page.

3.2.19. E3/src/main/java/gov/nist/e3/web/repository

The repository directory contains files related to the storage of API tokens.

ApiToken.java – Defines class that represents an API token.

ApiTokenID.java – Defines class that represents the multi-column key for the API tokens.

ApiTokenRepository.java – Defines interface for the database access object for API tokens.

ApiTokenStatus.java – Defines the valid inputs for the ApiTokenStatus attribute.

3.2.20. E3/src/main/java/gov/nist/e3/web/validation

The validation directory contains files related to the validation of JSON within the API.

ComplexValidation.java – Performs complex validation of JSON.

ComplexValidationArgumentResolver.java – Resolves arguments that arise in the validation process.

ComplexValidationConfig.java – Configures the complex validation process for the API.

ComplexValidationTest.java – Generates a test of the complex validation procedure for the API.

3.2.21. E3/src/main/java/gov/nist/e3/web/validation/result

The result directory contains the following files:

ValidationResult.java – Defines class that provides the results of the API validation process.

4. Using E3

While E3 can take input directly if the underlying code is run on a computer locally, it is intended to be called by a user-created Web interface. At present the API requires registration, at which time a security key will be provided. The API checks for a key before accepting any requests from a client and, upon accepting, proceeds to pass data to the portions of the code responsible for calculation. This data is then sent back to the client to be formatted by the client-side interface.

4.1. Overview

As E3 is currently a Beta version, specifics on the procedure for calling on the API from a Web interface, as well as guidance on how to handle certain situations, is in flux. This section is forthcoming upon finalization of base functionality.

4.1.1. Information Exchange Formats

E3 takes input and produces output in the form of JavaScript Oriented Notation (JSON) strings. This provides a consistent format for input and provides a consistent output type to allow developers to know exactly how communication with the API will proceed between the API and the interface calling it. Internally data is converted to objects and processed through serializers to allow calculation and rapid transition to and from the JSON format.

4.2. Sending a Request to E3 API Web Server

The process for sending a request to the E3 API server is as follows:

First, the JSON object needs to be constructed by the client. The format for a valid JSON request is specified below. Note that some result objects take much longer to calculate than others, which means responses may not be instantaneous.

Second, send the JSON object via a POST request to the `"/api/v2/analysis/"` endpoint of the E3 server with the API key in the header in the form:

`"Authorization: Api-Key YOUR_KEY_HERE"`

If the JSON object sent is invalid, an error will be sent back containing information about what is incorrect. Errors will also be sent back if something went wrong with the calculations. There may be errors that cannot be detected pre-processing, such as particular input parameters that cause divide by zero errors. Error messages will provide as much information as possible to aid in debugging requests. Once the server finishes the calculations for a request, the response is sent back as another JSON object, which the client can then interpret and display as they wish.

4.3. Guidance

Along with providing the details on the E3 code, it is beneficial to provide front-end developers guidance on how to map what their users will provide in their application to the appropriate E3

file format as well as how to interpret the E3 output file and how the results map to their desired performance measures. Each application will have its own unique set of information that could be using different terminology, desired results outputs, and potential irregular calculation requests. This section provides guidance by analysis type for both input and output files as well as identified edge cases that require careful consideration in designing their application as well as sending requests to and receiving results from E3.

4.3.1. General Guidance

There are several items of guidance that are independent of the type of analysis to be completed. Additional items will be added periodically as they are identified.

First, if a variable is not used in the analysis or required to calculate another variable required in the analysis, then it can be “null” or excluded completely, including the following:

- Analysis Object
 - interestRate (optional)
 - federalIncomeRate (optional)
 - otherIncomeRate (optional)
 - location (optional)
- BCN Object
 - life (if residualValue = false)
 - interval (if recur exists)
 - varRate (if recur exists and quantity value varies)
 - varValue (if recur exists and quantity value varies)
 - end (if recur exists and recurrence ends before study period)
 - quantityVarRate (if quantity varies)
 - quantityVarValue (if quantity varies)
 - quantityUnit (optional)

Second, residual values for an investment cost can be calculated using two approaches. (1) A user can specify for E3 to calculate the residual value of an investment cost by setting `rvBool = true`, which tells E3 to calculate the residual value of the investment using a linear depreciation approach based several BCN parameters (e.g., investment costs, initial and future occurrences, life of the investment, study period of the analysis) to calculate and include the residual value in the analysis automatically. This approach simplifies the inputs required by the user, but it limits transparency in the results and flexibility of the residual value calculation. (2) A user can define a separate BCN object that explicitly defines the residual value. In this case, the user must input all the necessary information, including the value and time of occurrence. The user must set `rvBool = true` to tell E3 to calculate the residual value and `rvOnly = true` to tell E3 that the BCN is

a residual value object. The valuePerQ should be provided as a positive value. This approach is more transparent and allows the user to use whatever method to calculate the residual value, and not just linear depreciation approach used in (1).

Third, E3 currently does not allow for an E3 request to include a combination of real and nominal denominated BCN object values. Instead, E3 assumes that all BCN objects are provided in the same term as defined in the Analysis Object (outputRealBool parameter). The bcnRealBool value is not currently checked for consistency but will be used in future versions of E3 to allow for providing a combination of real and nominal denominated BCN objects.

4.3.2. Guidance by Analysis Type

Due to the variety in the types of analysis required as well as varying terminology by topic area for which E3 can be leveraged for back-end economic calculations, it is beneficial to provide general guidance on how to map benefits, costs, and non-monetary values to E3 input file formatting. Additional guidance on other types of analysis will be added as validation of those analysis types are completed. Note that this guidance is only focused on the alternative summary results and does not discuss annual cash flows or non-monetary quantities.

4.3.2.1. Guidance for LCCA

LCCA is commonly used to evaluate the cost-effectiveness of an investment. Two examples for the same project with different financing options are provided in this section, one completely funded completely upfront, and another financed with a small down payment and fixed monthly loan payments.

4.3.2.2. Inputs – All Real Values

The example below is based on Example 5-1 from Sec. 5.2 in Handbook 135 [15]. Assume a federal agency is deciding whether to install a cheaper, conventional heating, ventilation, and air conditioning (HVAC) system or a more expensive, high-efficiency HVAC system at its facility. The study period is assumed to be the lifetime of the HVAC system at 20 years starting from the start of operating the new system, which is assumed to be January 1, 2022. The assumed real discount rate, MARR, and reinvestment rate are 3.0 % and the general rate of inflation is expected to be 2.3 %. The data is provided on a yearly basis, which will be used as the timestep for the calculations. The results we are interested in are only the summary measure results (Total LCC, NS, SIR, AIRR, and payback period). Based on this information, the Analysis Object would use the following values in Tab. 4-1.

Table 4-1 Analysis Values

Var Name	Format/Values	Req
type	LCCA	X
projectType	Buildings	
objToReport	[measure]	X
studyPeriod	20	X
timestepValue	Year	X
timestepComp	End_Of_Year	X
outputReal	True	X
interestRate		
discountRateReal	0.030	X
discountRateNom		
inflationRate	0.023	
marr	0.030	X
reinvestRate	0.030	X
federalIncomeRate		
otherIncomeRate		
numberOfAlternatives	2	X
baseAlternative	0	X
location		

Table 4-2 provides the current and future costs for both alternatives. All costs are provided in constant dollars.

Table 4-2 Example Costs

Cost Category	Cost Item	Occurrence(s)	Costs -Conventional	Costs - High Efficiency
Initial Investment	HVAC System	Year 0	\$103 000	\$130 000
Capital Replacement	Fan	Year 15	\$12 000	\$12 500
Operational	Electricity	Annual	\$30 000	\$24 000
Operational	Maintenance	Annual	\$7000	\$8000
Residual Value	Capital Equipment	Year 20	-\$3500	-\$3700

The maintenance cost is assumed to be constant in real terms while the electricity price is \$0.12/kWh and remains constant over the study period. Electricity consumption is assumed to be constant year-over-year (300 000 kWh for the conventional and 240 000 kWh for the high efficiency system). The costs for the conventional system map to E3 BCN object values as follows in Tab. 4-3:

Table 4-3 BCN Object Values - Conventional

VarName	HVAC System	Fan Replacement	Electricity	Maintenance	Residual Value
altIds	0	0	0	0	0
id	0	1	2	3	4
type	Cost	Cost	Cost	Cost	Cost
subType	Direct	Direct	Direct	Direct	Direct
name	HVAC System	Fan Replacement	Electricity	Maintenance	Residual Value
tags	Initial Investment	Capital Replacement	Energy	OMR	Capital Salvage Value
initialOccurrence	0	12	1	1	20
real	true	true	true	true	true
invest	true	true	false	false	True
life	20	12	Null	Null	Null
residualValue	false	false	false	false	True
residualValueOnly	false	false	false	false	True
recur	N/A	N/A	{"interval": 1, "end": 20, "varRate": "PERCENT_DELTA", "varRate": 0}	{"interval": 1, "end": 20, "varRate": "PERCENT_DELTA", "varRate": 0}	N/A
valuePerQ	103 000	12 000	0.12	7000	3500
quantity	1	1	250 000	1	1
quantityVarRate	Null	Null	Null	Null	Null
quantityVarValue	Null	Null	Null	Null	Null
quantityUnit	1	1	kWh	1	1

The costs for the high-efficiency system map to E3 BCN object values as follows in Tab. 4-4:

Table 4-4 BCN Object Values – High-Efficiency

VarName	HVAC System	Fan Replacement	Electricity	Maintenance	Residual Value
altIds	0	0	0	0	0
id	0	1	2	3	4
type	Cost	Cost	Cost	Cost	Cost
subType	Direct	Direct	Direct	Direct	Direct
name	HVAC System	Fan Replacement	Electricity	Maintenance	Residual Value
tags	Initial Investment	Capital Replacement	Energy	OMR	Capital Salvage Value
initialOccurrence	0	12	1	1	20
real	1	1	1	1	1
invest	1	1	0	0	1
life	20	12	Null	Null	Null
residualValue	false	false	false	false	true
residualValueOnly	false	false	false	false	true
recur	N/A	N/A	{"interval": 1, "end": 20, "varRate": "PERCENT_DELTA", "varRate": 0}	{"interval": 1, "end": 20, "varRate": "PERCENT_DELTA", "varRate": 0}	0
valuePerQ	130 000	12 500	0.12	8000	-3700
quantity	1	1	240 000	1	
quantityVarRate	Null	Null	Null	Null	Null
quantityVarValue	Null	Null	Null	Null	Null
quantityUnit					

Note that if the user is not concerned about the quantity of electricity consumed, the user could input total annual costs as the ValuePerQ and change the Quantity to one (1) and still obtain the same results.

The results in Tab. 4-5 show that the high efficiency system leads to net savings of \$47 147, an SIR of 2.73, and AIRR of 8.3 %.

Table 4-5 LCCA Example Results

Net Present Value	Conventional	High Efficiency
Initial Investment	\$103 000	\$130 000
Cost		
Capital Replacement	\$8417	\$8767
Residual Value	-\$1938	-\$2049
Electricity	\$446 324	\$357 059
OMR	\$104 142	\$119 019
Total Life Cycle Cost	\$659 945	\$612 798
Net Savings		\$47 147
SIR		2.73
AIRR		8.3 %

The results reports generated by E3 are independent of the type of analysis. LCCA will be focused on a subset of the results. The Measure Summary reports all the variables in Tab. 4-6. Those **bolded** are measures used in LCCA.

Table 4-6 Alternative Summary Object Results Values

Variable	VarName	Format
Alternative ID	altId	int
Total Benefits	totalBenefits	Float
Total Costs	totalCosts	Float
Total Costs – Investment	totalCostsInvest	Float
Total Costs – Non-investment	totalCostsNonInvest	Float
Net Benefits	netBenefits	Float
Net Savings	netSavings	Float
Savings-to-Investment Ratio	sir	Float
Internal Rate of Return*	irr	Float
Adjusted Internal Rate of Return	airr	Float
Simple Payback Period	spp	Float
Discounted Payback Period	dpp	Float
Benefit-Cost Ratio	bcr	Float
Quantity by Tag	quantitySum	List of Floats
Quantity Units by Tag	quantityUnits	List of Strings
MARR	marr	Float
Delta Quantity by Tag	deltaQuantity	List of Floats
Delta Net Savings by Tag	nsDeltaQuantity	List of Floats
Net Savings Percent Quantity by Tag	nsPercentQuantity	List of Floats
Net Savings Elasticity by Quantity by Tag	nsElasticityQuantity	List of Floats

4.3.2.3. Inputs – Combination of Real and Nominal Values

Capital investments are commonly financed, at least in part, due to funding constraints. The same example from Sec. 4.4.2.1.1 can be modified to replace the initial investment costs with a financing option (down payment and monthly loan payments). Assume that the conventional system project is funded using a loan with the following terms:

- 15-year loan
- 10 % down payment (\$10 300)
- \$700 monthly payments

The BCN objects are identical for all costs except that the initial investment for “HVAC System” is decreased from \$103 000 to \$10 300. An additional BCN is necessary to cover the loan payments (12 payments of \$700 annually). Currently, E3 does not allow for an E3 request to include a combination of real and nominal denominated BCN object values. Instead, E3 assumes that all BCN objects are provided in the same term as defined in the Analysis Object (outputRealBool parameter). Therefore, an additional step is required to convert the nominal/current loan payments to real/constant dollars. This is accomplished by including an escalation rate equal to the negative of the inflation rate to convert the nominal values to real values as shown in Tab. 4-7.

Table 4-7 BCN Loan Object Values

VarName	Loan Payments
altIds	0
id	10
type	Cost
subType	Direct
name	Loan Payments
tags	Financing
initialOccurrence	1
real	true
invest	False
life	Null
residualValue	False
residualValueOnly	False
recur	{"interval": 1, "end": 15, "varRate": "PERCENT_DELTA", "varRate": [-0.023]}
valuePerQ	700
quantity	12
quantityVarRate	Null
quantityVarValue	Null
quantityUnit	Null

4.3.2.4. Inputs – Nominal Values

A “current dollar” or nominal dollar analysis will set outputRealBool = false for the Analysis Object and bcnRealBool = false for all BCN objects. The analysis will use the nominal discount rate and general rate of inflation provided to calculate the results. An example using nominal values is provided in Sec. 4.5.1.1.2.

4.3.2.5. Guidance for BCA

BCA is a method that estimates all the benefits and costs associated with a decision. A key result from a BCA is the benefit-cost ratio (BCR), which takes the total benefits minus total non-investment costs and divides by the total investment costs (costs over which the user desires to maximize returns). The user determines which costs will be treated as investment costs, and therefore will influence the calculation of the BCR. For example, a user can choose whether to treat future costs as investment costs, which will impact both the numerator and denominator of the equation.

The example below is a simplistic analysis of the benefits and costs to a locality resulting from constructing a new monument. The study period is assumed to be the lifetime of the monument at 50 years is assumed to be January 1, 2022. The assumed real discount rate, MARR, and reinvestment rate are 3.0 % and the general rate of inflation is expected to be 2.3 %. The data is provided on a yearly basis, which will be used as the timestep for the calculations. The results we are interested in are only the summary measure results (Total Benefits, Total Costs, BCR, and IRR). Based on this information, the Analysis Object would use the following values in Tab. 4-8.

Table 4-8 Analysis Values

Var Name	Format/Values	Req
type	BCA	X
projectType		
objToReport	[measure]	X
studyPeriod	50	X
timestepValue	Year	X
timestepComp	End_Of_Year	X
outputReal	true	X
interestRate		
discountRateReal	0.030	X
discountRateNom		
inflationRate	0.023	
marr	0.030	X
reinvestRate	0.030	X
federalIncomeRate		
otherIncomeRate		
location		
numberOfAlternatives	2	X
baseAlternative	0	X

Table 4-9 provides the current and future benefits and costs for both alternatives. The baseline alternative is the status quo of not constructing the monument while the alternative to build the monument accounts for the incremental impacts relative to the status quo. Costs include the initial construction costs and annual OMR costs over the 50-year study period. The expected benefits are the free publicity from the media on the opening of the monument and an annually recurring increase in the economy from tourism resulting from the monument. All benefits and costs are provided in constant dollars.

Table 4-9 Example Benefits and Costs

Cost Category	Description	Status Quo	Build Monument
Initial Investment Cost	Construct monument	\$0	\$100 000
OMR Cost	Maintain monument	\$0	\$1000
One-Time Benefit	Free publicity	\$0	\$50 000
Recurring Benefit	Increased tourism	\$0	\$5000

Table 4-10 maps the benefits and costs to E3 BCN objects.

Table 4-10 BCN Object Values - Conventional

VarName	Investment Cost – Status Quo	Construct Monument	Maintain Monument	Free Publicity	Increased Tourism
altIds	0	1	1	1	1
id	0	1	2	3	4
type	Cost	Cost	Cost	Benefit	Benefit
subType	Direct	Direct	Direct	Direct	Externality
name	Investment Cost – Status Quo	Construct Monument	Maintain Monument	Free Publicity	Increased Tourism
tags	Investment Cost	Investment Cost	OMR Cost	Publicity	Tourism
initialOccurrence	0	0	1	1	1
real	true	true	true	true	true
invest	true	true	False	false	false
life	null	50	null	Null	Null
residualValue	false	false	false	false	false
residualValueOnly	false	false	false	false	false
recur	N/A	N/A	{"interval": 1}	N/A	{"interval": 1}
valuePerQ	0	100 000	1000	50 000	5000
quantity	1	1	1	1	1
quantityVarRate	Null	Null	Null	Null	Null
quantityVarValue	Null	Null	Null	Null	Null
quantityUnit	Null	1	1	1	1

The results in Tab. 4-11 show total net benefits of building the monument of \$51 463, a BCR pf 1.51, and an IRR of 7.3 %.

Table 4-11 BCA Example Results

Category	Net Present Value	Build Monument
Costs	Initial Investment Cost	\$100 000
	OMR	\$25 730
	Total	\$125 730
Benefits	Free Publicity	\$48 544
	Increased Tourism	\$128 649
	Total	\$177 193
Results	Net Benefits	\$51 463
	BCR	1.51
	IRR	7.3 %

The results reports generated by E3 are independent of the type of analysis. BCA will be focused on a subset of the results. The Alternative Summary reports all the variables in Tab. 4-12. Those **bolded** are measures used in BCA.

Table 4-12 Alternative Summary Object Results Values

Variable	VarName	Format
Alternative ID	altID	int
Total Benefits	totalBenefits	Float
Total Costs	totalCosts	Float
Total Costs – Investment	totalCostsInvest	Float
Total Costs – Non-investment	totalCostsNonInvest	Float
Net Benefits	netBenefits	Float
Net Savings	netSavings	Float
Savings-to-Investment Ratio	sir	Float
Internal Rate of Return*	irr	Float
Adjusted Internal Rate of Return	airr	Float
Simple Payback Period	spp	Float
Discounted Payback Period	dpp	Float
Benefit-Cost Ratio	bcr	Float
Quantity by Tag	quantitySum	List of Floats
Quantity Units by Tag	quantityUnits	List of Strings
MARR	marr	Float
Delta Quantity by Tag	deltaQuantity	List of Floats
Delta Net Savings by Tag	nsDeltaQuantity	List of Floats
Net Savings Percent Quantity by Tag	nsPercQuantity	List of Floats
Net Savings Elasticity by Quantity by Tag	nsElasticityQuantity	List of Floats

4.3.2.6. Guidance for Profit Maximization

Profit maximization compares revenues to expenses to determine the net income the entity earns. This terminology is distinctly different than that used for both LCCA and BCA. Assume a simplified example with a potential capital investment that will increase productivity and, therefore, increase revenue. The decisionmaker can either maintain the status quo or upgrade manufacturing equipment at an initial investment cost of \$1000 that will increase revenue by \$200 annually (in real terms) for the next 10 years (equipment's service life). Assume the real discount rate, MARR, and reinvestment rate are 3.0 % and the general rate of inflation is expected to be 2.3 %. The data is provided on a yearly basis, which will be used as the timestep for the calculations and use End-of-Year discounting. The only results that the decisionmaker is interested in are change in revenue, change in costs, total profit, and IRR. Based on this information, the Analysis Object would use the following values in Tab. 4-13.

