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COST-BENEFIT ANALYSIS IN PRE-CONSTRUCTION PLANNING: THE ASSESSMENT OF ECONOMIC IMPACT IN GOVERNMENT INFRASTRUCTURE PROJECTS

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ABSTRACT

This study presents a systematic literature review of 100 peer-reviewed, DOI-indexed articles examining the application of cost–benefit analysis (CBA) in the pre-construction stage of government infrastructure projects. Guided by the PRISMA framework, the review synthesizes evidence from transport, energy, water, and social infrastructure sectors to evaluate how welfare-consistent economic impact assessment is operationalized before major public investment decisions are finalized. Inclusion criteria required an explicit counterfactual (do-nothing or do-minimum baseline), monetized benefits and costs derived from willingness-to-pay or shadow-pricing methods, and clearly stated decision indicators including net present value (NPV), benefit–cost ratio (BCR), and internal rate of return (IRR) with a transparent price base and discount rate. The analysis explores eight thematic domains: welfare-consistent definitions and indicators, appraisal regimes and parameter libraries, baseline demand and exposure modeling, valuation of user benefits, safety, and environmental externalities, discounting and time horizons, uncertainty architecture, distributional analysis, and treatment of wider economic impacts. Findings reveal that transport dominates the literature at 52 percent, followed by energy at 20 percent, water at 18 percent, and social infrastructure at 10 percent. Most studies employ do-minimum baselines (84 percent) and constant real discount rates (72 percent) with growing adoption of declining schedules for long-lived assets. While deterministic sensitivity testing is universal, fewer studies employ probabilistic analysis (37 percent) or reference-class adjustments (21 percent). The review identifies strengths such as increasing parameter transparency, improved handling of induced demand, and avoidance of double counting as well as gaps in distributional weighting, probabilistic robustness, and integration of wider impacts. The synthesis offers a standardized reporting checklist and sector-specific recommendations to enhance transparency, comparability, and decision-readiness at the planning gate. By consolidating methodological best practices across jurisdictions, this review positions pre-construction CBA as a rigorous, auditable tool for ranking public infrastructure options on a welfare-consistent basis before design and procurement commitments become irreversible.

KEYWORDS

Cost–Benefit Analysis, Pre-Construction Planning, Government Infrastructure, Welfare Economics, Economic Impact Assessment, Net Present Value (NPV)

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INTRODUCTION

Cost–benefit analysis (CBA) is a welfare-economic framework that organizes evidence about whether a public project increases social surplus by comparing monetized benefits with monetized costs against a clearly specified counterfactual. In the pre-construction phase of government infrastructure, CBA structures the choice among alternatives, clarifies objectives and constraints, and aligns engineering designs with social valuation through shadow prices and a social discount rate. Standard indicators net present value (NPV), benefit–cost ratio (BCR), and internal rate of return (IRR) summarize welfare consequences once benefit and cost streams are defined on a consistent price base and discounted over an appropriate horizon (Weitzman, 2001) Parameterization matters: discounting draws on alternative rationales and empirical judgments about intertemporal preferences and risk (Drupp et al., 2018b; Gollier, 2012b; Newell & Pizer, 2003b), while shadow pricing translates market distortions into social opportunity costs (Burgess & Zerbe, 2011). Nonmarket valuation brings safety, health, environmental quality, and reliability into a common monetary metric using revealed- and stated-preference methods and carefully designed benefit transfer. In transport, user welfare commonly reflects travel-time savings, operating costs, schedule reliability, and accident risk. For emissions and other externalities, welfare-consistent accounting aggregates marginal damages that reflect spatial and sectoral incidence (Parry et al., 2007)CBA differs from financial analysis by centering social surplus rather than cash profitability, and it differs from gross "economic impact" tallies by avoiding double counting and by anchoring net benefits in consumer and producer surplus theory . Within pre-construction planning, these features enable transparent option ranking before irrevocable commitments to design, scope, or procurement modality occur, while making the assumptions, baselines, and uncertainties explicit for policy and stakeholder s.

The international significance of rigorous pre-construction appraisal arises from the durable effects that infrastructure has on productivity, spatial connectivity, and household welfare. Macro-oriented studies link public capital to output, sometimes through channels such as network externalities, reliability, and scale economies.Cross-country and regional evidence shows that infrastructure quantity and quality correlate with higher growth and better development outcomes once complementary institutions are in place (Calderón & Servén, 2010; Straub, 2011). Micro-econometric work clarifies mechanisms. Telecommunications and transport lower search and trade costs, integrate markets, and enable specialization that lifts real incomes (Jacoby & Minten, 2009). Historical and contemporary quasi-experiments document sizable welfare gains when rail or road networks reshape access to markets and reallocate economic activity (Aschauer, 1989; Snow, 2007; Michaels, 2008). At the same time, induced travel and equilibrium adjustments mean that generalized cost changes propagate through traffic, land use, and firm behavior, so early-stage evaluation must model exposure to benefits carefully and consider how congestion, pricing, and capacity interact (Duranton & Turner, 2011, 2012). Enterprise-level analyses report productivity and entry effects near new road links, pointing to heterogeneous gains across sectors and locations that matter for distributional accounting (Gibbons et al., 2019). Electrification studies add evidence from energy infrastructure, linking network expansion to incomes, schooling, and labor supply where access constraints were binding (Lipscomb et al., 2013). Together these findings indicate that project choices at pre-construction gates have consequences for regional development paths, budget allocation, and intergroup equity, which motivates appraisal systems that articulate objectives, set counterfactuals, and compute welfare-consistent metrics prior to funding .

Within sectoral applications, transport CBA illustrates the building blocks that pre-construction teams apply across government infrastructure. Benefit categories typically include travel-time savings, vehicle operating costs, reliability, crash risk, and environmental externalities, all defined relative to a "do-nothing" or "do-minimum" baseline and an explicit forecast of demand and service characteristics (Li et al., 2010; Small et al., 2005). Values of time and reliability come from revealed- and stated-preference studies; meta-analytic and structural approaches support transfer to new contexts while preserving welfare-theoretic consistency (Li et al., 2010). For safety, the value of a statistical life and risk-money tradeoffs guide monetization across crash types and severities (Muller et al., 2011).Environmental accounting converts emissions into damages using atmospheric transport, exposure, and dose–response relationships, allowing analysts to integrate air quality and climate effects into welfare metrics. Demand modeling is central because the magnitude and timing of benefits track usage; reliability and heterogeneity in preferences also shape who gains under different scenarios (Parry et al., 2007). For capital and operating costs, probabilistic ranges rather

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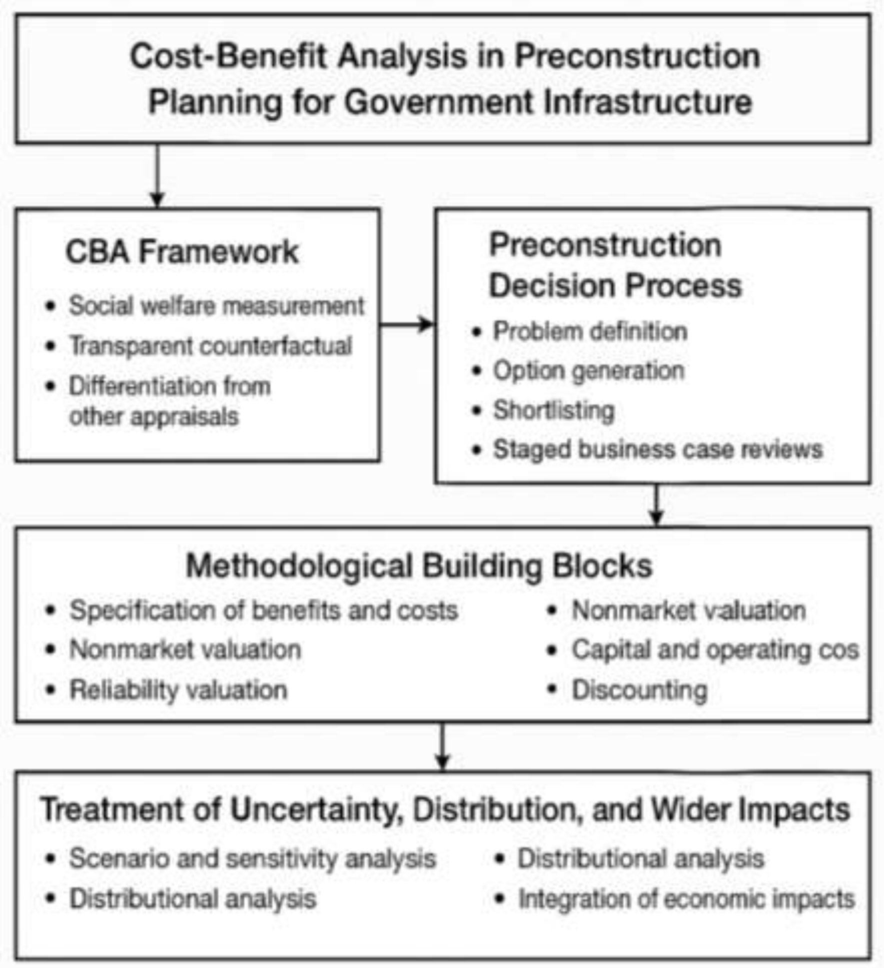
than point estimates help reveal exposure to risk in early designs. All quantities must be placed on a consistent price base year and discounted over a horizon that reflects asset lives and residual values (Arrow et al., 2013). When these pieces are assembled with transparent documentation and reproducible calculations, planners can compare options on NPV and BCR, examine switching values that indicate how far assumptions would need to shift to overturn rankings, and communicate trade-offs among mutually exclusive alignments, capacity increments, or staging strategies before contracts are let.