Table 4-13 Analysis Values

Var Name	Format/Values	Req
type	Profit Maximization	X
projectType	Manufacturing Process	
objToReport	[measure]	X
studyPeriod	50	X
timestepValue	Year	X
timestepComp	1	X
outputReal	True	X
interestRate		
discountRateReal	0.030	X
discountRateNom		
inflationRate	0.023	
marr	0.030	X
reinvestRate	0.030	X
federalIncomeRate		
otherIncomeRate		
location		
numberOfAlternatives	2	X
baseAlternative	0	X

Table 4-14 provides the current and future costs for both alternatives. All costs are provided in constant dollars.

Table 4-14 Example Revenue and Costs

Category	Item	Occurrence(s)	Status Quo	Upgrade
Initial Investment	Manufacturing Equipment	Year 0	0	1000
Additional Revenue	Additional Sales	Annually	0	200

E3 can be used two different ways to make the profit calculations. First, revenue could be treated as a negative cost, which leads to net savings to equal profit. Second, revenue could be treated as a benefit, which leads to net benefits to equal profit and total benefits to equal total additional revenue. Either approach will provide the same results, and the user can decide which method works best for them. In this example, we will treat revenue as a negative cost and use life cycle cost analysis measures to report the results.

Table 4-15 shows the mapping of revenues and costs to E3 BCN objects.

Table 4-15 BCN Object Values – Profit Maximization using LCCA

VarName	Investment Cost	Investment Cost	Additional Revenue
altIds	0	1	1
id	0	1	2
type	Cost	Cost	Benefit
subType	Direct	Direct	Direct
name	Zero Cost	Initial Investment	Additional Revenue
tags	Initial Investment	Equipment Upgrade	Additional Sales
initialOccurrence	0	0	1
real	true	true	true
invest	true	true	False
life	null	10	10
residualValue	false	false	false
residualValueOnly	false	false	false
recur	N/A	N/A	{"interval": 1}
valuePerQ	0	1000	200
quantity	1	1	1
quantityVarRate	Null	Null	Null
quantityVarValue	Null	Null	Null
quantityUnit	1	1	1

The comparison to make in this example is non-investment costs (negative revenue) to investment costs (equipment upgrade) as shown in Tab. 4-16. The net savings, which is the negative of the change in costs relative to the status quo base case (\$0), provides the additional profit of upgrading the equipment over its 10-year service life.

Table 4-16 Profit Maximization Example Results

Category	Net Present Value	Upgrade
Profit	Revenue (Total Costs – Noninvestment)	-\$1706
Profit	Total Costs - Investment	\$1000
Profit	Net Savings = Profit	\$706
Returns	SIR	1.71
Returns	AIRR	8.7 %
Returns	IRR	15.1 %

4.3.2.7. Guidance for Monetary and Non-monetary Synergies and Trade-Offs

As the increase in sustainability has grown over the last decade, the scope of evaluations has broadened from solely monetary impacts to include non-monetary impacts that may be difficult, or even impossible, to monetize. For example, the sustainable manufacturing standard includes metrics to determine the trade-offs between costs/profits and negative externalities (i.e., environmental impacts). These monetary/non-monetary comparisons could be applied to any analysis and, therefore, the example in this section will be simplified and generic to be applicable to different analysis types.

The example in Sec. 4.4.2.3 can be expanded to include a non-monetary value for environmental impacts (carbon emissions) associated with the equipment upgrade. Assume

that the equipment has embodied carbon emissions associated with its manufacturing and installation of 300 kg of carbon dioxide equivalent (CO₂e) while it reduces operational energy consumption that leads to decreased emission of 100 kg CO₂e annually. Therefore, there are two additional BCN objects to include in the E3 input file, a one-time environmental impact in Year 0 and a recurring negative environment impact in Year 1 through Year 10 as shown in Tab. 4-17.

Table 4-17 BCN Object Values – Environmental Impacts

VarName	Embodied Emissions	Operational Energy Emissions
altIds	1	1
id	1	2
type	Nonmonetary	Nonmonetary
subType	Externality	Externality
name	Embodied Emissions	Operational Energy Emissions
tags	Carbon Emissions	Carbon Emissions
initialOccurrence	0	1
real	True	True
invest	False	False
life	null	10
residualValue	False	False
residualValueOnly	False	False
recur	N/A	{"interval": 1}
valuePerQ	1	1
quantity	300	-100
quantityVarRate	Null	Null
quantityVarValue	Null	Null
quantityUnit	Kg CO ₂ e	Kg CO ₂ e

The “deltaQuant” value for the “Carbon Emissions” tag is $300 - (100 * 10) = -700$ kg CO₂e. In this case there are synergies between profit (\$706) and environmental impacts (700 kg reduction), or a \$1.01 of additional profit per kg of carbon emissions reduction.

4.3.3. Other Output Results Options

There are other results that the user can report if they are determined to be useful, including an additional economic measure (IRR) and real and nominal cash flows. Additionally, guidance thus far has focused on the Measures Summary results, which include summary metrics and aggregated costs and benefits by the standard BCN type-subtype categorization and optional BCN categorization by user defined BCN “tags.” E3 also provides detailed breakdown of nominal/non-discounted (“NonDiscounted”) and real/discounted (“Discounted”) cash flows by both categorization options by including “required” for the BCN categorization by type (cost, benefit, non-monetary) and subtype (direct, indirect, externality)⁴ and “optional” for user defined BCN “tags” (e.g., initial investment, OMR, salvage value) in the objects to report (objToReport) in the Analysis Object.

⁴ The Flow Summary also provides a breakdown by investment and non-investment costs.

4.3.4. Sensitivity and Uncertainty

Sensitivity and uncertainty analysis can be included for any type of analysis. Therefore, the examples provided in this section are generic to allow for them to apply to any use case of E3.

4.3.4.1. Sensitivity

E3 performs a one at a time (OAT) sensitivity analysis. OAT analysis involves altering a single variable in the analysis, usually by a relatively small amount, and then rerunning the analysis to compare the new results against the original output. This can be used to determine which variables are most impactful on the analysis as well as providing a test of model robustness and can be used to identify key variables to focus on in the model. Other types of sensitivity analysis (directional cosines, variance-based methods, variogram analysis of response surfaces) may be added in the future.

Sensitivity analysis objects are straightforward to construct. They comprise of an *id* value to identify the specific object and how it corresponds to output, a list of affected alternative IDs that tell which alternatives inputs need to be changed (*altIds*), a *variable* value that identifies the specific variable that sensitivity analysis is being performed on. All that remains is whether the variable is being altered by a gross amount or by a percentage of the original value (*diffType*) and what the numeric change is (*diffValue*).

Time variables may be altered but a few key points are worth considering. First, E3 currently does not use non-integer values of time in its analysis. If the change creates a non-integer value for time of occurrence the value will be ceilinged to the nearest integer. For end of year and midyear discounting this is a non-issue but may provide unexpected results for continuous compounding. Second, time variables must make sense in terms of how they relate to other time variables. For instance, time variables cannot be negative, the initial occurrence cannot exceed the study period or end date and the bcn life cannot be less than one. E3 checks for these conditions and will send back an error if they are not met.

4.3.4.2. Uncertainty

E3 performs a standard Monte Carlo analysis on the input BCN objects. The simulation initially performs 100 cycles as a burn in to prevent the unlikely event of a false convergence and proceeds to run the analysis with convergence checks every 100 cycles. The convergence check is done against the total costs, total benefits, and net benefits variables at a 1 % tolerance level (the ability to edit the tolerance is planned for a future release). And a maximum number of iterations of 50 000. If the analysis fails to converge within the maximum number of cycles the code will cease running and a warning will return that convergence was not reached.

E3 will only simulate a new value for the value or quantity in the BCN object if they are selected, as opposed to simulating a new value for them every single year of the study period. This is done for programming simplicity, to save calculation time and, in the limit, will not affect the accuracy of the simulation. Even with this simplification it is possible that a simulation could take several minutes based on the nature of uncertainty that has been added.

A valid simulation object includes an *id* variable linking it to its output and a list of sub-objects that includes the name of the variable with uncertainty (*variable*), the distribution being applied (*distribution*), and the arguments for the distribution (*distributionArgs*). Any variables not explicitly given uncertainty will be treated as deterministic. The current version of E3 only outputs the mean and standard deviation of all outputs, although percentiles are planned for a future version.

Due to the difficulty of accounting for multiple time variables and their relationships to each other, time variables are not currently allowed in uncertainty analysis, though this feature is planned for a future update. When using continuous distributions there is the possibility that an individual simulation may pull a value that is not valid, i.e., a negative cost value for an upfront investment cost. This can be avoided by using bounded distributions or using continuous distributions with a mean and standard deviation that make it vanishingly unlikely that such an incident can occur.

Certain outputs have the potential to produce a NaN or Infinity value as an output (irr, spp among others). If a simulation cycle results in an output like this the mean and standard deviation for that variable will be suppressed. This is to avoid a mean conditional on valid values being presented as a mean of the full sample. A future version may include a count of valid results (i.e. valid irr values or valid airr values) to be presented with the mean and standard deviation so reporting conditional means will have the proper context.

4.3.5. Accessing Output

E3 outputs results in a form of JSON string. JSON strings can be easily converted to objects in most languages as well as dictionaries in some. Accessing specific results requires that value be pulled from the associated output objects. The pattern for pulling a specific output involves first calling the appropriate output object ('measure' for instance) then, if the output is a list of objects the appropriate item, or items, from the list must be selected, then the specific output can be pulled. In Java this looks like, assuming the name of the received output is *response* and you are interested in the first element of the *measure* output, *measureOutput = response.measure.get(0)*. And if the output of interest is BCR then the next call would be *bcr = measureOutput.bcr*. In Python this call would look like, *bcr = response['measure'][0]['bcr']*.

4.3.6. Edge Cases

Throughout the validation process numerous conditions that involve input values that require special handling (i.e., edge cases) have been identified in E3. This section documents those that have been identified. As more edge cases are found, they will be added to this section to assist E3 users.

4.3.6.1. E3 Inputs

There are input scenarios that can cause issues in E3 calculations if not designed correctly. Below is a list of those currently identified in E3:

- A user requests a BCA analysis with no Benefit BCN types.
- A BCN that is defined as recurring while only including one occurrence in the study period.
- A non-baseline alternative with no attached BCN objects might cause problems with calculating measures.
- The use of scientific notation for inputs must be formatted with the following notation: “1e3”, and not “1X10^3”, for a value of 1000.
- Some characters such, as white space and escape characters, may cause errors.

4.3.6.2. E3 Outputs

Currently only one edge case has been identified that the user should consider

- Root finding algorithms can have multiple solution values while E3 only provides a single value. It’s also possible that no root may be found in the event of an even number of them if there is no sign change between the functional values at the bounds.

4.4. E3 Web API Examples

The E3 web API is being tested with multiple use cases to validate the results for each of the features and capabilities. The initial use case was a web application that directly calls on E3 - Present Value of PhotoVoltaics – [PV]². Additional use cases include comparing results from JSON strings constructed from examples in existing software tools developed by AEO to the results generated directly from the software. Thus far this approach has been applied to two software tools: Building Life Cycle Cost (BLCC) [27] and Economic Decision Guide Software Online Tool (EDGE\$) [28].

BLCC is used to validate deterministic LCCA using both real and nominal discount rates, end-of-year and mid-year discounting conventions, alternatives with zero costs, and non-monetary unit comparisons. Note that in FY2024 BLCC will be redeveloped as a web-based version using E3 as the calculation engine and official release is planned for FY2025.

EDGE\$ is used to validate deterministic analysis, sensitivity, and uncertainty for BCA using discrete end-of-year and continuous discounting conventions. Note that the current expectation is that EDGE\$ Version 2 (development to begin in FY2025) will use E3 as the calculation engine.

A sustainable manufacturing example from ASTM Standard E3200 is included that completes a LCCA of multiple machinery alternatives as well as evaluating “trade-off” measures for costs and environmental impacts. A web application based on AEO’s Smart Investment Tool (SITExpress) is currently under development (expected release in FY2024) and uses the E3 API for its calculations.

The E3 JSON input files used for the BLCC, EDGE\$, and manufacturing examples are provided as a supplement resource to this publication in the E3 GitHub directory.

The [PV]² web application is used to validate the deterministic analysis for LCCA, including all types of Direct Cost objects and results measures, for three alternatives. Additionally, Externality Costs and Non-Monetary BCNs are included for environmental impacts and the social cost of carbon (SCC) associated with electricity. [PV]² leverages the ability to use one BCN object for multiple alternatives.

Currently, the examples in this section do not address the following:

- Sub-year timesteps
 - Could be added to modified BLCC, EDGe\$, or [PV]² example files to test
- Other economic analysis types (e.g., profit maximization)
 - Could add a manufacturing example that includes revenue and profit terms

4.4.1. BLCC

The BLCC software provides comprehensive economic analysis of proposed capital investments that are expected to reduce long-term operating costs of buildings or building systems. Numerous alternative designs can be evaluated simultaneously to determine which has the lowest life-cycle cost. Comparative economic measures can be calculated for any design alternative relative to the designated base case. BLCC complies with ASTM building economics standards and federal requirements and guidance for both military and non-military projects. There are six different “modules” in BLCC targeting specific types of federal projects as described below.

FEMP Analysis, Energy Project: The criteria used as defaults in this module follow the life-cycle costing rules of the Federal Energy Management Program according to 10 Code of Federal Regulations (CFR) 436A as they apply to energy and water conservation and renewable energy projects funded by agencies from direct appropriations.

Federal Analysis, Financed Project: This is the module to be used for an LCC analysis of Energy Savings Performance Contracts (ESPC), Utility Energy Services Contracts (UESC) or other alternatively financed investments in energy or water conservation in the Federal Government. The criteria used as defaults in this module are applicable to all agencies in the Federal Government.

OMB Analysis, Non-Energy Project: This module supports analyses that are subject to the life-cycle costing guidelines of OMB Circular A-94 for the following types of projects:

(a) Cost-effectiveness, lease-purchase, internal government investment, and asset sales (b) Public investment and regulatory analyses

MILCON Analysis, Energy Project: This module supports LCC analyses, according to 10 CFR 436A, of agency-funded energy and water and renewable energy projects for military construction in the Army, Navy, and Air Force.

MILCON Analysis, ECIP Project: This module can be used for generating the "ECIP Report" for Military Construction (MILCON) projects funded by the DoD Energy Conservation Investment Program (ECIP) to retrofit existing energy systems.

MILCON Analysis, Non-Energy Project: This module supports LCC analyses of new acquisition or construction projects, lease-purchase decisions, modification of existing facilities and similar projects the purpose of which is not primarily to assess energy usage.

BLCC includes a file template as well as an example file for each of these project type modules. Each has its unique set of default assumptions based on the requirements and guidance for the given project type. The costs in BLCC are typically categorized as follows:

- Capital Component
 - Investment Cost
 - Replacement Costs
 - OM&R Costs – Annually Recurring
 - OM&R Costs – Non-Annually Recurring
- Contract Costs (*Financed Projects Only*)
 - Annually Recurring
 - Non-Annually Recurring
- Energy Costs
 - Electricity
 - Distillate Fuel Oil
 - Residual Fuel Oil
 - Natural Gas
 - Liquefied Petroleum Gas
 - Coal
- Water Costs

Several variations on this categorization exist depending on the analysis module. First, Contract Costs are only available in BLCC if the “Federal Analysis, Financed Project” type is selected. Costs related to contracts can be included in other modules by defining them as OM&R Costs. Second, the cost categorization is different for “MILCON Analysis, ECIP Project” because the baseline is assumed to have zero costs and each alternative defines its costs (or cost savings) relative to the baseline. The inputs for this project type are designed specifically for MILCON Energy Conservation Investment Program (ECIP), which is the predecessor to the Energy Resilience and Conservation Investment Program (ERCIP).

Four examples, each using a different project analysis module in BLCC, have been used to validate the calculations using both real and nominal dollars and discount rates, end-of-year

and mid-year discounting conventions, varying service date relative to the base date, alternatives with and without different cost categorization types including initial investment costs, residual values, recurring and non-recurring future costs, contract costs, items with multiple cost aspects (i.e. electricity consumption costs and demand charges), items with a non-monetary value of interest (i.e. cost and quantity of electricity consumption), and alternatives with zero cost items.

FEMP Analysis, Energy Project: “FEMP Energy” includes initial investment costs, recurring future costs, non-recurring future costs, residual values, multiple cost aspects and non-monetary values for electricity, and uses real dollars and discount rates with end-of-year discounting convention. The service date is the same as the base date.

Federal Analysis, Financed Project: “Federal Financed” varies from “FEMP Energy” in that it does not include any investment costs, includes annual contract payments, and uses nominal dollars and discount rates with end-of-year discounting convention.

OMB Analysis, Non-Energy Project: “OMB Non-Energy” is used to validate using a different real discount rate and mid-year discounting convention.

MILCON Analysis, ECIP Project: “MILCON ECIP” is used to validate using the unique cost/savings input format for the module, alternative with zero cost items, and service date being different than the base date.

The assumptions for MILCON Analysis, Energy Project and MILCON Analysis, Non-Energy Project modules are covered within one or more of the other examples.

Note these examples do not validate the following:

- Multiple alternatives to the baseline
 - Could use MILCON Non-Energy because it has three alternatives
 - Covered by [PV]² if power purchase agreement/lease option is included in analysis
- Sub-year timesteps
- Continuous discounting
- Other economic analysis types (e.g., BCA, profit maximization, trade-offs)

4.4.1.1. End-of-Year Discounting

Two examples from BLCC use end-of-year discounting because both are non-military projects: FEMP Analysis – Energy and Federal Analysis – Financed.

4.4.1.1.1. FEMP Analysis – Energy Project

The example file for a FEMP Analysis, Energy Project named “FEMP Energy” (using 2021 data) has been used to generate an E3 input JSON string that was submitted manually to the E3 API. The criteria used as defaults in the FEMP Energy Analysis Project module follow FEMP’s life-

cycle costing rules according to 10 CFR 436A as they apply to energy and water conservation and renewable energy projects funded by agencies from direct appropriations.

The project is “Heating/Cooling System” for a Park Service building in Washington, D.C. considering two alternatives: “Existing System” that keeps the existing baseboard heater and window air conditioning (AC) unit and “New System” that replaces the existing system with a heat pump. The analysis assumes a 15-year study period with base date of April 2021, end-of-year discounting, the DOE real discount rate (3 %), and provides all costs in constant/real dollar terms. The real DOE electricity price escalation rates for a commercial customer in Washington, D.C. shown in Tab. 4-18 are used for estimating electricity prices over the study period:

Table 4-18 Real Electricity Price Escalation Rates (Year-Over-Year Percentage Changes)

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
0.04	-1.00	-1.31	-0.95	-0.04	0.11	-0.04	0.23	-0.11	-0.46	-0.73	0.0	-0.12	-0.31	-0.54

This information maps to the E3 Analysis object as shown in Table 4-19:

Table 4-19 Analysis Object Values

Var Name	Var Type	Format/Values	Req
type	String	“LCCA”	X
projectType	String	“Buildings”	
objToReport	List of Strings	[required, measure]	X
studyPeriod	Int	15	X
timestepValue	String	“Year”	X
timestepComp	String	“End_Of_Year”	X
outputReal	Boolean	True	X
interestRate	Float		
discountRateReal	Float	0.03	X
discountRateNom	Float		
inflationRate	Float		X
marr	Float	0.03	X
reinvestRate	Float	0.03	X
federalIncomeRate	Float		
otherIncomeRate	Float		
location	List of Strings	{“country”: “United States”, “state”: “DC”, “zipcode”: “20008”}	
numberOfAlternatives	Int	2	X
baseAlternative	Int	0	X

The existing system includes the following costs:

- Capital Component: Baseboard Heater
 - Investment Costs
 - Initial Cost = \$500
 - Expected Life = 15 years

- Residual Value Factor = 10 %
- Capital Component: Window AC Unit
 - Investment Costs
 - Initial Cost = \$1000
 - Expected Life = 15 years
 - Residual Value Factor = 10 %
 - Replacement Costs: Fan
 - Cost = \$600
 - Replacement/Expected Life = 10 years
 - Residual Value Factor = 50 % ()
 - OM&R Costs – Annually Recurring
 - Routine Maintenance
 - \$50
 - Annual Rate of Increase = 0 %
 - OM&R Costs – Non-Annually Recurring
 - Cleaning
 - \$200
 - Occurrence = 10 years
 - Annual Rate of Increase = 0 %
 - Energy Costs
- Electricity
 - 15 000 kWh
 - \$0.08/kWh
 - DOE real electricity price escalation rates
 - No demand charge or annual utility rebates

These costs map to E3 BCN objects as shown in Tab. 4-20 for the existing system.

Table 4-20 BCN Object Values – Existing System

VarName	Baseboard Heater	AC Unit	Fan Repl.	Electricity	Maint.	Cleaning	BB RV	AC RV	Fan RV
altIds	0	0	0	0	0	0	0	0	0
id	0	1	2	3	4	5	6	7	8
type	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost
subType	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct
name	Baseboard Heater	AC Unit	Fan Replacement	Electricity	Maintenance	Cleaning	BB Residual Value	AC Residual Value	Fan Residual Value
tags	Initial Investment	Initial Investment	Replacement	Energy	OMR	OMR	Salvage Value	Salvage Value	Salvage Value
initialOccurrence	0	0	12	1	1	10	15	15	15
real	true	true	true	true	true	true	true	true	true
invest	true	true	true	false	false	False	true	true	true
life	15	15	12	Null	Null	Null	Null	Null	Null
residualValue	false	false	false	false	false	False	true	true	true
residualValueOnly	false	false	false	false	false	false	true	true	True
recur	N/A	N/A	{"interval": 12, "end": 15}	{"interval": 1, "end": 15, "varRate": "PERCENT_DELTA", "varRate": [DOE Esc Rate List]}	{"interval": 1, "end": 15}	{"interval": 1}	N/A	N/A	N/A
valuePerQ	500	1000	600	0.08	50	200	-50	-100	-300
quantity	1	1	1	15 000	1	1	1	1	1
quantityVarRate	Null	Null	Null	PERCENT_DELTA	Null	Null	Null	Null	Null
quantityVarValue	Null	Null	Null	[0.0]	Null	Null	Null	Null	Null
quantityUnit	Null	Null	Null	kWh	Null	Null	Null	Null	Null

The new system includes the following costs:

- Capital Component: Heat Pump
 - Investment Costs
 - Initial Cost = \$3000
 - Expected Life = 20 years
 - Residual Value Factor = 25 %
 - OM&R Costs – Annually Recurring
 - Routine OM
 - \$100
 - Annual Rate of Increase = 0 %
 - OM&R Costs – Non-Annually Recurring
 - Overhaul
 - \$600
 - Annual Rate of Increase = 0 %
- Energy Costs
 - Electricity
 - 10 250 kWh
 - \$0.08/kWh
 - DOE electricity price escalation rates
 - No demand charge or annual utility rebates

These costs map to E3 BCN objects as shown in Tab. 4-21 for the new system.

Table 4-21 BCN Object Values – New System

VarName	Heat Pump	Electricity	Routine OM	Overhaul	Heat Pump RV
altIds	1	1	1	1	1
id	8	9	10	11	12
type	Cost	Cost	Cost	Cost	Cost
subType	Direct	Direct	Direct	Direct	Direct
name	Heat Pump	Electricity	Maintenance	Cleaning	Heat Pump Residual Value
tags	Initial Investment	Energy	OMR	OMR	Salvage Value
initialOccurrence	0	1	1	10	15
real	true	true	true	true	true
invest	1	0	0	0	1
life	20	Null	Null	Null	Null
residualValue	false	false	false	false	true
residualValueOnly	false	false	false	false	true
recur	N/A	{"interval": 1, "end": 20, "varRate": "PERCENT_DELTA", "varRate": [DOE Esc Rate List]}	{"interval": 1, "end": 20}	{"interval": 8}	false
valuePerQ	3000	0.08	100	600	-750
quantity	1	10 250	1	1	1
quantityVarRate	Null	Null	Null	Null	Null
quantityVarValue	Null	Null	Null	Null	Null
quantityUnit		kWh			

The cash flow results from the E3 API reported in “required” – “TotalCostsNonDiscounted” were compared to the results in the BLCC reports in Tab. 4-22 to confirm consistency between E3 and BLCC. Within \$1 for every year’s cash flow for both alternatives.

Table 4-22 Nominal Cash Flow Comparison

Year	Existing System BLCC	Existing System E3	New System BLCC	New System E3
0	\$1500 ^a	\$1500	3000 ^a	\$3000
1	\$1250 ^a	\$1250	\$920 ^a	\$920
2	\$1239	\$1238	\$912	\$912
3	\$1223	\$1223	\$902	\$901
4	\$1212	\$1212	\$894	\$894
5	\$1211	\$1211	\$894	\$894
6	\$1213	\$1213	\$895	\$894
7	\$1212	\$1212	\$894	\$894
8	\$1215	\$1215	\$896	\$896
9	\$1214	\$1214	\$1495	\$1495
10	\$1208	\$1208	\$892	\$891
11	\$2000	\$2000	\$886	\$886
12	\$1200	\$1200	\$886	\$886
13	\$1199	\$1198	\$885	\$885
14	\$1195	\$1195	\$882	\$882
15	\$739	\$739	\$128	\$128

^aBLCC reports Year 0 and Year 1 cash flows together. Here the results are broken down to how they are discounted.

The difference in the LCC results as shown in Tab. 4-23 is minimal ($\approx 0.1\%$) and a result of rounding during the discounting and escalation calculations.

Table 4-23 Summary Results Comparison – FEMP Energy Project^a

Measure	Existing System - BLCC	Existing System - E3	New System - BLCC	New System - E3
Total Present Value Life Cycle Costs	\$16 297 ^b	\$16 277 ^b	\$13 680 ^b	\$13 665 ^b
Net Savings			\$2617	\$2613
SIR Ratio			4.04	3.99
AIRR			13.05 %	12.95 %
SPP			5	5
DPP			6	6
Annual Energy Consumption (kWh)	15 000	15 000	10 250	10 250
Total Energy Consumption (kWh)	225 000	225 000	153 750	153 750
Total Energy Reduction (kWh)			71 240	71 250

^aBLCC Service Date = 04/2021, but annual timestep assumes 15 complete years

^bBLCC reports Year 0 and Year 1 cash flows together. Here the results are broken down to how they are discounted.

Note: The results do not currently compare emissions reduction estimates. This could be completed by finding the source file within BLCC to obtain the emissions factors for each fuel type for Washington, DC and then adding non-monetary BCN objects with the same

information as the electricity BCN objects except replacing the quantity and units. An example of this is available from the [PV]² example.

4.4.1.1.2. Federal Analysis – Financed Project

The example file for a FEMP Analysis, Financed Project named “Federal Financed” (using 2021 data) has been used to generate an E3 input JSON string that was submitted manually to the E3 API. The criteria used as defaults in the FEMP Energy Analysis Project module follow FEMP’s life-cycle costing rules according to 10 CFR 436A as they apply to energy and water conservation and renewable energy projects funded through financing instead of the previous example that used direct appropriations. As a result, the analysis is completed in current/nominal terms and requires some adjustments to the costs data to function in E3 that are discussed below.

The project is “Lighting/Daylighting” for a federal building in Arizona considering two alternatives: “Existing” that keeps the existing lighting system and “Lighting Retrofit” that retrofits the lighting system to reduce energy consumption. The analysis assumes a 15-year study period (expected remaining life on existing lighting system) with base date of April 2021, end-of-year discounting, the DOE nominal discount rate (1.5 %) and implied inflation rate (-1.5 %)⁵, and provides all costs in current/nominal dollar terms. The nominal DOE electricity price escalation rates for a commercial customer in Arizona shown in Tab. 4-24 are used for estimating electricity prices and demand charges over the study period. Note that the nominal escalation rate estimates are negative because electricity prices are projected to increase at a slower rate than general inflation (or even decrease in some years).

Table 4-24 Nominal Electricity Price Escalation Rates (Year-Over-Year Percentage Changes)

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
-2.22	-2.79	-2.97	-0.87	-0.27	-1.39	-1.91	-1.85	-1.17	-0.74	-1.45	-1.69	-1.58	-1.58	-1.82

This information maps to the E3 Analysis object as shown in Tab. 4-25:

⁵ The implied inflation rate is a result of an inconsistency created from the 3.0 % floor on real discount rates defined in the CFR. The nominal escalation rate is calculated using nominal yields on long-term treasuries, resulting in a nominal discount rate below the floor (1.5 % versus 3.0 %). The inflation rate that will make the nominal and real discount rates consistent is -1.5 %, which is different than the inflation rate used by the Council of Economic Advisors (2.3 %) that is defined to be used in the CFR.

Table 4-25 Analysis Object Values

Var Name	Var Type	Format/Values	Req
type	String	LCCA	X
projectType	String	Buildings	
objToReport	List of Strings	[required, optional, measure]	X
studyPeriod	Int	15	X
timestepValue	String	Year	X
timestepComp	String	End_Of_Year	X
outputReal	Boolean	false	X
interestRate	Float		
discountRateReal	Float		
discountRateNom	Float	0.015	X
inflationRate	Float	-0.015	X
marr	Float	0.03	X
reinvestRate	Float	0.03	X
federalIncomeRate	Float		
otherIncomeRate	Float		
numberOfAlternatives	Int	2	X
baseAlternative	Int	0	X
location	List of Strings	{"country": "United States", "state": "AZ", "zipcode": "85364"}	

The existing system includes the following costs:

- Capital Component: Existing System
 - Investment Costs
 - \$0
 - OM&R Costs – Annually Recurring
 - \$5600
 - Annual Rate of Change = -1.5 %
 - Value is in Year 0 dollars and be converted to current/nominal dollars for every future year
 - Assumed to change at the general rate of inflation (-1.5 %) to make the real present value the same in each year
- Energy Costs
 - Electricity
 - 1 082 633 kWh
 - \$0.046/kWh
 - DOE nominal electricity price escalation rates
 - \$30 105 demand charge

These costs map to E3 BCN objects as shown in Tab. 4-26:

Table 4-26 BCN Object Values – Existing System

VarName	Existing System ^a	Electricity - Consumption	Electricity – Demand Charge	OMR Cost
altIds	0	1	2	3
id	0	3		4
type	Cost	Cost		Cost
subType	Direct	Direct		Direct
name	Existing System	Electricity-Consumption	Electricity-Demand Charge	OMR Cost
tags	Initial Investment	Energy-Consumption	Energy-Demand Charge	OMR
initialOccurrence	0	1	1	1
real	false	false	false	false
invest	true	false	False	false
life	15	Null	null	Null
residualValue	False	false	false	false
residualValueOnly	false	false	false	false
recur	{"interval": 1, "varRate": "PERCENT_DELTA", "varRate": -0.015}	{"interval": 1, "varRate": "PERCENT_DELTA", "varRate": [DOE Esc Rate List]}	{"interval": 1, "varRate": "PERCENT_DELTA", "varRate": [DOE Esc Rate List]}	{"interval": 1, "varRate": "PERCENT_DELTA", "varRate": -0.015}
valuePerQ	0	0.046	30 105	5600
quantity	1	1 082 633	1	1
quantityVarRate	Null	Null	Null	Null
quantityVarValue	Null	Null	Null	Null
quantityUnit	Null	kWh	null	Null

^aThe Existing System object was included in the example for completeness to match the BLCC example file and could be excluded from the JSON file submission because it has no value.

The new system includes the following costs:

- Capital Component: New System
 - Investment Costs
 - Initial Cost Paid by Agency = \$0
 - Initial Cost Financed = \$390 480
 - Covered in Contract Cost objects
 - Expected Life = 20 years
 - Annual Rate of Increase = -1.50 %
 - Assumed to increase at the general rate of inflation
 - Residual Value Factor = 25 %
 - Calculated based on the adjusted value at the end of the study period (Year 15)

- \$390 480 adjusted by -1.50 % annually
- OM&R Costs – Annually Recurring
 - Post-Contract Operation and Maintenance (OM) Costs
 - \$3000
 - Annual Rate of Increase = -1.5 %
 - Assumed to increase at the general rate of inflation
 - Year 11 through Year 15
- Energy Costs
 - Electricity
 - 206 911 kWh
 - \$0.046/kWh
 - DOE nominal electricity price escalation rates
 - \$3311 demand charge
- Contract Costs – Annually Recurring
 - Annual Contract Payment
 - \$67000
 - -1.60 % escalation rate
 - Usage Indices
 - Set to 100.0 % for the length of the contract and 0.0 % for remainder
 - Usage Factor 100.0 % for 10 years
 - Usage Factor 0.0 % for remaining (Year 11 through Year 15)

These costs map to E3 BCN objects as shown in Tab. 4-27.

Table 4-27 BCN Object Values – New System

VarName	New System ^a	Electricity-Consumption	Electricity-Demand Charge	Post-Contract OM Cost	Lighting Retrofit Residual Value	Contract Payments
altIds	1	1	1	1	1	1
id	4	5	6	7	8	9
type	Cost	Cost	Cost	Cost	Cost	Cost
subType	Direct	Direct	Direct	Direct	Direct	Direct
name	New System	Electricity	Electricity-Demand Charge	Post-Contract OM Cost	Lighting Retrofit Residual Value	Lighting Retrofit Contract Payment
tags	Initial Investment	Energy-Consumption	Energy-Demand Charge	OMR	Salvage Value	Contract Costs
initialOccurrence	0	1	1	11	15	1
real	false	false	false	false	false	false
invest	True	false	false	False	True	False
life	20	Null	Null	Null	Null	Null
residualValue	false	false	false	False	true	false
residualValueOnly	false	false	false	false	True	false
recur	N/A	{"interval": 1, "end": 15, "varRate": "PERCENT_DELTA", "varRate": [DOE Esc Rate List]}	{"interval": 1, "end": 15, "varRate": "PERCENT_DELTA", "varRate": [DOE Esc Rate List]}	{"interval": 1, "end": 15, "varRate": "PERCENT_DELTA", "varRate": -0.015}	N/A	{"interval": 1, "end": 10, "varRate": "PERCENT_DELTA", "varRate": -0.016}
valuePerQ	0	0.046	3311	3000	-77818.39	67000
quantity	1	206911	1	1	1	1
quantityVarRate	Null	Null	Null	Null	Null	PERCENT_DELTA
quantityVarValue	Null	Null	Null	Null	Null	[0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,-1.0,0.0,0.0,0.0,0.0]
quantityUnit	Null	kWh	Null	Null	Null	Null

^aThe New System object was included in the example for completeness to match the BLCC example file and could be excluded from the JSON file submission because it has no value.

The cash flow results from the E3 API reported in “required” – “TotalCostsNonDiscounted” were compared to the results in the BLCC reports in Tab. 4-28 to confirm consistency between E3 and BLCC. Within \$14 (0.02 %) for every year’s cash flow for both alternatives.

Table 4-28 Nominal Cash Flow Comparison

Year	Existing System - BLCC	Existing System - E3	New System - BLCC	New System - E3
0	0	0	0	0
1	\$83 656	\$83 648	\$78 478	\$78 472
2	\$81 400	\$81 386	\$77 076	\$77 067
3	\$79 061	\$79 048	\$75 674	\$75 667
4	\$78 338	\$78 327	\$74 552	\$74 543
5	\$78 062	\$78 051	\$73 516	\$73 506
6	\$76 973	\$76 960	\$72 367	\$72 355
7	\$75 525	\$75 511	\$71 172	\$71 161
8	\$74 145	\$74 132	\$70 007	\$69 994
9	\$73 258	\$73 248	\$68 935	\$68 922
10	\$72 678	\$72 669	\$67 928	\$67 914
11	\$71 623	\$71 613	\$13 278	\$13 277
12	\$70 424	\$70 411	\$13 059	\$13 057
13	\$69 315	\$69 303	\$12 855	\$12 853
14	\$68 224	\$68 211	\$12 654	\$12 652
15	\$66 996	\$66 984	-\$65 390	-\$65 389

^aBLCC reports Year 0 and Year 1 cash flows together. Here the results are broken down to how they are discounted.

The difference in the results is minimal ($\approx 0.02\%$) as shown in Tab. 4-29 and a result of rounding during the discounting and escalation calculations.

Table 4-29 Summary Results Comparison – Federal Financed Energy Project^a

Measure	Existing System - BLCC	Existing System - E3	New System - BLCC	New System - E3
Total Present Value Life Cycle Costs ^b	\$1 000 117	\$ 999 909	\$665 055	\$664 920
Net Savings			\$335 062	\$ 334 988
Annual Energy Consumption (kWh)	1 082 633	1 082 633	206 911	206 911
Total Energy Consumption (kWh)	16 239 495	16 239 495	3 103 665	3 103 665
Total Energy Reduction (kWh)			13 134 032	13 135 830

^aBLCC Service Date = 04/2021, but annual timestep assumes 15 complete years

^bBLCC reports Year 0 and Year 1 cash flows together. Here the results are broken down to how they are discounted.

Note: The results do not currently compare emissions reduction estimates. This could be completed by finding the source file within BLCC to obtain the emissions factors for each fuel type for Washington, DC and then adding non-monetary BCN objects with the same information as the electricity BCN objects except replacing the quantity and units. An example of this is available from the [PV]² example.

4.4.1.2. Mid-Year Discounting

Two examples from BLCC use mid-year discounting because both are military projects: OMB Analysis – Non-Energy and MILCON Analysis ECIP.

4.4.1.2.1. OMB Analysis – Non-Energy Project

The example file for an Office of Management and Budget (OMB) Analysis, Non-Energy Project named “OMB Non-Energy” (using 2021 data) has been used to generate an E3 input JSON string that was submitted manually to the E3 API. The criteria used as defaults in the OMB Non-Energy Analysis Project module follow OMB’s life cycle costing rules according to 10 CFR 436A as they apply to non-energy related federal projects.