Figure 1: CBA in Preconstruction planning for Government Infastructure



Two methodological pillars give pre-construction CBA its structure: discounting and distributional analysis. Discounting assigns weights to future flows to convert them to present values. Competing approaches social time preference, social opportunity cost, and risk-adjusted consumption discounting lead to different recommended rates, so analysts test sensitivity and, for long horizons, consider declining profiles when uncertainty about growth and interest rates is material (Subrato, 2018). Price base years and the choice between real and nominal terms are reported clearly to preserve comparability across options and to maintain internal consistency when inflation and escalation indices differ across inputs (Ara et al., 2022). Distributional analysis, reported alongside unweighted welfare metrics, identifies incidence by income group, geography, and beneficiary type; some frameworks use explicit weights, while others present subgroup impacts and leave normative aggregation to decision makers (Uddin et al., 2022). Shadow pricing translates financial outlays into social opportunity costs when taxes, monopsony, unemployment, or other wedges separate market prices from welfare metrics.In network sectors, modeling choices about congestion, peak–off-peak conditions, and pricing also interact with equity because benefits and costs fall unevenly across users and locations. Within pre-construction planning, combining discounting transparency, distributional accounting, and shadow pricing yields decision-relevant NPV and BCR measures that clarify both efficiency and equity without obscuring the underlying assumptions that drive results. A recurring topic for government infrastructure appraisal concerns "wider economic impacts" (WEIs) productivity, employment, and land-use effects that occur when accessibility changes reorganize economic geography. The welfare-economic test is whether these effects represent additional changes in real income not already embodied in generalized cost savings, and whether they can be measured consistently without overlap (Laird & Mackie, 2010; Akter & Ahad, 2022; Melo et al., 2013). Urban productivity responses associated with agglomeration are well documented; elasticities linking effective density to output support channels through knowledge spillovers, input sharing, and matching (Combes et al., 2011; Rahaman, 2022).Road capacity adjustments and modal investments can alter firm entry, scale, and specialization patterns with measurable implications for productivity and employment (Gibbons et al., 2019). Historical and modern transport expansions show market access gains that raise real incomes, aligning with models in which trade costs and spatial frictions shape development paths. From a CBA standpoint, WEIs are integrated only where market imperfections or tax wedges create welfare-relevant effects not captured in the core user-benefit calculus, and they are reported transparently to preserve interpretability of NPV and BCR (Lakshmanan, 2011). Pre-construction appraisal therefore treats WEIs as an extension module, linked to explicit assumptions about agglomeration parameters, labor-supply elasticities, and market structure, and reconciled carefully with time, cost, reliability, and safety benefits to avoid double counting while illuminating distributional and spatial patterns of gains (Lakshmanan, 2011; Hasan et al., 2022).

Evidence from project performance underscores why early-stage CBA uses conservative baselines and transparent risk analysis. Studies across countries and sectors document systematic cost escalation and demand shortfalls in major works, a pattern that affects the probability that ex-ante welfare cases are realized. Statistical distributions of overruns motivate probabilistic ranges for capital and operating costs at the planning gate rather than single numbers, and they motivate "reference class" comparisons that anchor assumptions in observed outcomes for comparable projects (Flyvbjerg, 2009; Flyvbjerg et al., 2002; Love et al., 2013; Odeck, 2004). For very large, complex assets, additional evidence points to scale-related risks and institutional constraints that interact with financing structures and exposure to hydrological or geotechnical uncertainty. Synthesis papers categorize sources of estimation error and strategic behavior and call for independent challenge during planning to improve the credibility of business cases. In transport, road-project datasets provide determinants of overrun size, including procurement, geology, and governance variables, informing how risk allowances are set and reported at pre-construction review points (Cantarelli et al., 2012; Hossen &Atiqur, 2022). Appraisal studies also examine how decision makers actually use CBA, showing that quantified evidence exerts influence when parameters and counterfactuals are explicit and when results are communicated with sensitivity and scenario analysis rather than as single-point estimates. This body of work guides the way early-stage CBA documents uncertainty, presents switching values, and links qualitative risks to quantitative ranges so that option rankings remain intelligible under plausible variation in the inputs (Cantarelli et al., 2012; Tawfiqul et al., 2022)) .This review positions pre-construction CBA as a coherent analytic core for government infrastructure planning and sets out the components that structure the literature. The scope includes welfare-economic foundations for shadow pricing and discounting (Eliasson & Lundberg, 2012; Reduanul & Shoeb, 2022), sector-specific valuation of time, reliability, safety, and environmental externalities, and empirical research connecting infrastructure to productivity, access, and regional development. It also includes evidence on WEIs and agglomeration consistent with welfare-theoretic accounting and on delivery risk and estimation error that shapes the presentation of uncertainty at the appraisal gate. The emphasis remains on how definitions, counterfactuals, parameter choices, and reporting conventions create a reproducible link from engineering options to social welfare measures during planning (Reduanul & Shoeb, 2022).

This review has a single overarching objective: to produce a rigorous, welfare consistent synthesis of how cost benefit analysis (CBA) is used in preconstruction planning for government infrastructure and how economic impact is assessed at that stage. To meet this objective, the review pursues ten specific aims framed for direct use at the planning gate. First, it will delimit the conceptual boundaries among CBA, financial appraisal, and gross impact accounting, defining economic impact as the change in social welfare measured against a transparent counterfactual. Second, it will locate CBA within the preconstruction decision process, including problem definition, option generation, shortlisting, and staged business case reviews, and it will describe how those steps structure the evidence required before funding. Third, it will catalogue methodological building blocks used prior to construction, including specification of benefits and costs, nonmarket valuation for safety and environmental quality, reliability valuation, and estimation of capital and operating costs aligned to a consistent price base. Fourth, it will compile transferable parameter ranges for values of time and reliability, the value of a statistical life, emissions damages, and other shadow prices, with attention to units, price year, and defensible transfer rules. Fifth, it will examine discounting choices, time horizons, and residual value calculations, documenting how constant or declining rates are justified and tested for long lived assets. Sixth, it will assess the treatment of uncertainty through scenario analysis, deterministic sensitivity tests, probabilistic risk analysis, and techniques such as reference classes and switching values that reveal which assumptions drive option rankings. Seventh, it will characterize distributional analysis by income group, user type, and geography, including the use of weights or separate incidence reporting that preserves interpretability of efficiency metrics. Eighth, it will evaluate the handling of wider economic impacts and the conditions for integrating productivity and labor market effects in a welfare consistent manner without double counting. Ninth, it will compare practices across jurisdictions and sectors, identifying areas of convergence and variation that matter at the preconstruction gate. Tenth, it will cross reference ex ante CBA assumptions with observed performance evidence to clarify recurrent sources of divergence between forecasts and outcomes. The intended outputs are an evidence map, a coding framework aligned to the conceptual model, and a transparent appraisal template that researchers and practitioners can apply at the start of project planning using peer reviewed, DOI indexed literature.