The project is “OMB Demo” for a buy versus lease decision for a building in Maryland. Therefore, the analysis purpose is “cost-effectiveness, lease purchase, internal government investment or asset sale analysis.” The baseline is “Lease” and the alternative is “Buy.” The analysis assumes a 15-year study period with base date of April 2021, mid-year discounting (presumably a DoD project), the real OMB discount rate for projects of 15 years (-0.8 %; average of 10-year and 20-year discount rates from Circular A-94), and provides all costs in constant/real dollar terms. This information maps to the E3 Analysis object as shown in Tab. 4-30:

Table 4-30 Analysis Object Values

Var Name	Var Type	Format/Values	Req
type	String	LCCA	X
projectType	String	Buildings	
objToReport	List of Strings	[measure, required, optional]	X
studyPeriod	Int	15	X
timestepValue	String	Year	X
timestepComp	String	Mid_Year	X
outputReal	Boolean	true	X
interestRate	Float		
discountRateReal	Float	-0.008	X
discountRateNom	Float		
inflationRate	Float		
marr	Float	-0.008	X
reinvestRate	Float	-0.008	X
federalIncomeRate	Float		
otherIncomeRate	Float		
noAlt	Int	2	X
baseAlt	Int	0	X
location	List of Strings	{"country": "United States", "state": "MD"}	

The example assumes that operational costs are identical between the two examples. The only difference is the purchase option includes the initial purchase cost, residual value, and maintenance costs while the leasing option only includes the lease payments.

The baseline (lease) alternative includes two cost objects:

- Capital Component: Leasing
 - Investment Costs
 - Initial Cost = \$0
 - Expected Life = 50 years
 - Annual Rate of Increase = 0 %
 - Residual Value Factor = 0 %
 - OM&R Costs – Annually Recurring
 - Lease Payment
 - \$500 000
 - Annual Rate of Increase = 0 %

The buy alternative includes two cost objects:

- Capital Component: Buy
 - Investment Costs
 - Initial Cost = \$5 000 000
 - Expected Life = 50 years
 - Annual Rate of Increase = 0 %
 - Residual Value Factor = 50 %
 - OM&R Costs – Annually Recurring: Building Maintenance
 - \$200 000
 - Annual Rate of Increase = 0 %

These costs map to E3 BCN objects as shown in Tab. 4-31:

Table 4-31 BCN Object Values

VarName	Leasing - Initial Cost ^a	Leasing - Lease Payment	Buying - Buy Cost	Buying - Building Maintenance	Buying - Residual Value
altIds	0	1	2	3	4
id	0	0	1	1	1
type	Cost	Cost	Cost	Cost	Cost
subType	Direct	Direct	Direct	Direct	Direct
name	Initial Cost	Lighting Retrofit Contract Payment	Initial Cost	Building Maintenance	Residual Value
tags	Initial Investment	OMR	Initial Investment	OMR	Salvage Value
initialOccurrence	0	1	0	1	15
real	true	true	true	true	true
invest	True	False	True	false	True
life	50	Null	50	Null	Null
residualValue	False	false	False	false	true
residualValueOnly	false	false	false	false	True
recur	N/A	{"interval": 1}	N/A	{"interval": 1}	N/A
valuePerQ	0	500 000	5 000 000	200 000	-2 500 000
quantity	1	1	1	1	1
quantityVarRate	Null	Null	Null	Null	Null
quantityVarValue	Null	null	Null	Null	Null
quantityUnit	Null	Null	Null	Null	Null

^aInitial Cost object for the lease option is included for completeness for the BLCC example and could be excluded from the E3 JSON submission.

The cash flow results from the E3 API reported in “required” – “TotalCostsNonDiscounted” were compared to the results in the BLCC reports in Tab. 4-32 to confirm consistency between E3 and BLCC with a perfect match for all values.

Table 4-32 Nominal Cash Flow Comparison

Year	Lease - BLCC	Lease - E3	Buy - BLCC	Buy - E3
0	\$0	\$0	\$5 000 000 ^a	\$5 000 000 ^a
1	\$500 000	\$500 000	\$200 000 ^a	\$200 000 ^a
2	\$500 000	\$500 000	\$200 000	\$200 000
3	\$500 000	\$500 000	\$200 000	\$200 000
4	\$500 000	\$500 000	\$200 000	\$200 000
5	\$500 000	\$500 000	\$200 000	\$200 000
6	\$500 000	\$500 000	\$200 000	\$200 000
7	\$500 000	\$500 000	\$200 000	\$200 000
8	\$500 000	\$500 000	\$200 000	\$200 000
9	\$500 000	\$500 000	\$200 000	\$200 000
10	\$500 000	\$500 000	\$200 000	\$200 000
11	\$500 000	\$500 000	\$200 000	\$200 000
12	\$500 000	\$500 000	\$200 000	\$200 000
13	\$500 000	\$500 000	\$200 000	\$200 000
14	\$500 000	\$500 000	\$200 000	\$200 000
15	\$500 000	\$500 000	-\$2 300 000	-\$2 300 000

^aBLCC reports Year 0 and Year 1 cash flows together. Here the results are broken down to how they are discounted.

The difference in the results as shown in Tab. 4-33 is minimal (0.43 %) and a result of rounding during the discounting and escalation calculations.

Table 4-33 Summary Results Comparison – OMB Non-Energy Project^a

Measure	Lease - BLCC	Lease - E3	Buy - BLCC	Buy - E3
Total Present Value Life Cycle Costs ^b	\$ 7 970 462	\$7 970 493	\$ 5 368 129	\$5 379 398
Net Savings			\$ 2 602 334	\$ 2 591 096
SIR Ratio			2.19	2.18
AIRR			4.53 %	4.50 %
SPP			15	15
DPP			15	15

^aBLCC Service Date = 04/2021, but annual timestep assumes 15 complete years

^bBLCC reports Year 0 and Year 1 cash flows together. Here the results are broken down to how they are discounted.

Note: The results do not currently compare emissions reduction estimates. This could be completed by finding the source file within BLCC to obtain the emissions factors for each fuel type for Washington, DC and then adding non-monetary BCN objects with the same information as the electricity BCN objects except replacing the quantity and units. An example of this is available from the [PV]² example.

4.4.1.2.2. MILCON Analysis – ECIP Project

The example file for a MILCON Analysis, ECIP Project named “MILCON ECIP” (using 2021 data) has been used to generate an E3 input JSON string that was submitted manually to the E3 API. The criteria used as defaults in the MILCON ECIP Analysis Project module follow FEMP’s life-

cycle costing rules according to 10 CFR 436A as they apply to energy and water conservation and renewable energy projects funded by agencies from direct appropriations. This module is structured differently than the other BLCC modules because it requires inputting alternative information as cost savings related to the baseline. Therefore, no inputs are required for the baseline.

The project is “Install DX Split System AC” in family housing office at Dahlgren, VA, Naval Station. The baseline is keeping the existing window air conditioners and assumes zero costs or cost savings. The alternative being considered is replacing the existing window air conditioners with a direct expansion (DX) split system. The analysis assumes a 21-year study period with base date of April 2021, “beneficial occupancy date” of 1 year after the base date, mid-year discounting, the DOE real discount rate (3 %), and provides all costs in constant/real dollar terms. The real DOE electricity price escalation rates for an industrial customer in Virginia as shown in Tab. 4-34 are used for estimating electricity prices over the study period:

Table 4-34 Real Electricity Price Escalation Rates (Year-Over-Year Percentage Changes)

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0.39	-1.93	-2.2	-0.98	0.52	0.29	0.23	0.29	-0.06	-0.23

2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
-0.35	-0.12	-0.12	-0.17	-0.52	-0.52	-0.29	-0.53	-0.47	-0.42	-0.54

This is the first example that includes a delay between the base date and occupancy date. This information maps to the E3 Analysis object as shown in Tab. 4-35:

Table 4-35 Analysis Object Values

Var Name	Var Type	Format/Values	Req
type	String	LCCA	X
projectType	String	Buildings	
objToReport	List of Strings	[required, measure]	X
studyPeriod	Int	15	X
timestepValue	Date	2021, 04, 01	X
timestepComp	Date	2022, 04, 01	
outputReal	String	Year	X
interestRate	String	Mid_Year	X
discountRateReal	Boolean	true	X
discountRateNom	Float		
inflationRate	Float	0.03	X
marr	Float		
reinvestRate	Float	-0.015	
federalIncomeRate	Float	0.03	X
otherIncomeRate	Float	0.03	X
type	Float		
projectType	Float		
numberOfAlternatives	Int	2	X
baseAlternative	Int	0	X
location	List of Strings	{"country": "United States", "state": "VA"}	

The alternative includes the following additional costs and cost savings:

- Capital Component Savings/Cost
 - Additional Investment Costs
 - Construction Cost = \$142 800
 - SIOH = \$10 200
 - Design Cost = \$17 000
 - Salvage Value of Existing Equipment = \$0
 - Public Utility Company Rebate = \$0
 - Annually Recurring Savings
 - Routine OM&R
 - Amount Saved = \$2270
 - Annual Rate of Increase = 2.0 %
 - Non-Annually Recurring Savings
 - Major Repair1 (Avoided Repair)
 - Amount Saved = \$9000
 - Occurrence = 6 years

- Annual Rate of Increase = 0 %
- Major Repair2 & Replacement
 - Amount Saved = -\$9000
 - Occurrence = 12 years
 - Annual Rate of Increase = 0 %
- Major Repair 3
 - Amount Saved = \$12 000
 - Occurrence = 18 years
 - Annual Rate of Increase = 0 %
- Scheduled Repair1
 - Amount Saved = -\$1500
 - Occurrence = 5 years
 - Annual Rate of Increase = 0 %
- Scheduled Repair2
 - Amount Saved = -\$1500
 - Occurrence = 10 years
 - Annual Rate of Increase = 0 %
- Scheduled Repair3
 - Amount Saved = -\$1500
 - Occurrence = 15 years
 - Annual Rate of Increase = 0 %
- Energy Costs
 - Electricity
 - 215 300 kWh
 - \$0.08711/kWh
 - DOE real electricity price escalation rates for industrial sector
 - No demand charge or annual utility rebates

Note that there are both positive and negative savings values because there are both avoided costs (positive savings) as well as additional costs (negative savings) associated with the project relative to the baseline.

These costs map to E3 BCN objects as shown in Tab. 4-36.

Table 4-36 BCN Object Values

VarName	Additional Investment Cost ^a	Routine OM&R	Major Repair1	Major Repair2 & Replacement	Major Repair3	Scheduled Repairs ^b	Electricity	Zero Baseline Cost ^c
altIds	1	1	1	1	1	1	1	0
id	0	1	2	3	4	5	6	7
type	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost
subType	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct
name	Additional Investment Cost	Routine OM&R	Major Repair1	Major Repair2 & Replacement	Major Repair3	Schedule Repairs	Electricity	Zero Baseline Cost
tags	Initial Investment	Routine OMR	Major Repair1	Major Repair2	Major Repair3	Scheduled Repairs	Energy	Initial Investment
initialOccurrence	0	2	7	13	19	6	2	0
real	true	true	true	true	true	true	true	true
invest	true	false	false	False	false	False	false	True
life	null	null	Null	Null	Null	Null	Null	Null
residualValue	false	false	false	false	false	false	false	False
residualValueOnly	false	false	false	false	false	False	false	false
recur	N/A	{"interval": 1, "varRate": "PERCENT_DELTA", "varRate": 0.02}	N/A	N/A	N/A	{"interval": 5, "end": 20}	{"interval": 1, "varRate": "PERCENT_DELTA", "varRate": [DOE Esc Rate List]}	N/A
valuePerQ	170 000	-2270	-9000	9000	-12 000	1500	0.08711	0
quantity	1	1	1	1	1	1	-215 300	1
quantityVarRate	Null	Null	Null	Null	Null	Null	null	Null
quantityVarValue	Null	Null	Null	Null	Null	Null	Null	Null
quantityUnit	Null	Null	Null	Null	Null	Null	kWh	Null

^aTotal Investment is used for Additional Investment Costs. Each cost line item could be included individually for greater results details.

^bScheduled Repairs are combined into a single recurring object. Each repair could be included individually if desired.

^cEach alternative requires at least one BCN object. Therefore, Zero Baseline Cost is included.

The occurrence dates in BLCC are based on initial occupancy (i.e., service date), which is one year after the base date. The scheduled repair does not occur in year 21 because the system is assumed to reach the end of its service life. The cost savings are included as negative costs in the BCN objects.

The results by line item from the E3 API were compared to the results in the BLCC reports in Tab. 4-37 to confirm consistency between E3 and BLCC. The ECIP Report in BLCC does not provide annual cash flows. Instead, it provides the discounted savings for each cost/savings item, which are all within 1.5 % of the BLCC results.

Table 4-37 Discounted Savings Comparison^a

Item	Discounted Savings - BLCC	Discounted Savings - E3
Total Investment	-\$170 000	-\$170 000
Energy and Water Savings	\$263 407	\$262 823
Routine OM&R	\$40 845	\$41 251
Major Repair1	\$7318	\$7427
Major Repair2 & Replacement	-\$6129	-\$6220
Major Repair3	\$6843	\$6945
Scheduled Repairs	-\$3275	-\$3323
Total Savings	\$139 010	\$138 903

^aBLCC reports Year 0 and Year 1 cash flows together. Here the results are broken down to how they are discounted.

The difference in the results is minimal (0.08 %) as shown in Tab. 4-38 and a result of rounding during the discounting and escalation calculations.

Table 4-38 Summary Results Comparison – MILCON ECIP Project

Measure	System Replacement - BLCC	System Replacement - E3
Net Savings^a	\$139 010	\$138 903
SIR Ratio	1.82	1.82
AIRR	5.97 %	5.97 %
SPP^b	7.95	9

^aDifferences in Total LCC is due to rounding during discounting and escalation calculations.

^bDPP not reported in BLCC.

Note: The results do not currently compare emissions reduction estimates. This could be completed by finding the source file within BLCC to obtain the emissions factors for each fuel type for Washington, DC and then adding non-monetary BCN objects with the same information as the electricity BCN objects except replacing the quantity and units. An example of this is available from the [PV]² example.

4.4.2. Economic Decision Guide Software (EDGE\$)

EDGE\$ – Economic Decision Guide Software – provides a standard economic methodology for evaluating investment decisions required to improve the ability of communities to adapt to, withstand, and quickly recover from natural, technology, and human-caused disruptive events. The tool helps the user to identify and compare the relevant present and future resilience costs and benefits associated with new capital investment versus maintaining a community's status-quo. Benefits include cost savings and damage loss avoidance because enhancing resilience on a community scale creates value, including co-benefits, even if a hazard event does not strike.

EDGE\$ is based on the process found in NIST's Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems (EDG). The EDG and EDGE\$ can be used as standalone tools but are designed as part of a more comprehensive planning process and in combination with the NIST Community Resilience Planning Guide for Buildings and Infrastructure Systems.

This tool has allowed for validation of the benefit-cost analysis calculations and all related economic measures/metrics in E3 (i.e., NPV cash flows for benefits and costs, net benefits (NB), and benefit-cost ratio (BCR)). Additionally, EDGE\$ allows validation of E3's continuous discounting methodology. Instead of calculating and adding to the principal at specific intervals as done in discrete discounting, continuous discounting uses a natural log-based formula to calculate and add back accrued interest at the smallest possible intervals. For additional details, please visit <https://www.nist.gov/services-resources/software/edge-economic-decision-guide-software-online-tool> to access both the EDG (<http://dx.doi.org/10.6028/NIST.SP.1197>) and EDGE\$ (<https://edges.nist.gov/>).

Three BCA examples were submitted manually to the E3 API to validate the BCA calculations for continuous discounting:

- Results comparisons to the EDGE\$ Web interface using continuous discounting
- Results comparisons to the EDGE\$ Web interface using continuous discounting with sensitivity and uncertainty estimates

The key assumption within the EDGE\$ software is that all costs are treated as investment costs. E3 provides the flexibility to define non-investment costs. For the examples below, all costs are defined as investment costs within the E3 calculations to provide a direct comparison to the results from EDGE\$.

4.4.2.1. Continuous Discounting

Examples are based on the BCA of different real world natural disasters that have been evaluated by AEO using the Economic Decision Guide and EDGE\$. The examples from EDGE\$ required modification because EDGE\$ uses continuous discounting, and therefore required modification to be complete as a deterministic analysis with discrete discounting. The examples were recreated and modified in Excel to provide the base results for which to compare and validate the BCA results generated by E3.

4.4.2.1.1. Hurricane Resilience

This example is based on the Buyout/Levee Case Study in Appendix B.2 of the Economic Decision Guide [28], which assumes that after a recent major flood, a city decides to adopt a flood mitigation strategy to reduce expected impacts of potential future flooding. Two mutually exclusive alternatives are considered: (1) buyout all properties in the 100-year floodplain and turn the area into greenspace or (2) build a 1.5-mile-long levee designed for a 100-year flood.

Assumptions for the benefit-cost analysis are as follows:

- Planning Horizon: 75 years
- Real Discount Rate: 5.00%
- Interest Rate: 5.00%
- Inflation Rate: 2.00%
- MARR: 4.00%
- Reinvestment Rate: 5.00 %
- Disaster Rate: Every 100 years
- Disaster Magnitude: 0 % of build cost
- Statistical Value of a Life: \$750 000⁶

This information maps to the E3 Analysis object as shown in Tab. 4-39:

⁶ Note that the statistical value of a life used in this example is different than in the other BCA examples and is for demonstration purposes only.

Table 4-39 Analysis Object Values

Var Name	Var Type	Format/Values	Req
type	String	BCA	X
projectType	String	Infrastructure	
objToReport	List of Strings	[required, measure]	X
studyPeriod	Int	75	X
timestepValue	String	Year	X
timestepComp	String	Continuous	X
outputReal	Boolean	True	X
interestRate	Float	Null	
discountRateReal	Float	0.05	X
discountRateNom	Float		
inflationRate	Float	0.02	X
marr	Float	0.04	X
reinvestRate	Float	0.05	X
federalIncomeRate	Float		
otherIncomeRate	Float		
numberOfAlternatives	Int	2	X
baseAlternative	Int	0	X
location	List of Strings	{"country": "United States", "state": "MD", "zipcode": "20879"}	

The mitigation measures are focused on a residential area with a high-risk of flooding within the 100-year flood plain. The area consists of 600 homes in total (average value of \$130 000), with 100 being considered waterfront properties (average value \$190 000). The buyout option would require all homes to be purchased, while the levee would require all 100 waterfront properties, and 100 additional properties, be purchased to make room for levee construction. Two hundred of the homes, including all homes in the levee construction area, are eligible for FEMA grants, which cover 75 % of the cost. The tax rate on all properties is 1.52 %. Regardless of the option, it is assumed that 25 % of the purchased homes do not return to the city's tax base.

Based on the benefit and cost information above, the benefits and costs of each alternative are shown in Tab. 4-40. Costs include initial investment costs associated with purchase and demolition of homes, direct and indirect design and construction costs of the mitigation strategy, and future OMR costs that are treated future investment costs with zero residual value (for consistency with EDGe\$ assumptions). Disaster related benefits include response and recovery costs, direct and indirect loss reductions, and reduced fatalities. Externalities can be both positive (benefits) and negative (costs). For this example, all externalities are treated as external benefits with externality costs defined as a negative external benefit to align with EDGe\$. The buyout leads to a large decrease in tax revenue while the levee leads to a smaller decrease in tax revenue while also flooding downstream of the levee, all of which are negative external benefits. Positive external benefits are only expected for the buyout option, including better stormwater management, value of greenspace, and increased visitation/tourism. Note

that the negative external benefits could be inputted as positive external costs and the results would remain the same.