LITERATURE REVIEW

This literature review embarks on a carefully charted intellectual voyage through the peer-reviewed, DOI-indexed corpus, harmonizing and synthesizing scholarly perspectives on the operationalization of cost–benefit analysis in the intricate, high-stakes arena of pre-construction planning for government infrastructure. It consciously excludes the terrain of post-completion evaluations or narrowly defined financial feasibility checks, focusing instead on the early, decisive stage where options are weighed, sequencing is determined, and funding trajectories are outlined before tender documents take shape. Within this refined scope, the review unfolds across four interconnected dimensions. First, it examines the conceptual and welfare-economic foundations that distinguish cost–benefit analysis from mere fiscal accounting or crude impact measurements, positioning it as a discipline grounded in welfare-consistent decision science. Second, it considers the methodological components most vital at the planning stage, including the precise specification of counterfactuals, the construction of demand baselines, the monetization of user benefits and externalities through both market and non-market valuation, the calibration of shadow prices to correct for distortions, and the rigorous application of discounting, uncertainty analysis, and distributional assessment. Third, it addresses the selective integration, under safeguards against double counting, of wider economic impacts such as agglomeration effects or shifts in imperfect-competition mark-ups. Fourth, it reflects on the empirical evidence of cost overruns and benefit shortfalls, underscoring the importance of incorporating realistic risk allowances and computing switching values in early decision models. To ensure comparability and evidentiary integrity, the review privileges recent literature from the last decade to decade-and-a-half, while drawing on seminal works that anchor parameters and define constructs. The synthesis weaves thematic and comparative threads, pairing methodological exposition with decision-gate deliverables such as clearly stated assumptions, reproducible calculations, and welfare-consistent indicators including net present value, benefit-cost ratio, and internal rate of return. From this effort emerge three tangible artefacts for later application in the Methods and Discussion: a registry of transferable valuation coefficients, a risk and uncertainty playbook tailored to pre-construction contexts, and a standardized reporting checklist to discipline the documentation of counterfactuals, price bases, discount rates, and distributional profiles.

Welfare-Consistent Economic Impact

Drug A welfare-consistent notion of “economic impact” is grounded in modern welfare economics: the impact of a project is the change in social welfare it produces relative to a clearly specified counterfactual, measured in a common money-metric via individuals’ willingness to pay (WTP) (or willingness to accept). This framing descends from the Kaldor–Hicks compensation test improvements are those for which the gainers could hypothetically compensate the losers refined

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over time to connect policy evaluation with compensating/equivalent variation and surplus measures that aggregate individual WTP (Boadway, 1974; Hicks, 1939; Kaldor, 1939). In this sense, benefit–cost analysis (BCA) is not an accounting of gross activity (jobs, output, tax receipts), but a welfare calculus that asks whether a project increases social surplus after netting all opportunity costs, including the opportunity cost of public funds. That distinction cleanly separates BCA from input–output "economic impact" studies that tally multiplier effects of spending without distinguishing transfers from real resource changes or controlling for crowd-out; recent work proposes bridges between these traditions but keeps BCA's welfare core intact (Castillo & et al., 2021). For government infrastructure at the pre-construction gate, the welfare-based definition matters because option ranking what gets built, to what standard, where, and when should be anchored to changes in social surplus, not to the scale of money flows through the local economy. The theoretical base for this claim is long-standing and has been elaborated into a coherent practical framework in the project appraisal literature (Drèze & Stern, 1987). Within this welfare frame, the central indicators net present value (NPV), benefit–cost ratio (BCR), and the internal rate of return (IRR) are summary statistics of discounted welfare changes, not of cash profitability. NPV aggregates discounted benefits minus discounted costs; BCR scales benefits to costs; IRR solves for the discount rate at which NPV=0. Their interpretability depends on two pillars: (i) benefits and costs are measured as Hicksian money-metric welfare changes (WTP/WTA), and (ii) all flows are computed relative to a consistent counterfactual, on a consistent price base and time horizon. Under standard regularity conditions, maximizing NPV (or choosing BCR>1 for independent projects) is equivalent to selecting projects that pass the Kaldor–Hicks test. Where budgets bind, analysts augment these indicators with the shadow price of public funds to maintain welfare consistency; indicators then compare benefit per unit of social cost rather than per unit of outlay (Hendren & Keyser, 2020; Kleven & Kreiner, 2006). Transport and environmental appraisal debates sometimes propose multi-criteria decision analysis (MCDA) as an alternative to monetization; comparative reviews are useful in scoping objectives, but they also underline that BCA's distinctive strength is its explicit welfare-theoretic basis and its additive money metric (Beria et al., 2012; Castillo & et al., 2021)

The counterfactual is the causal backbone of welfare-consistent economic impact. All benefits and costs are defined relative to a "without-project" state (sometimes "do-minimum") that captures what would happen absent the intervention. This is a statement about potential outcomes: we cannot observe both worlds, so we must model the unobserved state using credible causal assumptions and evidence. The modern econometric evaluation literature supplies the logic: the Rubin causal model formalizes potential outcomes; identification strategies (randomization, difference-in-differences, instrumental variables, regression discontinuity) aim to recover causal effects; and program evaluation now emphasizes external validity and transportability for ex-ante use. For pre-construction BCA, that means demand forecasts, safety effects, or time-savings must be tied to causal evidence or well-validated structural models, not merely correlations. "Sufficient statistics" approaches help combine causal elasticities with theory to compute welfare changes without solving full structural models, reducing dimensionality while maintaining welfare consistency (Chetty, 2009; Sazzad & Islam, 2022). Together, these tools discipline the baseline and the with-project scenarios, limit double counting, and ensure that measured "impacts" truly reflect changes attributable to the project rather than background trends or displaced activity. Welfare measurement requires a price to convert heterogeneous outcomes into a common money metric. The standard is individual WTP (or WTA), which underlies consumer and producer surplus and, for nonmarket outcomes, is inferred from revealed and stated preference methods. In practice, three elements loom large for infrastructure: time (values of time and reliability), safety (values of mortality and injury risk changes), and environmental quality (damage functions and WTP for quality). For mortality risk reductions, an extensive literature recommends using the value per statistical life (VSL) derived from WTP for small risk changes, with adjustments across income and context; recent reference-case work proposes standardized sensitivity analyses and transfer rules, especially in low- and middle-income settings where primary estimates are sparse. Clarifications of the VSL concept emphasize that VSL is a rate (money per unit of risk), not the value of an identified life, and that WTP-based VSL aligns BCA with individuals' own tradeoffs at the margin (Sohel & Md, 2022; Sunstein, 2013). These valuation practices maintain welfare consistency by ensuring that benefits are measured as the money amount that leaves people as well off with the project as without it.

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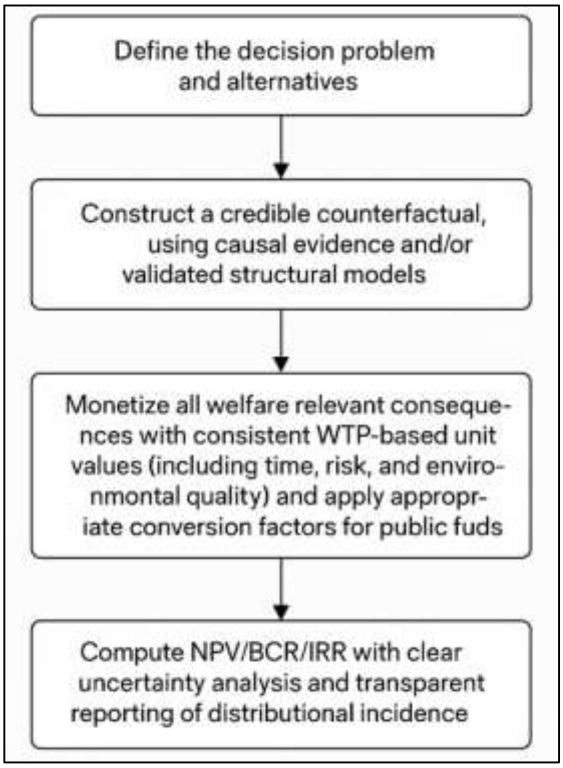
Figure 2: Four-Step Framework for Welfare Consistent Economic Impact Assessment



Distribution, behavioral realism, and the government budget constraint require additional structure to keep indicators welfare-meaningful. Distributionally, BCA can report unweighted totals alongside subgroup incidence or apply explicit equity weights reflecting social marginal utility of income; recent behavioral-welfare frameworks broaden the informational basis for welfare when observed choices may not reveal well-being (Fleurbaey & Schokkaert, 2013; Akter & Razzak, 2022). On the public-finance side, financing methods matter: raising $1 of revenue via distortionary taxes imposes an excess burden, so project appraisal should incorporate the marginal cost (or value) of public funds (MCF/MVPF) to convert budget outlays into social costs; otherwise, NPV conflates financial with welfare prices. Modern treatments show how to compute these conversion factors from elasticities and administrative tax formulas and, in the MVPF approach, how to compare heterogeneous policies on a common welfare scale (Castillo & et al., 2021; Chetty, 2009; Imbens & Wooldridge, 2009; Kleven & Kreiner, 2006). In infrastructure CBAs this enters as a shadow price on public funds, applied consistently to both costs and fiscal externalities (e.g., net tax receipts due to induced economic activity), guarding against misinterpreting fiscal flows as welfare benefits. A persistent source of confusion in pre-construction debates is the conflation of BCA with economic-impact/multiplier studies. Input–output or CGE models trace economy-wide output and employment effects of spending, but those gross flows are not welfare per se; most are transfers or re-allocations unless they relax real constraints or change preferences/technologies. BCA, by contrast, is built around changes in consumer/producer surplus and nonmarket WTP, and already counts generalized-cost savings (e.g., travel time) wherever they occur there is no additional welfare to claim by also counting the spending that produced the savings. Recent efforts show how to connect the two approaches coherently embedding project accounts in a SAM/CGE framework while retaining BCA's money-metric welfare measures but the unifying message is to prevent double counting and keep the counterfactual explicit (Castillo & et al., 2021). Comparative transport-appraisal work likewise finds that MCDA can supplement deliberation over non-monetizable objectives, but when the objective is economic efficiency, BCA's welfare foundation provides the appropriate test.

Uncertainty is unavoidable in pre-construction planning; welfare-consistent indicators remain meaningful only if analysts expose the assumptions that drive them and examine robustness. Best

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practice now emphasizes (i) deterministic sensitivity tests on key parameters; (ii) scenario analysis for correlated shocks; and (iii) probabilistic analysis that propagates distributions for major inputs (demands, unit values, costs) into NPV/BCR distributions. Recent guidelines and methods papers synthesize transparent approaches to value-of-information, standardized sensitivity analysis, and reporting conventions that make ex-ante welfare claims more credible and comparable across studies. Linking the uncertainty framework to the causal logic is crucial: the range should reflect identification risk (how sure we are that a parameter is causal for the context) and transfer risk (how well estimates travel across settings). That orientation helps decision makers read NPV and BCR as decision aids with stated confidence, not as point-value certainties. Putting the pieces together, a welfare-consistent definition of economic impact for pre-construction infrastructure appraisal proceeds in four linked steps. First, define the decision problem and alternatives; second, construct a credible counterfactual, using causal evidence and/or validated structural models; third, monetize all welfare-relevant consequences with consistent WTP-based unit values (including time, risk, and environmental quality) and apply appropriate conversion factors for public funds; and fourth, compute NPV/BCR/IRR with clear uncertainty analysis and transparent reporting of distributional incidence. The intellectual foundations Kaldor–Hicks, surplus theory, and money-metric welfare; causally disciplined counterfactuals; and coherent public-finance treatment ensure that "impact" means an improvement in social welfare, not just a surge of activity. This is the concept that travels across sectors and jurisdictions and that provides a defensible basis for ranking options before government commits to design, procurement, and construction.

International Appraisal Regimes Shaping Pre-Construction CBA

Across countries, the "rules of the game" for pre-construction cost–benefit analysis (CBA) are set not just by economic theory but by appraisal regimes: codified guidance, parameter libraries, institutional review processes, and decision gate rituals that govern how benefits and costs are defined, monetized, discounted, and compared. Cross-national surveys consistently show that while CBA is the dominant ex-ante tool for transport and other infrastructure sectors, regimes differ on scope (which impacts are in or out), parameter sources (values of time, safety, and carbon), treatment of uncertainty, and the place of distributional analysis and "wider economic impacts" (WEIs). Early comparative work in Europe documented convergence around monetising direct user benefits but sizable divergence on environmental, social, and equity effects, reflecting distinct policy priorities and modelling traditions (Bristow & Nellthorp, 2000; Hayashi & Morisugi, 2000). Subsequent syntheses observed a broad "family resemblance" across national manuals, tempered by country-specific modules for example reliability, agglomeration and different expectations about how ministers should use CBA evidence at the planning gate (Beukers et al., 2012; Holmen et al., 2022; Mackie et al., 2014). These regime differences matter because they shape option ranking long before designs are fixed: what is eligible to be counted, how it is priced, and how uncertainty is depicted will shift net present value (NPV) and benefit–cost ratios (BCRs) even for the same asset (Bristow & Nellthorp, 2000; Geurs et al., 2009). Within Europe, the UK's Transport Analysis Guidance (TAG) under the HM Treasury Green Book and the European Commission's Cohesion Policy CBA ecosystem have served as templates for others. Independent reviews highlight two features that make these regimes influential at the pre-construction stage. First, they define a canonical "core" of transport user benefits (time, operating costs, safety) and externalities, paired with published parameter sets (values of time and reliability, VSL, emission damage costs) and explicit counterfactuals; second, they embed sensitivity, switching-value tests, and documentation standards that force analysts to expose the assumptions that drive rankings (Mackie et al., 2014). Comparative scholarship also notes that UK/EU regimes have gradually opened space for WEIs where market imperfections justify them, but with safeguards to avoid overlap with user benefits and to keep NPV/BCR interpretable (Mackie et al., 2014; Mouter et al., 2013). A parallel strand observes that social and distributional impacts longer recognized in policy narratives have entered appraisal unevenly: UK and Dutch practice incorporate social impact and equity lenses more actively than some EU peers, though the monetisation depth still varies . In short, the European "style" at the pre-construction gate is to combine a welfare-economic core with increasingly codified modules for reliability, environment, and WEIs, evaluated transparently against a do-minimum baseline and reported with sensitivity analysis .

Figure 3: Key Components of International Appraisal Regimes

Scandinavian and Dutch practice illustrate how similar technical methods can interact with institutions in different ways. Sweden's transport sector has a long CBA tradition; research shows planners' rankings in national investment plans correlate with BCRs, although political rankings may deviate, especially for small projects (Mouter et al., 2013; Vickerman, 2017).Analyses of Swedish practice report robust plan-level rankings to parameter changes suggesting the core method provides stable signals to decision makers at the pre-construction gate even as debates continue on discounting and marginal cost of public funds (Vickerman, 2017). Norway, by contrast, exhibits a weaker link between CBA results and selection in national road plans, which comparative work attributes to political bargaining and regional considerations that dilute the weight of BCRs in gate decisions. The Netherlands adds a third variant: CBA is mandatory for major projects, but how decision makers use it depends on institutional norms and actors' beliefs about CBA's role; attitudinal and process studies in the Dutch context emphasize that acceptance is higher when analysts are explicit about uncertainties and present scenarios rather than single numbers. Together, this literature suggests that a technically similar CBA toolkit can produce different pre-construction behaviors depending on political interfaces and review culture, underscoring why a literature review must treat "use of CBA" as an institutional variable rather than an invariant feature of the method. Anglophone regimes outside Europe have converged on similar technical cores but diverge in how they operationalize them. Australia's ATAP Guidelines articulate a detailed pre-construction pathway: problem definition, longlist/shortlist, and CBA with standard prices covering time, vehicle operating costs, safety, and emissions, plus reliability and land-use considerations where material (ATAP). New Zealand marries a classical CBA manual with the Treasury's CBAx tool, which provides a parameter database and a structured template for distributional analysis and wellbeing framing features that the policy literature associates with improved transparency in budget bids and early project appraisal (NZ Treasury CBAx; Policy Quarterly discussion). In the United States, sector-specific BCA guidance proliferates for federal discretionary grants and modes; FRA's rail BCA guidance lays out a consistent method, parameter sources (e.g., DOT value of time, VSL), and reporting templates aimed squarely at pre-construction comparisons across alternatives. A common thread across these Anglophone regimes is that early-stage appraisals are expected to report scenario/sensitivity ranges, incorporate risk where possible, and document base-year prices and discounting conventions; where they differ is the degree to which distributional results, accessibility metrics, or WEIs are

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expected alongside core welfare metrics. (ATAP; NZ Treasury CBAx 2021/2022; FRA BCA Guidance, 2016).

Asian contributions to the appraisal-regime literature are longstanding. Hayashi and Morisugi's classic comparative analysis contrasted underlying concepts (efficiency, equity, sustainability) and methods (CBA vs. multi-criteria) across countries, stressing that institutional priorities determine which effects are monetized and which are presented qualitatively. Their EU–Japan comparison remains useful at the pre-construction stage for clarifying that methodological choices (e.g., whether to include WEIs or to use explicit distributional weights) are not merely technical but institutional, reflecting national policy goals and administrative capacity. These insights continue to underpin modern regime comparisons and the design of hybrid appraisal frameworks in Asia and Europe alike. (Annema et al., 2017; Bristow & Nellthorp, 2000; Holmen et al., 2022; Mackie et al., 2014). Regimes primarily diverge on three fronts that decisively shape pre-construction rankings. First, parameterization: values of time (and reliability), VSL, and emission damage costs vary and are updated at different cadences, shifting absolute NPVs and sometimes relative rankings. Comparative reviews document these differences and their implications for transferability across contexts (Currie et al., 2011; Mouter et al., 2013; Vickerman, 2017). Second, treatment of "wider" effects: regimes now commonly provide WEI modules (e.g., agglomeration, imperfect competition, labor market responses), but they differ on conditions and elasticities; surveys of guidance emphasize the need to avoid double counting and to report WEIs transparently alongside core welfare results . Third, social and distributional impacts: while equity is central to political legitimacy, incorporation into CBA remains uneven; UK/Dutch practice give social impacts greater prominence, whereas others rely more on qualitative statements or separate distributional annexes. For pre-construction planning, these differences translate into different expectations about what must be evidenced in an initial business case and how to present scenario ranges and switching values (Currie et al., 2011; Mouter et al., 2013; Vickerman, 2017). Beyond manuals, institutions determine whether quantified results steer early decisions or merely inform them. In the Netherlands, an analysis linking 106 CBAs to decisions found that while more favorable CBA results were associated with implementation, the relationship is mediated by factors such as project type and political context implying that pre-construction CBAs carry weight but not determinism (Annema, Koopmans, Kroesen, & Frenken, 2017). Process studies in the Dutch setting report that key actors accept CBA as a decision input when analysts engage with uncertainties and make assumptions explicit; resistance rises when CBA appears as a black box or when distributional narratives are absent. In Scandinavia, synthesized evidence suggests Swedish civil-service rankings strongly reflect BCRs, whereas political prioritization can diverge; in Norway, benefit–cost efficiency has historically had less influence on road investment selection, reflecting a different institutional interface (Arifur & Noor, 2022; Vickerman, 2017). For pre-construction planning, the functional implication is clear: the same CBA can be powerful or peripheral depending on review culture, transparency norms, and whether the regime requires explicit documentation that links NPV/BCR to objectives and constraints.