Table 4-40 Benefits and Costs by Alternative

Desc.	Tag	Object Name	Recurr.	Sub-Type	Type	Buyout	Levee
Costs	Initial Inv	Purchase of Homes	One-time	Direct	Cost	\$59 897 500	\$31 590 000
Costs	Initial Inv	Demolition of Homes	One-time	Direct	Cost	\$5 400 000	\$2 400 000
Costs	Initial Inv	Greenspace Const.	One-time	Direct	Cost	\$200 000	
Costs	Initial Inv	Levee Design	One-time	Direct	Cost		\$2 250 000
Costs	Initial Inv	Levee Construction	One-time	Direct	Cost		\$15 000 000
Costs	Initial Inv	Indirect Costs	One-time	Indirect	Cost	\$1 680 000	\$4 500 000
Costs	OMR	OMR	Recurring	Direct	Cost	\$15 000	\$63 871
Benefits	DRB	Response & Recovery Loss Reduction	Recurring	Direct	Benefit	\$9713	\$20 813
Benefits	DRB	Total Direct Loss Reduction	Recurring	Direct	Benefit	\$2 198 382	\$2 198 382
Benefits	DRB	Indirect Loss Reduction	Recurring	Indirect	Benefit	\$88 800	\$94 350
Benefits	DRB	Fatalities Averted	Recurring	Indirect	Benefit	\$97 500	\$105 000
Externality	NDRB	Stormwater Management	Recurring	Externality	Benefit	\$200 000	
Externality	NDRB	Value of Greenspace	Recurring	Externality	Benefit	\$9880	
Externality	NDRB	Increase in Visitors	Recurring	Externality	Benefit	\$1 468 200	
Externality	NDRB	Downstream Flooding	Recurring	Externality	Benefit		-\$113 886
Externality	NDRB	Tax Revenue Loss	Recurring	Externality	Benefit	-\$367 042	-\$120 042

These costs map to E3 BCN objects as shown in Tab. 4-41 and Tab. 4-42:

Table 4-41 BCN Object Values – Buyout

VarName	Purchase of Homes	Structure Demolition	Greenspace Construction	Indirect Costs	Total OMR Costs	Stormwater Mgmt	Total Loss Reduction	Indirect Loss Reduction	Response & Recovery Loss Reduction	Fatalities Averted	Tax Revenue	Value of Greenspace	Increase in Visitors
altIds	0	0	0	0	0	0	0	0	0	0	0	0	0
id	0	1	2	3	4	5	6	7	8	9	10	11	12
type	Cost	Cost	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
subType	Direct	Direct	Direct	Indirect	Direct	Externality	Direct	Indirect	Direct	Indirect	Externality	Externality	Externality
name	Purchase of Homes Buyout	Structure Demolition Buyout	Greenspace Construction	Indirect Costs Buyout	Total OMR Buyout	Stormwater Mgmt	Total Loss Reduction Buyout	Indirect Loss Reduction Buyout	Res-Rec Loss Reduction Buyout	Fatalities Averted Buyout	Tax Revenue Buyout	Value of Greenspace	Increase in Visitors
tags	Initial Inv	Initial Inv	Initial Inv	Initial Inv	OMR	NDRB	DRB	DRB	DRB	DRB	NDRB	NDRB	NDRB
initialOccurrence	0	0	0	0	1	1	1	1	1	1	1	1	1
real	True	True	True	True	True	True	True	True	True	True	True	True	True
invest	True	True	True	True	True	False	False	False	False	False	False	False	False
life	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
residualValue	False	False	False	False	False	false	false	False	False	False	False	False	False
residualValueOnly	false	false	false	false	false	false	false	false	false	false	false	false	false
recur	N/A	N/A	N/A	N/A	{"interval": 1, "end": 75}	{"interval": 1, "end": 75}	{"interval": 1, "end": 75}	{"interval": 1}	{"interval": 1}	{"interval": 1}	{"interval": 1}	{"interval": 1}	{"interval": 1}
valuePerQ	59 897 500	5 400 000	200 000	1 680 000	15 000	200 000	2 198 381	88 800.216	9712.5245	97 500	-367 042	9880	9880
quantity	1	1	1	1	1	1	1	1	1	1	1	1	1
quantityVarRate	Null	Null	Null	Null	null	null	null	null	null	null	null	null	null
quantityVarValue	Null	Null	Null	Null	null	null	null	null	null	null	null	null	null
quantityUnit	null	null	null	null	null	null	null	null	null	null	null	null	null

Table 4-42 BCN Object Values – Levee

Variable Name	Purchase of Homes	Structure Demolition	Levee Design	Levee Construction	Indirect Costs	Total OMR Costs	Downstream Flooding	Total Loss Reduction	Indirect Loss Reduction	Response & Recovery Loss Reduction	Fatalities Averted	Tax Revenue
altIds	1	1	1	1	1	1	1	1	1	1	1	1
id	13	14	15	16	17	18	19	20	21	22	23	24
type	Cost	Cost	Cost	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
subType	Direct	Direct	Direct	Direct	Indirect	Direct	Externality	Direct	Indirect	Direct	Indirect	Externality
name	Purchase of Homes Levee	Structure Demolition Levee	Levee Design	Levee Construction	Indirect Costs Levee	Total OMR Costs Levee	Downstream Flooding Levee	Total Loss Reduction Levee	Indirect Loss Reduction Levee	Res-Rec Loss Reduction Levee	Fatalities Averted Levee	Tax Revenue Levee
tags	Initial Inv	Initial Inv	Initial Inv	Initial Inv	Initial Inv	OMR	NDRC	DRB	DRB	DRB	DRB	NDRC
initialOccurrence	0	0	0	0	0	1	1	1	1	1	1	1
real	true	true	true	true	true	true	true	true	true	true	true	true
invest	True	True	True	True	True	true	False	False	false	false	False	False
life	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
residualValue	False	False	False	False	False	False	false	false	False	False	False	False
residualValueOnly	false	false	false	false	false	false	false	false	false	false	false	false
recur	N/A	N/A	N/A	N/A	N/A	{“interval”: 1, “end”: 75}	{“interval”: 1, “end”: 75}	{“interval”: 1, “end”: 75}	{“interval”: 1}	{“interval”: 1}	{“interval”: 1}	{“interval”: 1}
valuePerQ	31 590 000	2 400 000	2 250 000	15 000 000	4 500 000	63 871	-113 886	219 8381.82	94 350.2295	20 812.5525	105 000	-120 042
quantity	1	1	1	1	1	1	1	1	1	1	1	1
quantityVarRate	Null	Null	Null	Null	Null	null	null	null	null	null	null	null
quantityVarValue	Null	Null	Null	Null	Null	null	null	null	null	null	null	null
quantityUnit	null	null	null		null	null	null	null	null	null	null	null

Table 4-43 shows the comparison of the E3 results to those from EDGe\$, which are identical because there are no rounding differences in the calculations as seen in the LCCA examples from BLCC. The only exception is the IRR, which have minimal differences due to the different calculation method implemented for the root-finding algorithm. For additional details on the assumptions and results of this example, please see the Economic Decision Guide User Manual [28].

Table 4-43 Summary Results Comparison – Hurricane Resilience

NPV	Buyout - EDGe\$	Buyout - E3	Levee - EDGe\$	Levee - E3
Total Benefits	\$70 571 714	\$70 571 714	\$41 607 055	\$41 607 055
Total Costs	\$67 463 182	\$67 463 182	\$56 956 453	\$56 956 453
Net Benefits	\$3 108 532	\$3 108 532	-\$15 349 398	-\$15 349 398
Benefit-to-Cost Ratio^a	1.05	1.05	0.73	0.73
IRR^b	4.8 %	5.3 %	3.6 %	3.5%

^a BCR calculation in EDGe\$ assumes all costs are investments

^b Differences in IRR due to differences in the IRR solver.

4.4.2.1.2. Riverbend Flooding

This example is based on the case study in Sec. 3.2 of the EDGe\$ User Manual [28] that considers the benefits and costs of earthquake impact mitigation strategies for Riverbend, a small city of 50 000 people located in a valley along Central River, and the neighboring city of Fallsborough. The two cities are linked by a four-lane interstate bridge that represents the only route for traffic into the city. The bridge routinely fails to meet the traffic demand during peak hours and is sensitive to earthquake events.

Therefore, two alternatives are being considered to increase community resilience against seismic event hazards: (1) retrofit the existing bridge or (2) construct a new bridge. Consideration of seismic events was driven by the known hazards in the region and the potential loss of life, infrastructure damage, and economic impacts if a disaster occurs.

This example assumes the following:

- Planning Horizon: 50 years
- Real Discount Rate: 3.00%
- Interest Rate: 3.00%
- Inflation Rate: 2.00%
- MARR: 4.00%
- Reinvestment Rate: 5.00 %
- Disaster Rate: Every 25 years

- Disaster Magnitude: 0 % of build cost
- Statistical Value of a Life: \$ 7 500 000

This information maps to the E3 Analysis object as shown in Tab. 4-44:

Table 4-44 Analysis Object Values

Var Name	Var Type	Format/Values	Req
type	String	BCA	X
projectType	String	Infrastructure	
objToReport	List of Strings	[required, measure]	X
studyPeriod	Int	50	X
timestepValue	String	Year	X
timestepComp	String	Continuous	X
outputReal	Boolean	True	X
interestRate	Float	0.03	
discountRateReal	Float	0.03	X
discountRateNom	Float	Null	
inflationRate	Float	0.02	X
marr	Float	0.04	X
reinvestRate	Float	0.05	X
federalIncomeRate	Float	0.26	
otherIncomeRate	Float	0.26	
numberOfAlternatives	Int	2	X
baseAlternative	Int	0	X
location	List of Strings	{"country": "United States", "state": "MD", "zipcode": "20879"}	

The existing bridge is scheduled and budgeted for a deck replacement in 10 years, creating an opportunity to upgrade the bridge to be more resilient to seismic events. To upgrade the bridge, it must be closed to emergency services and regular traffic. There are additional vehicle-hours from rerouting as well as impacts on emergency vehicles. Heavier traffic on alternative routes will decrease the life of those roads.

The new bridge would be built with an offset alignment from the original bridge and according to current seismic codes and a design life of 125 years. The original bridge would remain in service but would no longer be useable should a seismic event occur, pushing all traffic to be maintained by the new bridge. Sharing traffic between the bridges will reduce traffic during peak hours that would benefit long-term economic development. Apart from the immediate benefits, the new bridge would be used to carry traffic when the old bridge eventually needs to be replaced and provide pedestrian access.

The benefits and costs of each alternative are shown in Tab. 4-45. Costs include initial investment costs and future recurring OMR costs treated as investment costs with zero residual value (for consistency with EDGe\$) of the alternative. Disaster related benefits include response and recovery costs, direct and indirect loss reductions, and reduced

fatalities. For this example, there are no externalities for the retrofit option while there are positive benefits of the new bridge including reductions in greenhouse gas and water pollution, reduced commute times, and improved community linkage.

Table 4-45 Benefits and Costs by Alternative

Desc.	Tag	Object Name	Recurr.	Sub-Type	Type	Retrofit	New Bridge
Costs	Initial Inv	Direct Cost	One-time	Direct	Cost	\$3 000 000	
Costs	Initial Inv	Indirect Cost	One-time	Indirect	Cost	\$500 000	
Costs	Initial Inv	Additional Roadwork Direct Cost	One-time	Direct	Cost		\$2 500 000
Costs	Initial Inv	Bridge Construction Direct Cost	One-time	Direct	Cost		\$4 250 000
Costs	Initial Inv	Additional Roadwork Indirect Cost	One-time	Indirect	Cost		\$120 000
Costs	Initial Inv	Bridge Construction Indirect Cost	One-time	Indirect	Cost		\$175 000
Costs	OMR	Additional Roadwork OMR	Recurring	Direct	Cost		\$3 710
Costs	OMR	New Bridge OMR	Recurring	Direct	Cost		\$25 000
Benefits	DRB	Indirect Loss Reduction	One-time	Indirect	Benefit	\$80 000	\$140 000
Benefits	DRB	Direct Loss Reduction	One-time	Direct	Benefit	\$10 400	
Benefits	DRB	Response and Recovery	Recurring	Direct	Benefit	\$24 000	\$40 000
Benefits	DRB	Fatalities Averted	Recurring	Indirect	Benefit	\$30 000	\$60 000
Externalities	NDRB	Greenhouse Gas Emissions	Recurring	Externality	Benefit		\$77 329
Externalities	NDRB	Water Pollution	Recurring	Externality	Benefit		\$39 081
Externalities	NDRB	Better Linking of Communities	Recurring	Externality	Benefit		\$39 799
Externalities	NDRB	Reduced Commute Time	Recurring	Externality	Benefit		\$100 000

These costs map to E3 BCN objects as shown in Tab. 4-46 and Tab. 4-47:

Table 4-46 BCN Object Values – Retrofit

VarName	Direct Cost	Indirect Costs	Indirect Loss Reduction	Direct Loss Reduction	Response & Recovery	Fatalities Averted
altIds	0	0	0	0	0	0
id	0	1	2	3	4	5
type	Cost	Cost	Benefit	Benefit	Benefit	Benefit
subType	Direct	Indirect	Indirect	Indirect	Direct	Indirect
name	Retrofit Direct Cost	Retrofit Indirect Cost	Retrofit Indirect Loss Reduction	Retrofit Direct Loss Reduction	Retrofit Response and Recovery	Fatalities Averted Retrofit
tags	Initial Investment	Initial Investment	DRB	DRB	DRB	DRB
initialOccurrence	0	0	1	1	1	1
real	true	true	true	true	true	true
invest	True	True	false	false	false	False
life	Null	Null	Null	Null	Null	Null
residualValue	False	False	False	False	False	False
residualValueOnly	false	false	false	false	false	false
recur	N/A	N/A	{"interval": 1, "end": 50}	{"interval": 1, "end": 50}	{"interval": 1}	{"interval": 1}
valuePerQ	3 000 000	500 000	80 000	80 000	24 000	30 000
quantity	1	1	1	1	1	1
quantityVarRate	Null	Null	null	null	null	null
quantityVarValue	Null	Null	null	null	null	null
quantityUnit	null	null	null	null	null	null

Table 4-47 BCN Object Values – New Bridge

VarName	Add. Roadwork	Bridge Const.	Add Roadwork Indirect Cost	Bridge Const. Indirect Cost	Additional Roadwork OMR	New Bridge OMR	Greenhouse Gas Emissions	Water Pollution	Better Linking of Comm.	Bridge Indirect Loss Red.	Response & Recovery	Fatalities Averted	Reduced Commute Time
altIds	1	1	1	1	1	1	1	1	1	1	1	1	1
id	6	7	8	9	10	11	12	13	14	15	16	17	18
type	Cost	Cost	Cost	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
subType	Direct	Direct	Indirect	Indirect	Direct	Direct	Externality	Externality	Externality	Indirect	Direct	Indirect	Externality
name	Additional Roadwork Direct Cost	Bridge Const. Direct Cost	Additional Roadwork Indirect Cost	Bridge Const. Indirect Cost	Additional Roadwork OMR	New Bridge OMR	Greenhouse Gas Emissions	Water Pollution	Better Linking of Comm.	Bridge Indirect Loss Red.	New Bridge Response and Recovery	New Bridge Fatalities Averted	Reduced Commute Time
tags	Initial Inv	Initial Inv	Initial Inv	Initial Inv	OMR	OMR	NDRB	NDRB	NDRB	DRB	DRB	DRB	NDRB
initialOccurrence	0	0	0	0	1	1	1	1	1	1	1	1	1
real	true	true	true	true	true	true	true	true	true	true	true	true	true
invest	True	True	True	True	true	true	False	False	False	false	false	False	False
life	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
residualValue	False	False	False	False	False	False	false	false	false	False	False	False	false
residualValueOnly	false	false	false	false	false	false	false	false	false	false	false	false	false
recur					{"interval": 1, "end": 50}	{"interval": 1, "end": 50}	{"interval": 1, "end": 50}	{"interval": 1, "end": 50}	{"interval": 1, "end": 50}	{"interval": 1, "end": 50}	{"interval": 1, "end": 50}	{"interval": 1, "end": 50}	{"interval": 1, "end": 50}
valuePerQ	2 500 000	4 250 000	120 000	175 000	3710	25 000	77 329	39 081	39 799	140 000	40 000	60 000	100 000
quantity	1	1	1	1	1	1	1	1	1	1	1	1	1
quantityVarRate	Null	Null	Null	Null	null	null	null	null	null	null	null	null	null
quantityVarValue	Null	Null	Null	Null	null	null	null	null	null	null	null	null	null
quantityUnit	null	null	null	null	null	null	null	null	null	null	null	null	null

The results from E3 are identical to the EDGe\$-based calculations as shown in Tab. 4-48 because there are no differences from rounding as seen in the BLCC examples for LCCA. For additional details on the assumptions and results of this example, please see the Economic Decision Guide User Manual [28].

Table 4-48 Summary Results Comparison – Riverbend Flooding

NPV	Retrofit - EDGe\$	Retrofit - E3	New Bridge - EDGe\$	New Bridge - E3
Total Benefits	\$3 683 524	\$3 683 524	\$12 657 879	\$12 657 879
Total Costs	\$3 500 000	\$3 500 000	\$7 777 368	\$7 777 368
Net Benefits	\$183 523	\$183 523	\$4 880 511	\$4 880 511
Benefit-to-Cost Ratio	1.052	1.052	1.63	1.63

4.4.2.1.3. Wildland Urban Interface (WUI)

This example is based on the case study in Appendix B.3 of the EDGe\$ User Manual [28] that considers the benefits and costs of reducing the recurrence rate of a disaster using wildfire hazard management practices.

Assume several towns in a WUI area recently had a wildland fire burn near them with minimal impacts (minor smoke issues, no evacuation, no reported health impacts or property damage). The fire ended when a large rainstorm passed through. In examining the impacts of the fire, one major issue was that it burned a riparian forest, which led to a large amount of runoff into the local river. The town relies on this river for drinking water, and the large amount of runoff has caused substantial issues with their water treatment plant.

Worried that a larger fire could inhibit the ability of the treatment plant to provide water, a proposal was put forward that the towns should seek assistance in managing the forest in their area. This would include an organized reconstruction (reseeding and run-off barriers) of the riparian forest and management (prescribed burns) of adjacent forested areas to lessen the chances of a wildfire. Because initial reseeding must occur regardless of whether mitigation plans are implemented, only the reduction in reseeding cost in the future need to be entered into the analysis.

The baseline is to do nothing, and therefore has zero costs or benefits associated with this alternative. The alternative is to implement mitigation strategies designed to reduce the likelihood wildland urban interface (WUI) fires.