Modeling for Government Infrastructure

Establishing a defensible counterfactual is the first non-negotiable step in pre-construction appraisal. Analysts specify a "do-nothing" or "do-minimum" baseline that fixes policy settings, maintenance, and committed works, and then forecast how demand and level-of-service evolve absent the candidate project. The choice is not cosmetic: every welfare metric in cost–benefit analysis (CBA) net present value, benefit–cost ratio, internal rate of return derives from incremental changes relative to that baseline. In transport, baseline design implies a coherent network representation, an origin–destination (O–D) matrix consistent with demographics and land use, and route choice rules that obey user equilibrium; in energy and water, it implies load and hydrology scenarios with reliability criteria spelled out and linked to user costs of outages or shortages. Two modeling traditions tie these pieces together. First, discrete-choice demand models grounded in random utility theory translate attributes (time, cost, comfort, reliability) into probabilities of choosing modes, routes, times, technologies, or locations; these models allow transparent transfer of behavioral parameters into forecasts (Hong & Fan, 2016; Ortúzar & Willumsen, 2011). Second, assignment and system models map demand onto networks over time, so exposures vehicle kilometers, passenger hours, throughput, or outage minutes line up with welfare valuation modules. Calibrating both to observed behavior and reporting validation diagnostics is essential; back-casting onto past years is often the simplest credibility check before any benefits are computed. (Hong & Fan, 2016; Ortúzar & Willumsen,

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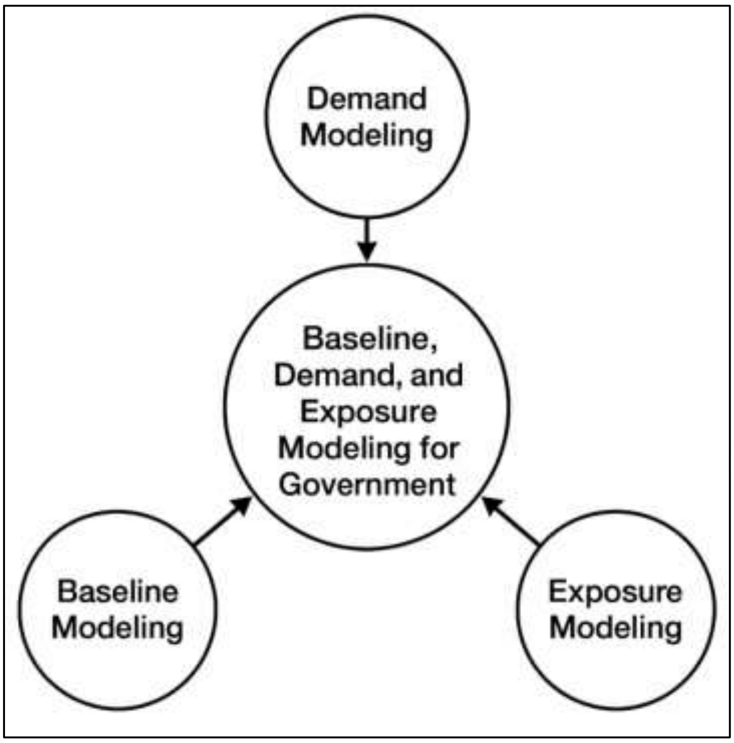
2011). On the demand side, the workhorse remains individual-level discrete choice. Activity- or tour-based model systems articulate the full day's schedules and capture interdependencies among trip timing, mode, and destination that four-step trip models handle only approximately (Bowman & Akiva, 2001). The attraction for pre-construction CBA is that estimated marginal utilities of time and money slide directly into welfare measures: the ratio of their coefficients yields a revealed value of time and, with extensions, a value of reliability. Modern practice calibrates mixed logit (random-parameters) and nested logit structures to accommodate taste heterogeneity, correlation, and flexible substitution patterns; estimation is routinely accomplished by simulation methods detailed in Train (2009). These systems are not "black boxes": they demand careful specification of choice sets (e.g., feasible routes or modes), attention to endogeneity (e.g., price and congestion), and rigorous validation against withheld data. Where resources allow, activity-based systems reduce aggregation error and improve exposure modeling for policies that shift departure times or induce trip-chaining, both decisive for valuing time and reliability. (Bowman & Akiva, 2001; Hong & Fan, 2016; Ortúzar & Willumsen, 2011).

Figure 4: Core Components of Government Baseline



Mapping demand onto networks is equally determinative for exposure metrics. Static user-equilibrium assignment is often adequate for screening, but dynamic traffic assignment (DTA) becomes important whenever queue spillbacks, within-peak dynamics, or reliability are central to benefits. Recent reviews synthesize DTA formulations (link-based vs. cell-transmission vs. simulation-based) and their numerical properties, providing practical guidance on when to invest in dynamic models during pre-construction (Fosgerau & Karlström, 2010; Hong & Fan, 2016; Wang et al., 2018). DTA's payoff for CBA is two-fold: it yields time-resolved exposures (travel time distributions, schedule delay, speed profiles) and it preserves network feedbacks that condition induced demand and rerouting. Because appraisal values *changes* in generalized cost, analysts should retain consistent priors for variability and correlation across scenarios and test whether projected benefits hinge on dynamic effects (e.g., peak-spreading). Where DTA is not feasible, robust static alternatives can still deliver decision-quality results by using reliability skims and scenario averaging (Wang et al., 2018; Wong, 2011).

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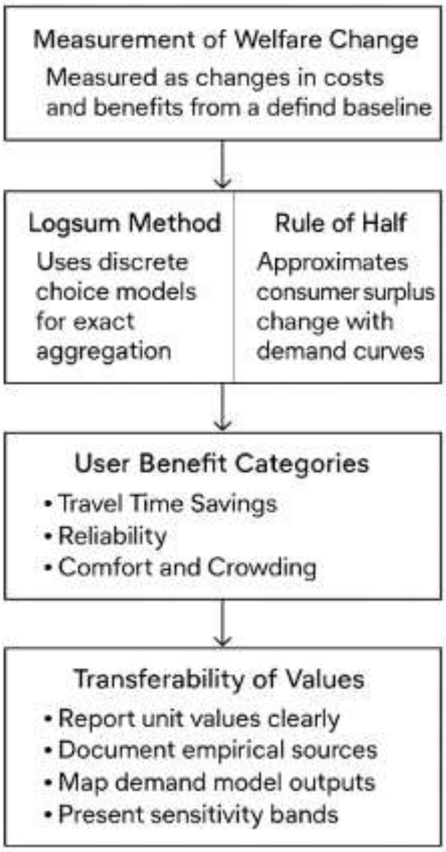
The same logic extends beyond transport. In electricity planning, the "baseline" combines load forecasting with existing network performance and regulatory reliability criteria. Probabilistic short- and long-term load forecasting has become standard, and recent tutorials explain methods (from generalized additive models to machine learning ensembles) and critically for appraisal how to represent forecast uncertainty. Exposure to unreliability is measured by indices such as SAIDI and SAIFI, but CBA requires translating minutes-out into welfare loss using value-of-lost-load (VoLL) or customer interruption cost studies; sector-specific estimates document wide heterogeneity by customer class and outage context. For water supply and multipurpose reservoirs, the classic performance triplet reliability, resilience, and vulnerability offers a clean exposure language for benefits when projects reduce failure frequencies and depths; those metrics can be embedded in cost–loss functions aligned to end users (Hashimoto, Stedinger, & Loucks, 1982). In both sectors, the key is the same as in transport: define the baseline clearly, forecast demand probabilistically, simulate system performance under stressors, and monetize the *difference* in exposure between baseline and project cases. Credibility finally rests on validation and transparency. History shows that forecasts can mis-estimate exposure dramatically; well-known audits of urban rail systems documented persistent over-prediction of ridership and under-prediction of costs, reinforcing the need for back-casting, out-of-sample validation, and reference-class checks before leaning on benefit calculations (Pickrell, 1990). In practice, pre-construction teams should: (i) publish baseline and project O–D tables and network performance diagnostics; (ii) disclose key elasticities (e.g., demand with respect to generalized cost); (iii) report reliability metrics and their mapping to money values; and (iv) run systematic sensitivity and scenario tests, including induced-demand ranges and demand shocks. Doing so moves the argument from "model says" to "assumptions imply," which is precisely what decision makers need at the planning gate (Pickrell, 1990).

User Benefits and Operating Cost Savings

In pre-construction appraisal, user benefits and operator (agency) cost savings are measured as changes in welfare relative to a clearly specified baseline. The core principle is money-metric utility: benefits and costs are valued by how much individuals would be willing to pay (or accept) to obtain (or avoid) the change. For transport and most linear infrastructure, the workhorse is the consumer-surplus change implied by generalized travel cost time, out-of-pocket expenses, schedule delay, comfort/crowding while on the supply side analysts track operating and maintenance (O&M) costs, staffing, energy/fuel, and lifecycle wear. Welfare measurement should be grounded in internally consistent formulas so that totals add across user classes and time and do not double-count overlapping effects. Two complementary welfare tools dominate practice. First, when demand models are discrete-choice (e.g., logit or mixed logit), the logsum (inclusive value) provides a direct estimator of compensating variation for each traveler or market segment, ensuring exact aggregation of option values across modes, routes, times, and even trip-making decisions when they are modeled in utility (de Jong et al., 2007; Small & Rosen, 1981). Second, when analysts work from demand curves or sketch models, the rule-of-half approximates the consumer-surplus change for marginal and newly generated trips, provided changes are not too large and price/time shifts are well characterized (Mackie et al., 2001). Both approaches require a consistent price base year, clear discounting conventions, and segmentation by user type (commute, business, leisure), income, mode, and time-of-day to reflect heterogeneous valuations.

The largest user benefit category is typically travel-time savings. Transferable values of time (VOT) vary systematically with income, trip purpose, and context; meta-analyses show higher VOT for business travel and for congested/low-quality conditions, and they provide elasticities and adjustment rules that make cross-study transfer credible at the planning gate (Abrantes & Wardman, 2011). Where projects alter reliability, benefits arise from reduced travel-time variance and schedule delay. Reliability should be measured as a change in the distribution of travel times e.g., improvements in the 90th percentile or buffer time not as a fudge factor applied to mean time; empirical syntheses document welfare-consistent reliability ratios that allow conversion to money metrics without overlap with average time savings (Bates et al., 2001). Comfort and crowding can be integrated as generalized-cost penalties per passenger-minute when supported by preference evidence, keeping these distinct from time and reliability terms in the utility function.

Figure 5: Framework for Measuring and Transferring User Benefits



Vehicle/plant operating costs (fuel, parts, tires, lubrication, routine maintenance) should be tied to physical exposure vehicle-kilometres, speed profiles, grades and priced with transparent unit costs, while tolls and fares are treated carefully: a toll is a cost to users and a transfer to the operator; only deadweight components (e.g., pricing that reduces overuse of a congested facility) yield net welfare gains in the user-benefit ledger. On the supply side, operator O&M savings include energy, staffing, routine maintenance, and incident response costs; when these are funded from distortionary taxation, some regimes apply a conversion factor for the marginal cost of public funds in the accounting price of resources. To avoid double counting, do not simultaneously claim a reduction in user fuel costs and an identical "agency fuel saving" unless the agency truly bears part of that cost. Transferability hinges on parameter provenance and context alignment. Good practice is to (i) report every unit value with units and price year, (ii) document its empirical source and any income or context adjustment factors, (iii) map demand and assignment outputs to the exact exposure definitions used by the unit value (e.g., person-hours by purpose for VOT; percentile travel time for reliability), and (iv) present sensitivity bands around all high-leverage parameters. When discrete-choice models are available, logsum-based welfare provides internal consistency across simultaneous changes in time, cost, and attributes; when using sketch methods, the rule-of-half offers a tractable approximation so long as analysts show the implied demand shifts and keep generated-trip benefits separate from diverted-trip benefits.

Valuing Safety and Health

In welfare consistent cost benefit analysis at the pre construction stage, safety and health enter primarily through the value of a statistical life (VSL) and companion unit values for non fatal injuries by severity, converting heterogeneous risk changes into a common monetary metric that integrates seamlessly with other benefits and costs under consistent discounting and price base conventions. VSL represents the marginal rate of substitution between wealth and a small fatality risk reduction, derived from observed trade offs between money and safety in wage premia for hazardous occupations or consumer safety purchases and from stated preference experiments. Empirical

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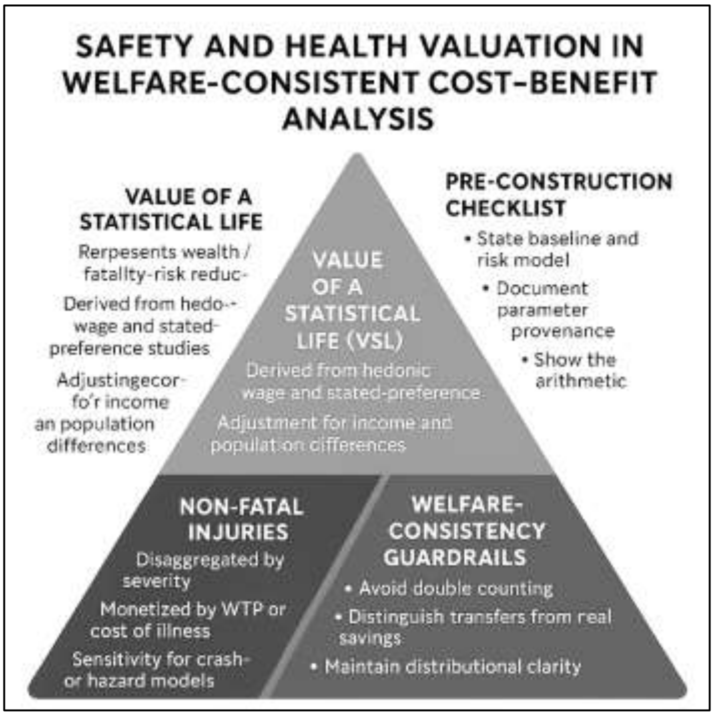
estimation falls into two broad families: hedonic wage studies, which exploit compensating differentials to infer willingness to pay (WTP) for risk reductions after correcting for selection and measurement errors, and contingent valuation or discrete choice experiments, which elicit WTP directly for safety improvements in diverse contexts (Aldy & Viscusi, 2008; Hirth et al., 2000; Kniesner et al., 2012).

Figure 6: Framework for Safety and Health Valuation



Meta analyses synthesize these findings to produce central VSL estimates and defensible sensitivity bands, such as those widely used for U.S. appraisals, while preserving uncertainty for robust policy analysis. Transferring VSL to new contexts requires systematic adjustments: first, convert source values to the appraisal's price year and currency using GDP deflators and purchasing power parity factors; second, apply an income elasticity factor commonly between 0.5 and 1.0 for high income transfers, with higher values for low and middle income settings to reflect proportional WTP differences across populations; and third, consider population characteristics such as age or baseline health by reporting unweighted VSL totals and, where ethically or analytically justified, conducting sensitivity with a value of a statistical life year (VSLY). The transfer protocol should document the original VSL source and method, price adjustments, income elasticity rationale, and present low, central, and high values for transparent sensitivity analysis (Kochi et al., 2006; Mrozek & Taylor, 2002). Non fatal injuries, which projects frequently affect alongside fatalities, warrant disaggregation by severity using MAIS/ISS levels or policy specific categories, and monetization via WTP based unit values or, lacking these, cost of illness hybrids that adjust medical costs upward to approximate full welfare losses. Operationally, analysts forecast changes in crashes by type and severity with crash modification functions, apply the appropriate unit values per case, and sum across severities and time with consistent discounting. The modeling chain from risk mechanics to monetized benefits must be explicit early in pre construction

In transport, assignment outputs flows, speeds, travel time distributions feed crash prediction models to estimate expected changes in fatalities and injuries by severity. In construction safety programs, changes in worker exposure hours, hazard rates, and compliance drive risk reduction estimates. In utilities or environmental projects, analysts translate reduced probabilities of catastrophic failure or pollutant exposure into Δ probability × consequence metrics. Monetization multiplies these risk change estimates by VSL or injury unit values, adhering to the same price year and discounting architecture used for time savings, reliability, and other benefits. Given substantial uncertainty in safety benefit estimates, best practice includes one way sensitivity tornado charts, scenario bundles

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(e.g., high versus low injury baselines), and probabilistic ranges for key parameters, ensuring transparency on how safety benefits compare to travel time or O and M ledgers. Three guardrails safeguard welfare consistency: first, avoid double counting by treating each risk reduction only once as a consumer surplus gain rather than recasting it as both a user benefit and a wider economic impact; second, distinguish transfers (medical payments, insurance reimbursements) from real resource savings, excluding pure transfers from net present value (NPV) unless they generate net fiscal deadweight effects; and third, maintain distributional clarity by reporting unweighted totals alongside subgroup incidence (by age, user type, or geography) and applying any normative weighting transparently under explicit decision rules (Murphy & Topel, 2006; Robinson et al., 2019a; Viscusi, 2018). A concise pre construction checklist ensures rigor: state the baseline and risk model, crash or hazard types, severity mappings, exposure variables, and validation diagnostics; document parameter provenance, VSL/injury values, price year, income and demographic adjustments; and show the arithmetic, risk deltas by severity multiplied by unit values, additivity checks, and consistency with other benefit streams, to deliver a defensible, transparent safety and health appraisal (Viscusi & Aldy, 2003).