This example assumes the following:

- Planning Horizon: 50 years
- Real Discount Rate: 4.00%
- Interest Rate: 3.00%
- Inflation Rate: 2.00%
- MARR: 4.00%

- Reinvestment Rate: 5.00 %
- Disaster Rate: Every 25 years
- Disaster Magnitude: 0 % of build cost
- Statistical Value of a Life: \$750 000

This information maps to the E3 Analysis object as shown in Tab. 4-49:

Table 4-49 Analysis Object Values

Var Name	Var Type	Format/Values	Req
type	String	BCA	X
projectType	String	Infrastructure	
objToReport	List of Strings	[required, measure]	X
studyPeriod	Int	50	X
timestepValue	String	Year	X
timestepComp	String	Continuous	X
outputReal	Boolean	True	X
interestRate	Float	0.03	
discountRateReal	Float	0.05	X
discountRateNom	Float		
inflationRate	Float	0.02	X
marr	Float	0.04	X
reinvestRate	Float	0.05	X
federalIncomeRate	Float	Null	
otherIncomeRate	Float	null	
numberOfAlternatives	Int	2	X
baseAlternative	Int	0	X
location	List of Strings	{"country": "United States", "state": "MD", "zipcode": "20879"}	

The benefits and costs of WUI management plan are shown in Tab. 4-50. Costs include initial investment costs and OMR costs treated as investment costs with zero residual value (for consistency with EDGe\$). Benefits include sludge removal cost, water treatment cost, reseeding cost, and indirect loss reductions. Externalities can be both positive (benefits) and negative (costs) and can be one-time or recurring impacts. In this example, there are one-time external benefits for improved river health and a recurring external cost of lost recreational value from limitation on access to the forested area, which are treated as a negative benefit to align with the EDGe\$ example. Note that this value could also be inputted as a positive cost and obtain the same results.

Table 4-50 Benefits and Costs by Alternative^a

Desc.	Tag	Object Name	Recurr.	Sub-Type	Type	Mitigation
Costs	Initial Inv	Straw Wattles	One-time	Direct	Cost	\$6 250 860
Costs	Initial Inv	Indirect Costs	One-time	Indirect	Cost	\$625 086
Costs	OMR	Total OMR costs	Recurring	Direct	Cost	\$28 430
Benefits	DRB	Sludge removal cost reduction	Recurring	Direct	Benefit	\$68 000
Benefits	DRB	Water Treatment Chemical Cost Reduction	Recurring	Direct	Benefit	\$3343
Benefits	DRB	Reseeding Cost Reduction	Recurring	Direct	Benefit	\$7200
Benefits	DRB	Indirect Loss Reduction	Recurring	Indirect	Benefit	\$23 543
Externality	NDRB	Increased River Health (Watershed)	One-time	Externality	Benefit	\$3 780 000
Externality	NDRB	Increased River Health (Salmon)	One-time	Externality	Benefit	\$4 620 000
Externality	NDRB	Recreational Value	Recurring	Externality	Benefit	-\$51 850

^aBase Case is zero benefits and costs

These costs map to E3 BCN objects as shown in Tab. 4-51:

Table 4-51 BCN Object Values – Mitigation

VarName	Straw Wattles	Indirect Costs	Total OMR Costs	Indirect Loss Reduction	Sludge Removal Cost	Water Treatment Chemical Cost	Re seeding	Recreational Value	River Health (Salmon)	River Health (Watershed)
altIds	1	1	1	1	1	1	1	1	1	1
id	0	1	2	3	4	5	6	7	8	9
type	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
subType	Direct	Indirect	Direct	Indirect	Direct	Direct	Direct	Externality	Externality	Externality
name	Straw Wattles	Indirect Costs	Total OMR Costs	Indirect Loss Reduction	Sludge Removal Cost	Water Treatment Chemical Cost	Re seeding	Recreational Value	River Health (Salmon)	River Health (Watershed)
tags	Null	null	OMR	DRB	DRB	DRB	DRB	NDRB	NDRB	NDRB
initialOccurrence	0	0	1	1	1	1	1	1	1	1
real	true	true	true	true	true	true	true	true	true	true
invest	True	True	true	false	false	false	false	False	False	False
life	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
residualValue	False	False	False	False	False	False	False	False	False	False
residualValueOnly	false	false	false	false	false	false	false	false	false	false
recur	N/A	N/A	{"interval": 1}	{"interval": 1}	{"interval": 1}	{"interval": 1}	{"interval": 1}	{"interval": 1}	N/A	N/A
valuePerQ	6 250 860	625 086	28 430	23 543.2	68 000	3343.04	7200	51 850	4 620 000	3 780 000
quantity	1	1	1	1	1	1	1	1	1	1
quantityVarRate	Null	Null	null	null	null	null	null	null	null	null
quantityVarValue	Null	Null	null	null	null	null	null	null	null	null
quantityUnit	null	null	null	null	null	null	null	null	null	null

The results from E3 are identical to the EDGe\$ calculations as shown in Tab. 4-52. For additional details on the assumptions and results of this example, please see the Economic Decision Guide User Manual [28]. Note that if the user desires calculation of supplemental measure results with and without externalities, it is necessary to submit two JSON strings to E3.

Table 4-52 Summary Results Comparison - WUI

Measure (NPV)	Mitigation - EDGe\$	Mitigation - E3
Total Benefits	\$7 380 709	\$7 380 709
Total Costs^a	\$7 015 776	\$7 015 776
Net Benefits	\$364 934	\$364 934
Benefit-to-Cost Ratio	1.05	1.05
IRR	4.79 %	4.6 %

^aAssumes all costs are investments.

4.4.2.2. Continuous Discounting with Sensitivity

This uses the same example from Sec. 4.5.2.1.3 (WUI) but adds sensitivity objects to see the variability of the discount rate (a global variable) as well as the value per quantity for two BCN objects (non-global variables) to validate a percent and gross change to the value.

Table 4-53 and Tab. 4-54 show the results from the two sensitivity analyses. First, increase the discount rate from 3 % to 6 % (increase quantity value by “gross” “0.03”). The increase in the real discount rate from 3 % to 6 % leads to future benefits and costs decreasing in net present value terms and lowering the net benefits as shown in Tab. 4-53.

Table 4-53 Summary Results Comparison – Riverbend Flooding with Sensitivity – Discount Rate (Global Variable)

NPV	Retrofit - 3 %	Retrofit - 6 %	New Bridge - 3 %	New Bridge - 6 %
Total Benefits	\$3 683 524	\$2 218 926	\$12 657 879	\$7 625 009
Total Costs	\$3 500 000	\$3 500 000	\$7 777 368	\$7 486 173
Net Benefits	\$183 524	-\$1 281 074	\$4 880 511	\$138 835
Benefit-to-Cost Ratio	1.052	0.63	1.63	1.02

Second, double the cost of the bridge (increase quantity value by “percent” of “100.0”). Doubling the initial direct costs of constructing the new bridge leads to a direct decrease in net benefits equivalent to the incremental increase in construction costs as shown in Tab. 4-54.

Table 4-54 Summary Results Comparison – Riverbend Flooding with Sensitivity – New Bridge Construction Costs

NPV	Retrofit - Original	New Bridge - Original	New Bridge - 0.5x New Bridge Cost	New Bridge - 2x New Bridge Cost
Total Benefits	\$3 683 524	\$12 657 879	\$12 657 879	\$12 657 879
Total Costs	\$3 500 000	\$7 777 368	\$ 5 652 368	\$ 12 027 368
Net Benefits	\$183 523	\$4 880 511	\$7 005 510	\$630 510
Benefit-to-Cost Ratio	1.052	1.63	2.24	1.05

4.4.3. WUI Example with Uncertainty

Uncertainty calculations are a new feature of E3 Version 2. To illustrate the process for using and interpreting uncertainty calculations an additional example has been constructed. **Note:** The values used for this example are pulled from a myriad of sources, some of which are highly generalized. Furthermore, several assumptions were made that are, at best, weakly defensible and certain aspects of the uncertainty characterization are vastly oversimplified and/or done for the convenience of providing an easy-to-follow example. As such the results herein should only be treated as an illustrative example for E3 and not a realistic analysis of the examples framing.

4.4.3.1. Input Data

This example relates to the Camp Fire that occurred in California in 2018. As part of the aftermath of that event the California Resilience Challenge funded a report on the effectiveness of mitigation measures on reducing fire risk and insurance premiums [29]. The report also calculated the annual average losses (AAL) for a multitude of mitigation scenarios. These AAL estimates and their associated mitigation measures are used as the basis for this example.

A total of eight different scenarios are presented in the report but we will focus on three for the sake of brevity and presentability of the results:

1. Baseline – No additional mitigation
2. Base mitigation
 - a. Class A Roof
 - b. 5-30 feet – Reduced Fuel Zone 2 (Lean, Clean and Green)
 - c. 30-100 feet – Reduced Fuel Zone 3
 - d. Default Fire Resistant Siding
 - e. Combustible Attachments Allowed
 - f. Fire-resistant Windows Not Required
3. Plus Mitigation
 - a. Requires everything from Base Mitigation except:

- i. An additional 0-5 foot noncombustible zone
- ii. Fire resistant siding is required.
- iii. No combustible attachments allowed.
- iv. Fire resistant windows required.

In examining these scenarios, the report finds AALs of \$23.900 million for the baseline, \$11.259 million for the Base Mitigation and \$7.867 million for the Plus mitigation. These values will serve as benefits in the analysis. The analysis then will be a cost benefit analysis of the AAL of the three alternatives against the additional construction costs associated with the mitigation measures.

The costs for the mitigation measures are not given in the report. As such estimates are derived from other sources. All values are per house.

1. Cost of Class A Roof construction – \$27 670 vs typical (\$21 810) [30].
2. Cost of creating noncombustible zone - \$1642 (Single Story) to \$2882 (two-story) [31]. This example uses the average of these values. It will be assumed the baseline is no action and therefore the cost for it is zero.
3. Reduced Fuel Zones 2 and 3 – No good sources were found for what specific actions should be taken so the gravel component of the noncombustible was removed from the calculation. Resulting value is \$903 to \$2337 [31]. This example uses the average of these values. It will be assumed the baseline is no action and therefore the cost for it is zero.
4. Fire Resistant Siding – \$24 300 (Mean of range) vs typical (\$29 930) [30]. We will assume the difference between default fire resistant siding and required fire resistant siding is the percentage of homes that use it. For illustration purposes we will assume default only has 50 % of homes covered.
5. Windows – \$11 530 vs typical (\$8 470) [30].
6. Combustible Attachments – These include overhangs, awnings, sunshades or other combustible elements. No good sources for either prevalence or cost was found for non-combustible options versus standard ones. For the sake of this example, we will simply assume that any overhangs are from a Class A roof and the difference in cost for any sunshades or awnings is entirely based on the fabric used. Based on an estimated cost range of \$300 to \$600 for awning material [32] we will assume that non-combustible awning fabric is on the high side (~\$600) and the base line will use the median value of the cost (~\$450). It will be assumed each home has only one awning.

Lastly, the building inventory is needed to find aggregate cost of each mitigation measure. The report that the AAL values is based on focused on the Town of Paradise, California. As such we will take their building stock destroyed by the Camp Fire (roughly 18 000 structures) and assume uniformity in building design for the sake of this example. Furthermore, we will assume all buildings are new construction and the town builds back to its pre-fire condition.

4.4.3.2. Uncertainty

The uncertainty for this example will come from two places, uncertainty in the costs of mitigation and uncertainty in the AAL. We will assume that the baseline home has no uncertainty associated with it for simplification purposes. As such we will be using relative costs. For some of the distributions chosen for this example we can simply shift the distributions along the price axis without affecting the uncertainty characterization, however it is important to note that certain distributions require alternate means of accounting for such alterations.

As an aside, cases where the baseline is uncertain require different considerations. In order to relative costs where the baseline is uncertain, we would need to find the distribution representing the relative difference for certain variables, which is not always an easy task. It is often times simpler to keep all values in absolute terms and simply assign the baseline to the appropriate alternative. This will automatically account for the baseline's uncertainty relative to the other alternatives in the simulation process.

4.4.3.2.1. Mitigation Construction Uncertainty

Using information on ranges provided in [31] allow for an estimate of the creation of noncombustible and reduced fuel zones. For the fire-resistant siding the distribution is also assumed uniform (min – \$(23 620), max - \$36 240) while the standard deviation for the difference in cost for windows is \$51.67 [31]. We will assume that window prices follow a uniform distribution with the given standard deviation. For simplicity, the noncombustible attachment will be treated as rectangular distributions (\$450 to \$600 for noncombustible). Lastly, values taken from [31] are used to generate the triangular distribution for Class A roof construction (min - \$23 310, mode - \$27 670, max - \$55 150).

4.4.3.2.2. Average Annual Losses Uncertainty

Using the OEP curves from [29] we will assume the maximum range for AAL percent reduction when looking at mitigation ranges. We will assume the baseline is deterministic to simplify the understanding of the example. The Base Mitigation reduction range is from approximately 29 % to 75 % (reduction in AAL is 53 %) and for Pule Mitigation it ranges from 38 % to 88 % (reduction in AAL is 68 %) based on return period for the fire. Triangular distributions will be used.

4.4.3.3. E3 Input

Table 4-55 contains the Analysis object information for the example, while Tab. 4-56 and Tab. 4-57 contain the BCN object information. Note that the BCN objects have the number of houses (18 000) baked into the *quantity* variable. Alternatively, the *quantity* variable could simply be the monetary value of each BCN object per house and the *quantityValue* could be the number

of houses. Alternative objects are not shown. The Uncertainty object information is provided in Tab. 4-58. All tables have unused optional variables suppressed.

Table 4-55 Analysis Object Values

Variable	Value
type	"LCCA"
projectType	"BUILDING"
outputObjects	["measure", "uncertainty"]
studyPeriod	50
timestepValue	"Year"
timestepComp	"End_Of_Year"
outputReal	true
interestRate	0.03
discountRateReal	0.03
inflationRate	0.02
marr	0.04
reinvestRate	0.03
federalIncomeRate	0.26
otherIncomeRate	0.26
location	{ city: "Maryland", zipcode: "20879" }
numberOfAlternatives	3
baseAlternative	2

Table 4-56 BCN Object Values (0 through 4)⁷

Variable	Class A Roof	Non-Combustible Zone	Reduced Fuel Zones 2 and 3	Default Fire Resistant Siding	Full Fire-Resistant Siding
id	0	1	2	3	4
altIds	[0,1]	[1]	[0,1]	[0]	[1]
type	"Cost"	"Cost"	"Cost"	"Cost"	"Cost"
subType	"Direct"	"Direct"	"Direct"	"Direct"	"Direct"
name	"Class A Roof"	"Non-Combustible Zone"	"Reduced Fuel Zones 2 and 3"	"Default Fire Resistant Siding"	"Full Fire-Resistant Siding"
initialOccurrence	0	0	0	0	0
real	true	true	true	true	true
invest	true	true	true	true	true
residualValue	false	false	false	false	false
residualValueOnly	false	false	false	false	false
recur	N/A	N/A	N/A	N/A	N/A
quantityValue	1	1	1	1	1
quantity	105 480 000	40 716 000	29 160 000	-50 670 000	-101 340 000

Table 4-57 BCN Object Values (5 through 9)⁸

Variable	Fire-Resistant Windows	Non-Combustible Attachments	AAL Reduction – Base Mitigation	AAL Reduction – Plus Mitigation	Zero Baseline
id	5	6	7	8	9
altIds	[1]	[1]	[0]	[1]	[2]
type	"Cost"	"Cost"	"Benefit"	"Benefit"	"Cost"
subType	"Direct"	"Direct"	"Direct"	"Direct"	"Direct"
name	"Fire Resistant Windows"	"Non-Combustible Attachments"	"AAL Reduction - Base Mitigation"	"AAL Reduction - Plus Mitigation"	"Zero Baseline"
initialOccurrence	0	0	1	1	0
real	true	true	true	true	true
invest	true	true	false	false	true
residualValue	false	false	false	false	false
residualValueOnly	false	false	false	false	false
recur	N/A	N/A	{"interval": 1}	{"interval": 1}	N/A
quantityValue	1	1	1	1	1
quantity	55 080 000	1 350 000	12 641 000	16 033 000	0

⁷ Spaces in "quantity" values are there for NIST format and should be suppressed in program input.

⁸ Spaces in "quantity" values are there for NIST format and should be suppressed in program input.

Table 4-58 Uncertainty Object Values⁹

Uncertainty Sub-Object	Variable	Value
N/A	id	0
N/A	seed	2658
Uncertainty item 1	variable	"bcnObjects.0.quantity"
Uncertainty item 1	distribution	"Triangular"
Uncertainty item 1	distributionArgs	[27 000 000, 105 480 000, 600 120 000]
Uncertainty item 2	variable	"bcnObjects.1.quantity"
Uncertainty item 2	distribution	"Rectangular"
Uncertainty item 2	distributionArgs	[29 556 000, 51 876 000]
Uncertainty item 3	variable	"bcnObjects.2.quantity"
Uncertainty item 3	distribution	"Rectangular"
Uncertainty item 3	distributionArgs	[16 254 000, 42 066 000]
Uncertainty item 4	variable	"bcnObjects.3.quantity"
Uncertainty item 4	distribution	"Rectangular"
Uncertainty item 4	distributionArgs	[-107 460 000, 6 120 000]
Uncertainty item 5	variable	"bcnObjects.4.quantity"
Uncertainty item 5	distribution	"Rectangular"
Uncertainty item 5	distributionArgs	[-214 920 000, 12 240 000]
Uncertainty item 6	variable	"bcnObjects.5.quantity"
Uncertainty item 6	distribution	"Rectangular"
Uncertainty item 6	distributionArgs	[53 469 088.8, 56 690 911.2]
Uncertainty item 7	variable	"bcnObjects.6.quantity"
Uncertainty item 7	distribution	"Rectangular"
Uncertainty item 7	distributionArgs	[0, 2 700 000]
Uncertainty item 8	variable	"bcnObjects.7.quantity"
Uncertainty item 8	distribution	"Triangular"
Uncertainty item 8	distributionArgs	[6 931 000, 12 641 000, 17 925 000]
Uncertainty item 9	variable	"bcnObjects.8.quantity"
Uncertainty item 9	distribution	"Triangular"
Uncertainty item 9	distributionArgs	[9 082 000, 16 033 000, 21 032 000]

4.4.3.4. Results

The results of the uncertainty analysis are presented in Tab. 4-59. Because of the uncertainty calculations results now include a mean and standard deviation output. E3 does not currently support prediction/confidence intervals for the uncertainty output, although they are planned for a future release. The uncertainty calculations use a Monte Carlo simulation process that terminates when multiple key variables have a successive mean calculation of their simulation cycles at less than 0.1 % or at 50 000 simulation cycles if there is no convergence. At present there is no option to alter the maximum number of runs in E3 though this will be included in a future version.

⁹ Spaces in "quantity" values are there for NIST format and should be suppressed in program input.

Table 4-59 Uncertainty Results

Variable	Base Mitigation - Mean	Base Mitigation - Standard Deviation	Plus Mitigation - Mean	Plus Mitigation - Standard Deviation
totalBenefits	\$318 729 571	\$57 705 486	\$411 506 615	\$64 110 343
totalCosts	\$217 109 024	\$124 497 173	\$262 441 929	\$137 454 883
totalCostsInvest	\$217 109 024	\$124 497 173	\$262 441 929	\$137 454 883
totalCostsNonInvest	\$0	\$0	\$0	\$0
netBenefits	\$101 620 547	\$138 092 706	\$149 064 687	\$150 433 420
netSavings	-\$217 109 024	\$124 497 173	-\$262 441 929	\$137 454 883
sir	NaN	NaN	NaN	NaN
irr	0.084	0.095	0.091	0.106
airr	NaN	NaN	NaN	NaN
dpp	NaN	NaN	NaN	NaN
spp	NaN	NaN	NaN	NaN
bcr	NaN	NaN	NaN	NaN

Looking at Tab. 4-59 we can see that there are numerous variables that are returning “NaN”. If we look at the deterministic analysis in Tab. 4-60 we can see that those variables do have values. When running an uncertainty analysis there is the potential that a simulation cycle may return a value outside the range of allowable values. E3 catches these and assigns them “NaN” in the output. During the calculation of the final mean and standard deviation of the output if there are any “NaN” values in the output list then the mean and standard deviation will also be “NaN”. This is intentional. Any mean reported without the “NaN” cycles would be conditional on a valid value existing. To avoid misleading results in the analysis only non-conditional means and standard deviation of are reported.