Environmental Externalities and Natural Capital in CBA

In pre-construction appraisal, environmental externalities are valued as changes in social welfare that arise when a project alters emissions, exposures, or ecosystem functions relative to a clearly specified baseline. The practical pipeline is: (1) model how the option changes activity and technology (e.g., vehicle kilometers by speed bin, stack characteristics, land conversion); (2) translate activity into physical emissions or biophysical impacts ($PM_{2.5}$, NO_x, CO_2, noise, habitat loss); (3) propagate these through exposure or impact pathways (air quality dispersion, hydrology, habitat production functions) to estimate changes in morbidity/mortality risks, crop yields, materials damage, or ecosystem services; and (4) convert those physical effects into a money metric consistent with willingness-to-pay (WTP). Done correctly, the outputs slot cleanly into the same discounting and price-base architecture as user benefits and operating costs, so decision makers can compare options on a single welfare scale. Integrated "emissions-to-damages" accounts demonstrate the approach: marginal damages depend on where and when pollutants are emitted, the size and vulnerability of the exposed population, and atmospheric chemistry, so unit values should be location- and time-specific whenever material (Muller et al., 2011). For local and regional air pollutants, the appraisal objective is to estimate monetized health and non-health damages from changes in concentrations. A defensible chain expresses damages as the product of (i) Δconcentration in each receptor grid cell, (ii) exposed population and baseline incidence, (iii) concentration–response functions for health endpoints, and (iv) unit values for mortality and morbidity (e.g., VSL and willingness-to-pay to avoid illness days). Non-health channels material corrosion, visibility loss, crop yield are added on the same footing if relevant. Because marginal damages vary by source and location, analysts should avoid generic national averages when siting and chemistry produce large gradients; at the screening stage, transparent ranges that reflect receptor density can approximate this heterogeneity. A similar "physics-to-welfare" chain supports noise, vibration, and water-quality externalities, with appropriate propagation models and valuation studies; what matters is that each pathway ends in a money-metric welfare change aligned to the exposure definition used in the modeling (Muller et al., 2011).

For greenhouse gases, the canonical metric is the social cost of carbon (SCC): the present value of global welfare damages from one additional tonne of CO_2-equivalent emitted today. SCC embodies a long chain from carbon cycle to climate to sectoral damages and it is sensitive to discounting, damage functions, and equity weights. While many agencies publish central values, recent scholarship shows that damages and optimal prices vary by emitting country/region, reflecting heterogeneity in vulnerability and income; for planning-gate transparency, analysts should (i) state which SCC series is used (global or country-level), (ii) report the discount rate, and (iii) test low/central/high values to show how rankings shift with climate-damage assumptions (Ricke et al., 2018). In multi-gas contexts, apply consistent global warming potentials or GTP/GWP* conventions and ensure that upstream and downstream emissions (construction, energy supply) are treated once either inside the project ledger or in the baseline, but not both. "Natural capital" enters CBA when land- or water-based projects change ecosystem functions that people value. Two implementation routes are common. The production-function approach links biophysical changes (e.g., wetland area, riparian vegetation, floodplain storage) to outcomes people care about (flood

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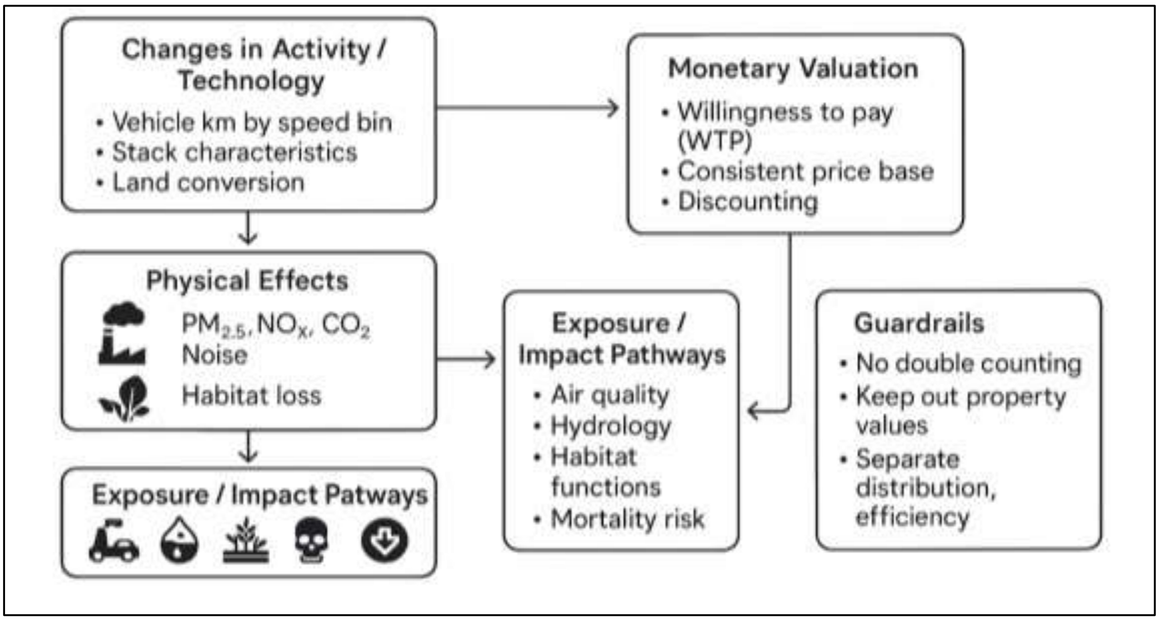
damages avoided, water purification, recreation, habitat), then monetizes those outcomes using WTP-based values or defensible cost-based proxies where WTP is unavailable. The spatially explicit ecosystem-services route integrates land-use scenarios with ecological models to produce maps of services and beneficiaries before valuing them. A core message from applied work is to tether valuation tightly to observable decisions and beneficiaries, avoid mixing accounting prices with market transfers, and report uncertainties that arise from both ecology and preferences, not only from prices (Bateman et al., 2013).