Table 4-60 Results using Deterministic Analysis

Variable	Base Mitigation - Value	Plus Mitigation - Value
totalBenefits	\$325 249 947	\$428 558 306
totalCosts	\$83 970 000	\$130 446 000
totalCostsInvest	\$83 970 000	\$130 446 000
totalCostsNonInvest	\$0	\$0
netBenefits	\$241 279 947	\$298 112 306
netSavings	-\$83 970 000	-\$130 446 000
sir	0	0
irr	0.15	0.14
airr	0.058	0.055
dpp	Infinity	Infinity
spp	Infinity	Infinity
bcr	3.873	3.285

Interpreting the results can be as simple as selecting the alternative with the highest mean for the measure of interest, however this ignores the effects of the standard deviation¹⁰. Since the results now represent a distribution of possible results some analysis may need to be done looking at the spread of the potential outcomes. Considering that the calculation of net benefits and net savings under uncertainty can be considered sums of independent random variables (E3 does not allow for dependency as of yet), the central limit theorem (CLT) may apply in certain cases. The CLT classically states that the sum of n independent and identically distributed random variables will generally approach a normal distribution, provided that the variance of the distribution is finite. While the CLT is stated for independent and identically distributed variables. It also generally holds for non-identically distributed variables provided that no individual variable dominates the sum.

While care should be taken in using CLT in any formal analysis it does hold in this instance, so we may use it to check for stochastic dominance. Stochastic dominance is a means of determining whether one random variable is more likely to exceed another random variable. For the purposes of this case, we may consider an alternative to be stochastically dominant if the normal distribution of one alternative's net benefits distribution is more likely to exceed the normal distribution of the other's net benefits distribution. There are three orders of stochastic dominance, we will focus on first and second order as they are the most commonly used. First order stochastic dominance applies when the cumulative distribution function (CDF) of one distribution exceeds the cumulative distribution of the other for all values of x or $F_A(x) \leq F_B(x)$ for all x . Second order stochastic dominance requires that the distribution $D(x) = \int_{min}^x (F_B(x) - F_A(x))dx \geq 0$ for all x .

Plotting the CDFs for the example results in Fig. 4-1. From the figure the Plus Mitigation option is stochastically dominant over the Base Mitigation option in terms of Net Benefits. It is also possible to compare the probability that each option will exceed a certain value of net benefits. For instance, there may be a specific net benefit value, assumed \$350 000 000, that is of interest. Using the CDFs, we can determine that the probability that the given net benefits will be exceeded is 0.036 and 0.091 for the Base and Plus Mitigation options, respectively.

¹⁰ This remainder of this section is not necessary for proper use of E3 and is only meant to show the extension of E3's results to additional analysis. It assumes familiarity with probability theory that is not required for use of E3.

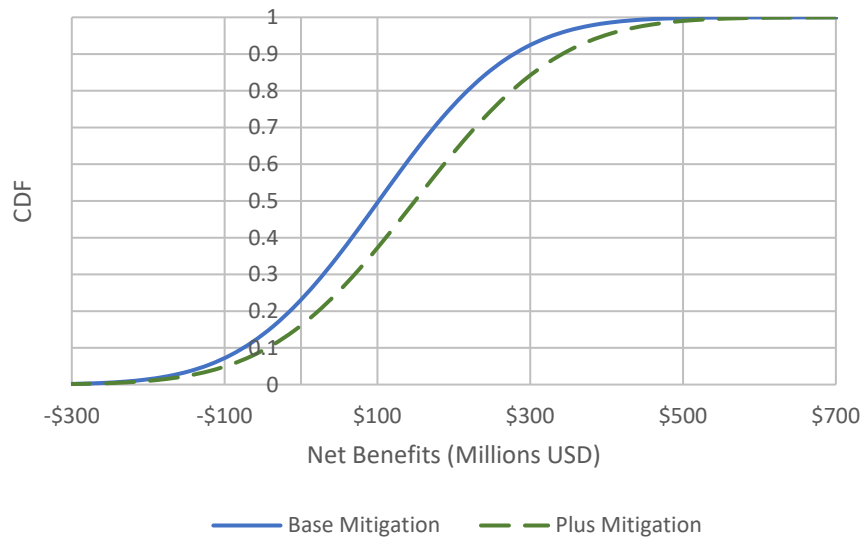


Figure 4-1 Plot of Normal CDFs for WUI Example with Uncertainty

4.4.4. Sustainable Manufacturing

NIST Advanced Manufacturing Series 200-11 [33] “presents techniques for evaluating manufacturing investments from the perspective of environmentally sustainable manufacturing by pairing economic methods of investment analysis with environmental aspect of manufacturing, including manufacturing processes.” Example 10 in [33] provides analysis of multiple investment alternatives across a range of metrics: MEER, Net Present Value (NPV), Internal Rate of Return (IRR), and pairwise comparisons. Below are the details of Example 10 that are used for validating E3.

Analysis assumptions:

- 10-year study period
- 4 % real discount rate
- \$2000 environmental hurdle rate
- \$2000 maximum environmental expenditure rate (MEER)

Costs by alternative are as follows:

- Base case (Alternative 0)
 - \$25 000 in machinery repairs
- Alternative 1
 - \$100 000 to purchase a new piece of machinery
 - Decrease in annual maintenance costs by \$8000

- \$10 000 salvage value at end of study period
- Environmental impact would be decreased by 5 %
- Alternative 2
 - \$150 000 to purchase a new piece of machinery
 - Decrease in annual maintenance costs by \$20 000
 - \$20 000 salvage value
 - Environmental impact decreased by 10 %
- Alternative 3
 - \$200 000 to purchase a high-efficiency piece of machinery
 - Decrease in annual maintenance costs by \$20 000
 - \$30 000 salvage value
 - Decrease in annual energy costs by \$4000
 - Environmental impact decreased by 20 %

Tab. 4-61 shows the costs and environmental impacts by alternative.

Table 4-61 Costs and Environmental Impacts

Alternative	Initial Costs Machinery	Initial Costs Repairs	Future Savings and Reductions - Maintenance Savings	Future Savings and Reductions - Salvage Value	Future Savings and Reductions - Energy Savings	Future Savings and Reductions - Environmental Impact Reduction
0	\$0	\$25 000	\$0	\$0	\$0	0 %
1	\$100 000	\$0	\$8000	\$10 000	\$0	5 %
2	\$150 000	\$0	\$20 000	\$20 000	\$0	10 %
3	\$200 000	\$0	\$20 000	\$30 000	\$4000	20 %

These costs, savings, and impact reductions map to E3 BCN objects as shown in Tab. 4-62 and Tab. 4-63.

Table 4-62 BCN Object Values – Alternative 0 and Alternative 1

VarName	Repair 0	Machinery Purchase 1	Maintenance 1	Salvage Value 1	Environmental Impact 0	Environmental Impact 1
altIds	0	1	1	1	0	1
id	0	1	2	3	4	5
type	Cost	Cost	Cost	Cost	Nonmonetary	Nonmonetary
subType	Direct	Direct	Direct	Direct	Externality	Externality
name	Repair 0	Machinery Purchase 1	Maintenance 1	Salvage Value 1	Environmental Impact 0	Environmental Impact 1
tags	OMR	Initial Investment	OMR	Salvage Value	Environmental Impact	Environmental Impact
initialOccurrence	0	0	1	10	0	1
real	true	true	true	true	true	true
invest	false	true	false	True	False	False
life	Null	null	null	Null	Null	Null
residualValue	False	false	false	true	False	False
residualValueOnly	false	false	false	true	false	false
recur	N/A	N/A	{"interval": 1}	N/A	{"interval": 1}	{"interval": 1}
valuePerQ	25 000	100 000	-8000	-10 000	1	1
quantity	1	1	1	1	100	95
quantityVarRate	Null	Null	Null	Null	Null	Null
quantityVarValue	Null	Null	Null	Null	Null	Null
quantityUnit	Null	Null	Null	Null	Units	Units

Table 4-63 BCN Object Values – Alternative 2 and Alternative 3

VarName	Machinery Purchase 2	Machinery Purchase 3	Maintenance 2/3	Salvage Value 2	Salvage Value 3	Energy 3	Environmental Impact 2	Environmental Impact 3
altIds	2	3	[2,3]	2	3	3	2	3
id	6	7	8	9	10	11	12	13
type	Cost	Cost	Cost	Cost	Cost	Cost	Nonmonetary	Nonmonetary
subType	Direct	Direct	Direct	Direct	Direct	Direct	Externality	Externality
name	Machinery Purchase 2	Machinery Purchase 3	Maintenance 2/3	Salvage Value 2	Salvage Value 3	Energy 3	Environmental Impact 2	Environmental Impact 3
tags	Initial Investment	Initial Investment	OMR	Salvage Value	Salvage Value	Energy	Environmental Impact	Environmental Impact
initialOccurrence	0	0	1	10	10	1	1	1
real	true	true	true	true	true	true	true	true
invest	true	true	false	True	True	False	False	False
life	null	null	null	Null	Null	Null	Null	Null
residualValue	false	false	false	True	True	False	False	False
residualValueOnly	false	false	false	true	true	false	false	false
recur	N/A	N/A	{"interval": 1}	N/A	N/A	{"interval": 1}	{"interval": 1}	{"interval": 1}
valuePerQ	150000	200000	-20000	-20000	-30000	-4000	1	1
quant	1	1	1	1	1	1	90	80
quantVarRate	Null	Null	Null	Null	Null	Null	Null	Null
quantVarValue	Null	Null	Null	Null	Null	Null	Null	Null
quantUnit	Null	Null	Null	Null	Null	Null	Units	Units

The environmental impacts (non-monetary BCN objects) could be submitted in numerous ways to get the desired comparison. In this example, the baseline is assumed to have 100 “units” of the environmental impact annually while the alternatives have a fraction of those 100 units annually. The units are aggregated over 10 years with the baseline having a total of 1000 units. Alternative 1, 2, and 3 have a total of 950, 900, and 800 units, respectively.

The results from the E3 API were compared to the results in the example in Tab. 4-64 to confirm consistency between E3 and BLCC. Ref. [33] does not provide annual cash flows or total NPV in the example, and instead provide the net savings, IRR, and percentage change in environmental impacts. The results are identical for the NPV (which is reverse engineered for Ref. [33]), net savings, IRR, and environmental impact percentage changes for all alternatives.

Table 4-64 Summary Results Comparison

Alt.	NPV - Ref. [33]	NPV - E3	NS - Ref. [33]	NS - E3	IRR - Ref. [33]	IRR - E3	Environmental Impact - Ref. [33]	Environmental Impact - E3
0	\$25 000	\$25 000	-	-	-		-	-
1	\$28 357	\$28 357	-\$3357	-\$3357	3.2 %	NaN	-5.0 %	-5.0 %
2	-\$25 729	-\$25 729	\$50 729	\$50 729	11.0 %	3.0 %	-10.0 %	-10.0 %
3	-\$14 928	-\$14 928	\$39 928	\$39 928	8.0 %	8.0 %	-20.0 %	-20.0 %

Alternative 2 and Alternative 3 are preferred when compared to the base case as well as Alternative 1 because the total NPV costs and the environmental impacts are lower. Alternative 1 has a tradeoff where total NPV costs are higher than the base case, but the environmental impacts are lower. Choosing between Alternative 2 and Alternative 3 requires a pairwise comparison, as there is a tradeoff between the costs and environmental impacts.

When combined with the provided environmental hurdle rate and MEER, the E3 results provide all the necessary information to complete the additional calculations to make the pairwise comparison. In this example, the net present value per percent change in environmental impact (NPVP) needs to be calculated, which is the dollar trade-off per percent reduction in environmental impact.

Relative to Alternative 2, Alternative 3 has higher costs (additional \$10 801) and 10 % lower environmental impacts. The average cost per percent reduction in environmental impacts (or Net Present Value per Percent Increase) is \$1080, which is lower than the MEER of \$2000. Therefore, Alternative 3 is preferred to Alternative 2.

Note that E3 generates three measures that could be used for trade-offs between monetary and non-monetary results:

- nsPercentQuantity is the Net Savings Per Percent Change in Quantity
- nsDeltaQuantity is the Net Savings Per Unit Change in Quantity
- nsElasticityQuantity is the Net Savings Elasticity Per unit of Quantity Change

In this example, the Net Savings Per Percent Change in Quantity could be used in this example if the example only compared Alternative 3 to Alternative 2 as the base case. This value would be equivalent to the NPVP. Net Savings of -\$10 801 and Percent Change in Quantity of -10 % means nsPercQuant would be \$1080.

Other measures discussed in the sustainable manufacturing standard section include the Net present value elasticity (NPVE), which is equivalent to the nsElasticityQuant value.

The nsDeltaQuant could be used to compare the additional costs of a unit of emissions reduction to the social cost of those emissions. For example, an alternative that reduces greenhouse gas (GHG) emissions by 100 metrics tons at an additional cost of \$3000 could be compared to the externality cost of those GHG emissions (e.g., social cost of carbon) to determine if the additional benefits to society are worth the additional costs.

4.4.5. [PV]²

The [PV]² web application allows a user to complete a life cycle cost analysis and grid-based electricity reduction estimate of a residential solar photovoltaic system. This tool has allowed for validation of the life-cycle cost analysis calculations and all related economic measures/metrics in E3 (i.e., NPV cash flows, NS, IRR, SIR, and AIRR). Additionally, the tool allowed for validation of changes in quantity flows and non-monetary externalities (impacts that are not realized by the entity making the investment decision), specifically life cycle impact assessment of the solar photovoltaic system and its electricity production including global warming potential and other environmental impact categories. The tool currently post-processes the monetization of the global warming potential impact category using the social cost of carbon (SCC). For additional details on [PV]², please visit <https://pv2.el.nist.gov/> to access the web application and the user guide [34]. The code for the tool is also available on GitHub at <https://github.com/usnistgov/pv2>.

Additional capabilities are being considered for inclusion within [PV]² to test other aspects of the E3 functionality, specifically:

- Sensitivity analysis of key user inputs that have the greatest potential impact on the results (e.g., discount rate, study period)
- Uncertainty analysis of the user inputs considered to have the greatest uncertainty (e.g., energy price escalation rates)

4.4.6. Other Examples

Additional examples may be added in future versions of this document. Under consideration are as follows: electric vehicles, battery storage, HVAC equipment, DHW equipment, Agency Vehicle Fleet, Product Service Life Improvements, Environmental Justice. User feedback and new use cases will determine what examples are added in the future.

5. Planned Release and Current Capabilities and Future Capabilities

5.1. Release of E3

E3 V1 was released to the public in April 2022. E3 V2 is currently available on GitHub (<https://github.com/usnistgov/e3>) and at the E3 web API path (<https://e3.nist.gov/api/v2/>). . The external facing E3 web API is available on a case-by-case basis for external developers by contacting the E3 development team.

E3 V2 supersedes Version 1 and includes several fundamental changes as well as an expansion of capabilities. First, E3 has been rewritten in Java to take advantage of existing libraries that simplify and improve performance of E3 calculations. This improved performance is important for the new uncertainty capabilities available in Version 2.

The legacy python-based version of E3 will not be further developed nor will a web API be maintained for internal or external use. However, the code will remain available on GitHub as legacy code within the E3 GitHub directory. The current release of E3 (Java-based) is the focus of future development and support.

5.2. Current Capabilities

The current version of E3 has been designed to complete the following economic analysis and guidance is provided to map different terminology to E3:

- Life Cycle Cost Analysis (LCCA)
 - costs, savings, net savings
- Benefit-Cost Analysis (BCA) / Cost-Benefit Analysis (CBA)
 - benefits, costs, net benefits
- Profit Maximization
 - revenue, cost, profit, loss
- Cost Minimization
 - Costs, savings, net savings
- Monetary / Non-monetary Trade-Off Analysis
 - Costs, savings, net savings, cost per unit change

The above economic analysis types can use the following capabilities/features:

- Deterministic estimates
- Sensitivity testing
- Uncertainty analysis

- Different discounting conventions
 - End-of-Year (EOY)
 - Mid-Year
 - Continuous
 - Nominal and real discount rates

5.3. Future Capabilities¹¹

The following economic analysis types are not currently included, but may be added in the future including guidance and examples on mapping to E3:

- Non-monetary to non-monetary trade-offs
- Others identified by stakeholders and users
- Optimization algorithms
- Incremental measures (BCR, IRR, etc.)
- Stochastic Dominance
- Prediction bounds on simulation results.
- Adjusting simulation/sensitivity procedure to account for time related variables

Additional features not currently included, but may be added in the future include:

- Default datasets
 - Energy price escalation rates
 - Discount and inflation rates
- New modules
- User feedback

A few capabilities that would be useful to include in E3 in the future include the following:

- Allow alternatives with no BCN objects (e.g., baseline case)
- Allow BCNs for an alternative to include both nominal and real dollar values (e.g., loan payments in nominal dollars and other costs in real dollars)
- Alternative simulation and sampling methods, including dependency.

Access to E3 is limited to those that receive a valid authentication token from NIST, which is currently provided on a limited basis for security (cybersecurity) and cost (cloud server services)

¹¹ These lists are subject to change as development progresses

reasons. Access may be expanded and improve in the future based on user demand and NIST security requirements.

E3 could be included in future versions of existing ASTM standards as a resource/supplement with examples explicit to each standard.

References

- [1] ASTM (2021) Committee E06 on Performance of Buildings - Committee Scope (<https://www.astm.org/COMMIT/SCOPES/E06.htm>).
- [2] ASTM (2021) Standard Terminology of Building Economics, ASTM Designation E833 – 14(2021). (West Conshohocken, PA). Chilson P (2008) The Border. *The Best American Travel Writing 2008*, ed Bourdain A (Boston, MA, Houghton Mifflin Company), Vol. 1, Chapter 8, 3rd Ed., pp 44–51.
- [3] ASTM (2015) Standard Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems, ASTM Designation E1185-15. (West Conshohocken, PA). Taylor BN (2011) The current SI seen from the perspective of the proposed new SI. *Journal of Research of the National Institute of Standards and Technology* 116(6):797. <https://doi.org/10.6028/jres.116.022>
- [4] ASTM (2020) Standard Guide for Summarizing the Economic Impacts of Building-Related Projects, ASTM Designation E2204-15(2020)e1. (West Conshohocken, PA).
- [5] ASTM (2017) Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, ASTM Designation E917-17e1. (West Conshohocken, PA).
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Appendix A. List of Acronyms

AC

Air Conditioning

AEO

Applied Economics Office

AHP

Analytical Hierarchy Process

AIRR

Adjusted Internal Rate of Return

API

Application Programming Interface

ASTM

American Society for Testing and Materials

AWS

Amazon Web Services

BCA

Benefit-Cost Analysis

BCN

Benefit/Cost/Non-Monetary

BEES

Building for Environmental and Economic Sustainability

BIRDS

Building Industry Reporting and Design for Sustainability

BLCC

Building Life Cycle Cost

CDF

Cumulative Distribution Function

CFR

Code of Federal Regulations

CLI

Command Line Interface

CLT

Central Limit Theorem

DHS

Department of Homeland Security

DOE

Department of Energy

DPP

Discounted Payback Period

DX

Direct Expansion

E3

Economic Evaluation Engine

ECIP

Energy Conservation Investment Program

EDG

Economic Decision Guide

EDGE\$

Economic Decision Guide Software

EO

Executive Order

EL

Engineering Laboratory

ELDST

Engineering Laboratory Data, Security, and Technology

FEMA

Federal Emergency Management Agency

FEMP

Federal Energy Management Program

FHWA

Federal Highway Administration

FRP

Functional Reactive Programming

GHG

Greenhouse Gas

GSA

Government Services Administration

GUI

Graphical User Interface

HVAC

Heating, Ventilation, and Air Conditioning

IRR

Internal Rate of Return

JSON

JavaScript Object Notation

JVM

Java Virtual Machine

LCC

Life Cycle Cost

LCCA

Life Cycle Cost Analysis

LCIA

Life Cycle Impact Assessment

MARR

Minimum Alternative Rate of Return

MEER

Maximum Environmental Expenditure Rate

MILCON

Military Construction

NB

Net Benefits

NIST

National Institute of Standards and Technology

NPV

Net Present Value

NPVE

Net Present Value Elasticity

NPVP

Net Present Value Per Percent Change

NS

Net Savings

OAT

One at a Time

OM

Operation and Maintenance

OMB

Office of Management and Budget

OMR

Operations, Maintenance, and Repair

ORM

Object-Relational Mapping

PV

Photovoltaic

[PV]2

Present Value of Photovoltaics

RDF

Resource Description Framework

REST

Representational State Transfer

RSS

Really Simple Syndication

RV

Residual Value

SIR

Savings-to-Investment Ratio

SPP

Simple Payback Period

SpUD

Sprinkler Use Decisioning

SQL

Structured Query Language

ToGS

Turnout Gear Selector

TOPS-BC

Tools for Operations Benefit-Cost Analysis

WUI

Wildland-Urban Interface

Appendix B. Example JSON Input

B.1. Standard Input

```
{
  "analysisObject" : {
    "type" : "BCA",
    "projectType" : "Infrastructure",
    "outputObjects" : ["required","measure","optional"],
    "studyPeriod" : 50,
    "timestepValue" : "Year",
    "timestepComp" : "End_Of_Year",
    "outputReal" : true,
    "interestRate": 0.03,
    "discountRateReal" : 0.03,
    "inflationRate" : 0.023,
    "marr" : 0.03,
    "reinvestRate" : 0.03,
    "federalIncomeRate": 0.22,
    "otherIncomeRate": 0.05,
    "numberOfAlternatives" : 2,
    "baseAlternative" : 0
  },
  "alternativeObjects" : [
    {
      "id" : 0,
      "name" : "Alt 0 Status Quo",
      "bcns" : [0]
    },
    {
      "id" : 1,
      "name" : "Alt 1 Build Monument",
      "bcns" : [1,2,3,4]
    }
  ],
  "bcnObjects" : [
    {
      "id" : 0,
      "altIds" : [0],
      "type" : "Cost",
      "subType" : "Direct",
      "name" : "Investment Cost - Status Quo",
      "tags" : "Initial Investment",
```

```

    "initialOccurrence" : 0,
    "real" : true,
    "invest" : true,
    "residualValue" : false,
    "residualValueOnly" : false,
    "quantityValue" : 0.0,
    "quantity" : 1.0
  },
  {
    "id" : 1,
    "altIds" : [1],
    "type" : "Cost",
    "subType" : "Direct",
    "name" : "Construct Monument",
    "tags" : "Investment Cost",
    "initialOccurrence" : 0,
    "real" : true,
    "invest" : true,
    "residualValue" : false,
    "residualValueOnly" : false,
    "quantityValue" : 100000.0,
    "quantity" : 1.0
  },
  {
    "id" : 2,
    "altIds" : [1],
    "type" : "Cost",
    "subType" : "Direct",
    "name" : "Maintain Monument",
    "tags" : "OMR Costs",
    "initialOccurrence" : 1,
    "real" : true,
    "invest" : false,
    "life" : 50,
    "residualValue" : false,
    "residualValueOnly" : false,
    "recur" : {
      "interval" : 1,
      "varRate" : "Percent_Delta",
      "varValue" : 0.0
    },
    "quantityValue" : 1000.0,
    "quantity" : 1.0
  }

```

```

},
{
  "id" : 3,
  "altIds" : [1],
  "type" : "Benefit",
  "subType" : "Direct",
  "name" : "Free Publicity",
  "tags" : "Publicity",
  "initialOccurrence" : 1,
  "real" : true,
  "invest" : false,
  "residualValue" : false,
  "residualValueOnly" : false,
  "quantityValue" : 50000.0,
  "quantity" : 1.0
},
{
  "id" : 4,
  "altIds" : [
    1
  ],
  "type" : "Benefit",
  "subType" : "Externality",
  "name" : "Increased Tourism",
  "tags" : "Tourism",
  "initialOccurrence" : 1,
  "real" : true,
  "invest" : false,
  "residualValue" : false,
  "residualValueOnly" : false,
  "recur" : {
    "interval" : 1
  },
  "quantityValue" : 5000.0,
  "quantity" : 1.0
}
]
}

```

B.2. Sensitivity Input

```

{
  "analysisObject": {

```

```

    "type": "LCCA",
    "projectType": "Infrastructure",
    "outputObjects": ["sensitivity","measure"],
    "studyPeriod": 50,
    "timestepValue": "Year",
    "timestepComp": "End_Of_Year",
    "outputReal": true,
    "interestRate": 0.03,
    "discountRateReal": 0.04,
    "inflationRate": 0.02,
    "marr": 0.04,
    "reinvestRate": 0.05,
    "numberOfAlternatives": 2,
    "baseAlternative": 0
  },
  "alternativeObjects": [
    {
      "id": 0,
      "name": "Base",
      "bcns": [10]
    },
    {
      "id": 1,
      "name": "Mitigation",
      "bcns": [0,1,2,3,4,5,6,7,8,9,10,11
    ]
    }
  ],
  "bcnObjects": [
    {
      "id": 0,
      "altIds": [1],
      "type": "Cost",
      "subType": "Direct",
      "name": "Straw Wattles",
      "tags": "Initial Investment",
      "initialOccurrence": 0,
      "real": true,
      "invest": true,
      "residualValue": false,
      "residualValueOnly": false,
      "quantityValue": 6250860.0,
      "quantity": 1.0
    }
  ]

```

```

},
{
  "id": 1,
  "altIds": [1],
  "type": "Cost",
  "subType": "Indirect",
  "name": "Indirect Costs",
  "tags": "Initial Investment",
  "initialOccurrence": 0,
  "real": true,
  "invest": true,
  "residualValue": false,
  "residualValueOnly": false,
  "quantityValue": 625086.0,
  "quantity": 1.0
},
{
  "id": 2,
  "altIds": [1],
  "type": "Cost",
  "subType": "Direct",
  "name": "Total OMR costs",
  "tags": "OMR",
  "initialOccurrence": 4,
  "real": true,
  "invest": true,
  "residualValue": false,
  "residualValueOnly": false,
  "recur": {
    "interval": 4,
    "varValue": 0.0,
    "end": 50
  },
  "quantityValue": 28430.0,
  "quantity": 1.0
},
{
  "id": 3,
  "altIds": [1],
  "type": "Benefit",
  "subType": "Indirect",
  "name": "Indirect Loss Reduction",
  "tags": "DRB",

```

```

    "initialOccurrence": 1,
    "real": true,
    "invest": false,
    "residualValue": false,
    "residualValueOnly": false,
    "recur": {
      "interval": 1,
      "varValue": 0.0,
      "end": 50
    },
    "quantityValue": 23543.2,
    "quantity": 1.0
  },
  {
    "id": 4,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Direct",
    "name": "sludge removal cost",
    "tags": "DRB",
    "initialOccurrence": 1,
    "real": true,
    "invest": false,
    "residualValue": false,
    "residualValueOnly": false,
    "recur": {
      "interval": 1,
      "varValue": 0.0
    },
    "quantityValue": 68000.0,
    "quantity": 1.0
  },
  {
    "id": 5,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Direct",
    "name": "Water Treatment Chemical Cost",
    "tags": "DRB",
    "initialOccurrence": 1,
    "real": true,
    "invest": false,
    "residualValue": false,

```



```

    "residualValueOnly": false,
    "recur": {
      "interval": 1,
      "varValue": 0.0
    },
    "quantityValue": 3343.04,
    "quantity": 1.0
  },
  {
    "id": 6,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Direct",
    "name": "Reseeding",
    "tags": "DRB",
    "initialOccurrence": 1,
    "real": true,
    "invest": false,
    "residualValue": false,
    "residualValueOnly": false,
    "recur": {
      "interval": 1,
      "varValue": 0.0
    },
    "quantityValue": 7200.0,
    "quantity": 1.0
  },
  {
    "id": 7,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Externality",
    "name": "Recreational Value",
    "tags": "NDRB",
    "initialOccurrence": 1,
    "real": true,
    "invest": false,
    "residualValue": false,
    "residualValueOnly": false,
    "recur": {
      "interval": 1,
      "varValue": 0.0,
      "end": 50
    }
  }

```

```

    },
    "quantityValue": -51850.0,
    "quantity": 1.0
  },
  {
    "id": 8,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Externality",
    "name": "River Health (Salmon)",
    "tags": "NDRB",
    "initialOccurrence": 5,
    "real": true,
    "invest": false,
    "residualValue": false,
    "residualValueOnly": false,
    "quantityValue": 4620000.0,
    "quantity": 1.0
  },
  {
    "id": 9,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Externality",
    "name": "River Health (Watershed)",
    "tags": "NDRB",
    "initialOccurrence": 10,
    "real": true,
    "invest": false,
    "residualValue": false,
    "residualValueOnly": false,
    "quantityValue": 3780000.0,
    "quantity": 1.0
  },
  {
    "id": 10,
    "altIds": [0],
    "type": "Cost",
    "subType": "Direct",
    "name": "Zero Cost Baseline",
    "tags": "Baseline Costs",
    "initialOccurrence": 0,
    "real": true,

```

```

        "invest": false,
        "residualValue": false,
        "residualValueOnly": false,
        "quantityValue": 0.0,
        "quantity": 1.0
    }
},
"sensitivityObjects": [
    {
        "id": 1,
        "altIds": [0,1],
        "variable": "analysisObject.discountRateReal",
        "diffType": "Gross",
        "diffValue": 0.03
    }
]
}

```

B.3. Uncertainty Input

```

{
  "analysisObject": {
    "type": "LCCA",
    "projectType": "Infrastructure",
    "outputObjects": ["uncertainty"],
    "studyPeriod": 50,
    "timestepValue": "Year",
    "timestepComp": "End_Of_Year",
    "outputReal": true,
    "interestRate": 0.03,
    "discountRateReal": 0.04,
    "inflationRate": 0.02,
    "marr": 0.04,
    "reinvestRate": 0.05,
    "numberOfAlternatives": 2,
    "baseAlternative": 0
  },
  "alternativeObjects": [
    {
      "id": 0,
      "name": "Base",
      "bcns": [10]
    },
  ],
}

```

```

{
  "id": 1,
  "name": "Mitigation",
  "bcns": [0,1,2,3,4,5,6,7,8,9,10,11]
}
],
"bcnObjects": [
  {
    "id": 0,
    "altIds": [1],
    "type": "Cost",
    "subType": "Direct",
    "name": "Straw Wattles",
    "tags": "Initial Investment",
    "initialOccurrence": 0,
    "real": true,
    "invest": true,
    "quantityValue": 6250860.0,
    "quantity": 1.0
  },
  {
    "id": 1,
    "altIds": [1],
    "type": "Cost",
    "subType": "Indirect",
    "name": "Indirect Costs",
    "tags": "Initial Investment",
    "initialOccurrence": 0,
    "real": true,
    "invest": true,
    "quantityValue": 625086.0,
    "quantity": 1.0
  },
  {
    "id": 2,
    "altIds": [1],
    "type": "Cost",
    "subType": "Direct",
    "name": "Total OMR costs",
    "tags": "OMR",
    "initialOccurrence": 4,
    "real": true,
    "invest": true,

```

```

    "recur": {
      "interval": 4,
      "end": 50
    },
    "quantityValue": 28430.0,
    "quantity": 1.0
  },
  {
    "id": 3,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Indirect",
    "name": "Indirect Loss Reduction",
    "tags": "DRB",
    "initialOccurrence": 1,
    "real": true,
    "recur": {
      "interval": 1,
      "end": 50
    },
    "quantityValue": 23543.2,
    "quantity": 1.0
  },
  {
    "id": 4,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Direct",
    "name": "sludge removal cost",
    "tags": "DRB",
    "initialOccurrence": 1,
    "real": true,
    "recur": {
      "interval": 1
    },
    "quantityValue": 68000.0,
    "quantity": 1.0
  },
  {
    "id": 5,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Direct",

```

```

    "name": "Water Treatment Chemical Cost",
    "tags": "DRB",
    "initialOccurrence": 1,
    "real": true,
    "recur": {
      "interval": 1
    },
    "quantityValue": 3343.04,
    "quantity": 1.0
  },
  {
    "id": 6,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Direct",
    "name": "Reseeding",
    "tags": "DRB",
    "initialOccurrence": 1,
    "real": true,
    "recur": {
      "interval": 1
    },
    "quantityValue": 7200.0,
    "quantity": 1.0
  },
  {
    "id": 7,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Externality",
    "name": "Recreational Value",
    "tags": "NDRB",
    "initialOccurrence": 1,
    "real": true,
    "recur": {
      "interval": 1,
      "end": 50
    },
    "quantityValue": -51850.0,
    "quantity": 1.0
  },
  {
    "id": 8,

```

```

    "altIds": [1],
    "type": "Benefit",
    "subType": "Externality",
    "name": "River Health (Salmon)",
    "tags": "NDRB",
    "initialOccurrence": 5,
    "real": true,
    "quantityValue": 4620000.0,
    "quantity": 1.0
  },
  {
    "id": 9,
    "altIds": [1],
    "type": "Benefit",
    "subType": "Externality",
    "name": "River Health (Watershed)",
    "tags": "NDRB",
    "initialOccurrence": 10,
    "real": true,
    "quantityValue": 3780000.0,
    "quantity": 1.0
  },
  {
    "id": 10,
    "altIds": [0],
    "type": "Cost",
    "subType": "Direct",
    "name": "Zero Cost Baseline",
    "tags": "Baseline Costs",
    "initialOccurrence": 0,
    "real": true,
    "quantityValue": 0.0,
    "quantity": 1.0
  }
],
"uncertainty": [
  {
    "id": 0,
    "variables": [
      {
        "variable": "bcnObjects.0.quantityValue",
        "distribution": "Normal",
        "distributionArgs": [2,0.2]
      }
    ]
  }
]

```

```
}  
]  
}  
]  
}
```


Appendix C. Change Log

The entire document has been updated to NIST 2022 format for accessibility (January 2024 revision)

The following changes were made to the front matter:

- Removed Tasha Kim as an author (January 2024 revision)
- Moved list of abbreviations to Appendix A (January 2024 revision)

The following changes were made to the text of the document:

- Section 1.2.2, pg. 6, completely rewritten to account for progress made since last version (January 2024 revision)
- Section 2 and all subsections completely rewritten to account for change from Python to Java (January 2024 revision)
- Section 3 and all subsections completely rewritten to account for change from Python to Java (January 2024 revision)
- Remove Previous Version Section 4.3 as local run method is being developed (January 2024 revision). Renumbered the sections to the following:
 - Previous 4.4 to Current 4.3
 - Previous 4.5 to Current 4.4
 - Previous 4.5.1 to Current 4.4.1
 - Previous 4.5.2 to Current 4.4.2
 - Previous 4.5.3 to Current 4.4.4
 - Current Section 4.4.3 added as an example of uncertainty analysis for E3 (January 2024 revision)
 - Previous 4.5.4 to Current 4.4.5
 - Previous 4.5.5 to Current 4.4.6
- Current Section 4.4, added text to acknowledge that E3 will likely be shifted to use E3 as a back end (January 2024 revision)
- Current Section 4.4, added text to note the current development of an E3 backed version of AEO's Smart Investment Tool (SITExpress) (January 2024 revision)
- Section 5.1, added text noting the update from V1 to V2 (January 2024 revision)
- Section 5.3, updated future capabilities to account for completed work and new future work (Optimization algorithms, Incremental measures, Stochastic dominance, Prediction bounds on simulation results, Alternative simulation and sampling methods, including dependencies) (January 2024 revision)

- Added Appendix B to present formatted JSON input strings

The following changes were made to figures:

- Alt text added to Figure 1-1 (January 2024 revision)
- Figure 2-1 has been updated to account for the change from Python to Java (January 2024 revision)
- Alt text added to Figure 2-1 (January 2024 revision)
- Added Figure 4-1, with alt text (January 2024 revision)

The following changes were made to tables:

- Table 3-2 moved from Section 3 to Section 2, relabeled Table 2-1 (January 2024 revision)
- Table 3-2 updated “Var Names” to account for changes from Python to Java (January 2024 revision)
- Table 3-3 moved from Section 3 to Section 2, relabeled Table 2-2 (January 2024 revision)
- Table 3-3 updated “Var Names” to account for changes from Python to Java (January 2024 revision)
- Table 3-4 moved from Section 3 to Section 2, relabeled Table 2-3 (January 2024 revision)
- Table 3-4 updated “Var Names” to account for changes from Python to Java (January 2024 revision)
- Table 3-5 moved from Section 3 to Section 2, relabeled Table 2-4 (January 2024 revision)
- Table 3-5 updated “Var Names” to account for changes from Python to Java (January 2024 revision)
- Table 2-5 added to account for addition of uncertainty to version 2 (January 2024 revision)
- Table 2-6 added to account for addition of uncertainty to version 2 (January 2024 revision)
- Table 3-6 moved from Section 3 to Section 2, relabeled Table 2-7 (January 2024 revision)
- Table 3-6 updated “Var Names” to account for changes from Python to Java (January 2024 revision)
- Table 3-7 moved from Section 3 to Section 2, relabeled Table 2-8 (January 2024 revision)
- Table 3-7 updated “Var Names” to account for changes from Python to Java (January 2024 revision)
- Table 3-8 moved from Section 3 to Section 2, relabeled Table 2-9 (January 2024 revision)
- Table 3-8 updated “Var Names” to account for changes from Python to Java (January 2024 revision)

- Table 3-9 moved from Section 3 to Section 2, relabeled Table 2-10 (January 2024 revision)
- Table 3-9 updated “Var Names” to account for changes from Python to Java (January 2024 revision)
- Table 3-10 moved from Section 3 to Section 2, relabeled Table 2-11 (January 2024 revision)
- Table 3-10 updated “Var Names” to account for changes from Python to Java (January 2024 revision)
- Table 2-12 added to account for addition of uncertainty to version 2 (January 2024 revision)
- The following tables had their format changed to be more accessible and Var Names updated to account for the change from Python to Java (January 2024 revision)
 - Table 4-2, 4-9, 4-14, 4-16, 4-22, 4-23, 4-28, 4-29, 4-31, 4-32, 4-33, 4-37, 4-38, 4-40, 4-43, 4-45, 4-48, 4-50, 4-52, 4-53, 4-54, 4-56, 4-57, 4-58, 4-59, 4-60, 4-61, 4-64
- The following tables had their Var Names updated to account for the change from Python to Java (January 2024 revision)