Figure 7: Process Framework for Valuing Environmental Externalities

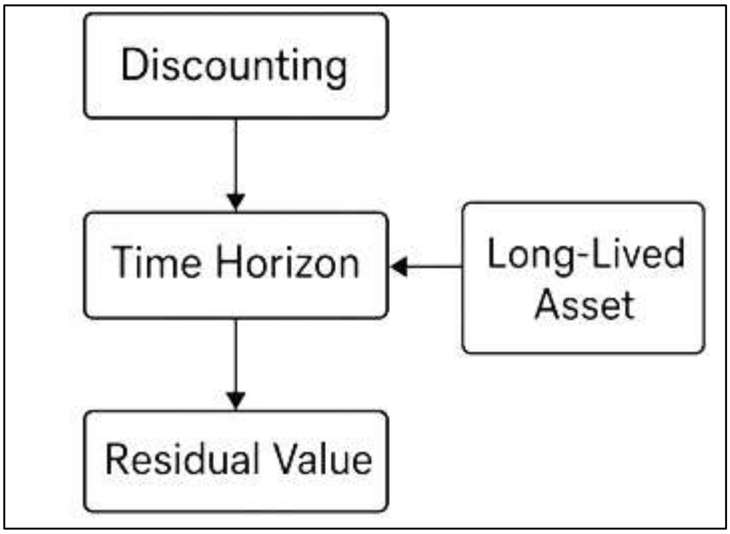


Because primary valuation is not always feasible at concept stage, benefit transfer is often necessary. Credible transfer rests on three practices: (1) choose studies from similar ecological and policy contexts; (2) adjust values for income levels, scope, and site characteristics using reported elasticities or meta-analytic functions; and (3) propagate transfer error with sensitivity bands so decision makers see how much rankings rely on imported numbers. Contemporary reviews emphasize function transfer over single-point value transfer whenever the receiving site differs materially from the study site; they also recommend explicit tests for scope sensitivity and for embedding effects in stated-preference sources (Johnston & Rosenberger, 2010). Across all environmental modules, three guardrails keep the ledger welfare-consistent. First, no double counting: if time savings already capture improved speeds, do not also claim the same speed-driven fuel savings under "environment," and avoid counting both market prices and damage costs for the same unit of fuel. Second, keep capitalized property-value effects out of totals when the underlying benefits (e.g., quieter streets, cleaner air, access to green space) are already monetized in the ledger hedonic prices mirror the present value of those very flows. Third, separate distribution from efficiency: report who gains and who loses (by neighborhood or income group) alongside the unweighted NPV/BCR; apply normative weights, if the regime requires them, only after transparent reporting of totals. In coastal and riverine settings where risk reduction is a central service (e.g., mangroves attenuating storm surge), be explicit about joint products and substitutes (levees, early-warning systems) to prevent stacking overlapping benefits. Sector syntheses show that when exposure modeling, valuation, and transfer are aligned to beneficiaries and biophysical pathways, environmental and natural-capital benefits integrate seamlessly with user benefits in pre-construction CBA and materially affect option ranking often by surfacing advantages of designs that protect or restore ecosystem functions over like-for-like gray alternatives (Barbier et al., 2011).

Residual Value for Long-Lived Assets

In pre-construction CBA, discounting converts future streams of benefits and costs into a common money metric today so mutually exclusive options can be ranked on welfare, not on the raw size of undiscounted flows. For public projects, the discount rate is a *social* parameter, not a private hurdle rate: it encodes how society trades off present against future consumption, how fast living standards are expected to grow, and how risk is priced across time. A convenient organizing lens is the Ramsey formula, which decomposes the social time preference rate into pure time preference, the elasticity of marginal utility with respect to consumption, and expected consumption growth. That framing clarifies why rates differ across jurisdictions and why sensitivity testing is obligatory when long-lived assets or long-tailed externalities are involved (Arrow et al., 2013). For very long horizons, the main technical issue is uncertainty about future growth and returns. If the future discount rate is itself uncertain, then the *certainty-equivalent* discount factor falls over time, which implies declining discount rates even when each short-run rate is constant. This "gamma discounting" argument and related results formalize why analysts often report both constant and declining schedules for very long-lived or intergenerational effects (Weitzman, 2001).

Figure 8: Time Horizons, and Residual Value in Pre-Construction Cost–Benefit Analysis



In practice, a transparent protocol at the planning gate is to compute NPV/BCR at one or two constant real rates for comparability across alternatives, and then add a declining-rate sensitivity (e.g., a step-down schedule) to show how rankings behave when growth and interest-rate uncertainty compound. Not all project cash flows should be discounted at the same rate. Welfare-consistent practice distinguishes flows by their systematic risk their correlation with aggregate consumption. Risky benefits that arrive in booms are worth less at the margin than risk-reducing benefits that arrive in downturns. A tractable public-economics implication is to discount *consumption-like* flows with a risk-adjusted rate and *risk-mitigating* flows with a lower rate that reflects their hedging value. For long-dated assets under uncertain growth and catastrophic risk, theory supports lower effective rates than those used for short-to-medium horizons, strengthening the case for schedules that fall with time rather than a single constant number (Gollier, 2012a). That logic is consistent with empirical evidence from asset markets suggesting very long-run discount rates can be markedly lower than short-run rates, lending external support to the declining-rate sensitivities used in public appraisal for century-scale externalities (Giglio et al., 2015). The horizon should be long enough to capture the economic life of major components and any material externalities beyond that life. For transport structures, 30–60 years often captures most user-benefit and cost exposure; for energy, water, and coastal resilience projects, horizons may be longer when decommissioning, residual risks, or environmental effects persist. Two practical tests help: first, confirm that extending the horizon by a decade changes NPV/BCR only marginally; second, check that any omitted tail is explicitly represented in a residual calculation. When unit values (e.g., value of time, value of statistical life, damage costs) grow with income, analysts should implement *real* growth of those values in line with income projections to avoid understating far-future benefits, while guarding against compounding that overwhelms plausibility. All modeling must be in either real or nominal terms consistently, with the discount rate expressed in the same terms and a clearly stated price-base year (Drupp et al., 2018a; Newell & Pizer, 2003a).

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Residual value is not a bookkeeping afterthought; it is the present value of the asset's remaining service potential net of decommissioning and environmental liabilities at the terminal year of analysis. There are three defensible, transparent methods. *(i) Market-based salvage:* use expected resale or scrap value for movable equipment and materials, minus disposal costs. *(ii) Depreciated replacement cost:* prorate the replacement cost of components by remaining life fractions at the terminal year; this mirrors straight-line or age-efficiency profiles for structures and systems. *(iii) Continuation value:* compute the discounted value of net benefits beyond the terminal year under a steady-state or declining profile; this requires explicit assumptions about post-horizon demand, costs, and parameter growth (Drupp et al., 2018a; Newell & Pizer, 2003a). Whichever route is chosen, analysts should: separate land (often non-depreciating) from structures; include decommissioning and site remediation costs where relevant; avoid double counting by ensuring the residual does not re-capitalize flows already valued within the horizon; and report low/central/high values tied to lifespan and reuse assumptions. For projects with significant environmental liabilities, residuals can be negative; those tails belong in the ledger. The planning gate may show a minimal, decision-useful package includes: (1) NPV/BCR at a central real rate and one alternative rate; (2) a declining-rate sensitivity for assets or externalities with long tails; (3) explicit real growth assumptions for any income-elastic unit values; (4) a residual-value annex showing method, components, and decommissioning assumptions; and (5) a one-page table that reconciles all discounting choices (rate, horizon, price base) so reviewers can replicate the arithmetic. To keep the welfare interpretation clean, do not mix financial discount rates with social rates; do not apply a "risk premium" by inflating the discount rate when the underlying risk has already been modeled in quantities or valued separately; and always explain how choices about rate, horizon, and residual affect option rankings rather than only absolute NPVs. These practices make the treatment of time explicit, auditable, and comparable exactly what is needed before committing to design and procurement for long-lived public assets.

Uncertainty Architecture

Pre-construction CBA succeeds or fails on how it treats uncertainty. Because all welfare indicators (NPV, BCR, IRR) are functions of inputs demand, unit values (e.g., value of time, VSL), capital and O&M costs, emissions damages, discounting an appraisal needs a structured uncertainty architecture that makes three things explicit: (i) what can vary and why (causal stories, data limits, transfer error), (ii) how variation propagates into the welfare metrics, and (iii) how decision makers should read the results at the planning gate. A practical architecture stacks four layers, from simplest to richest: deterministic sensitivity, scenario design, probabilistic risk analysis, and reference class forecasting. Each layer answers a different question: "what matters most?", "which combinations are plausible?", "how likely are outcomes?", and "how do our assumptions compare with what has actually happened on comparable projects?"

Deterministic sensitivity is the entry point. One-way tests vary a single input (e.g., ±25% capital cost; ±15% demand; ±0.5 percentage points on the discount rate) while holding others fixed, producing tornado charts that rank variables by NPV impact. Two-way tests explore interaction between the most influential pair (e.g., costs × demand). The aim is not to claim precision but to expose leverage which assumptions drive option rankings so reviewers can focus their scrutiny and evidence-gathering. As soon as a model includes more than a handful of uncertain inputs, however, local one-at-a-time checks can mislead (because they ignore interactions). When interactions or nonlinearities are plausible, move to global sensitivity analysis (GSA) that perturbs inputs across their full ranges and quantifies variance contributions (e.g., Sobol' indices) for each input and input-interaction; modern reviews show why GSA is the right diagnostic when multiple modules (demand, assignment, valuation, cost) interact in early-stage appraisal (Pianosi et al., 2016; Saltelli et al., 2010). Scenario design answers a different question: what joint states of the world are plausible and policy-relevant? Rather than sprinkling independent shocks, scenario sets deliberately bundle correlated driverse.g., High-Growth/Low-Cost, Central, Low-Growth/High-Cost, and a Policy-Shift case (carbon price ↑, congestion pricing on/off). Good scenarios are (i) mutually intelligible (clear narratives and parameter tables), (ii) externally coherent (macro/demographic assumptions don't contradict sector modules), and (iii) decision-oriented (each illuminates a tension the gate must resolve). Presenting NPV/BCR for each scenario, with the switching values (the parameter shifts needed to overturn rankings), allows reviewers to reason in the space where planning actually occurs: bundles of assumptions rather than isolated coefficients. Scenario design and GSA are complements: the first

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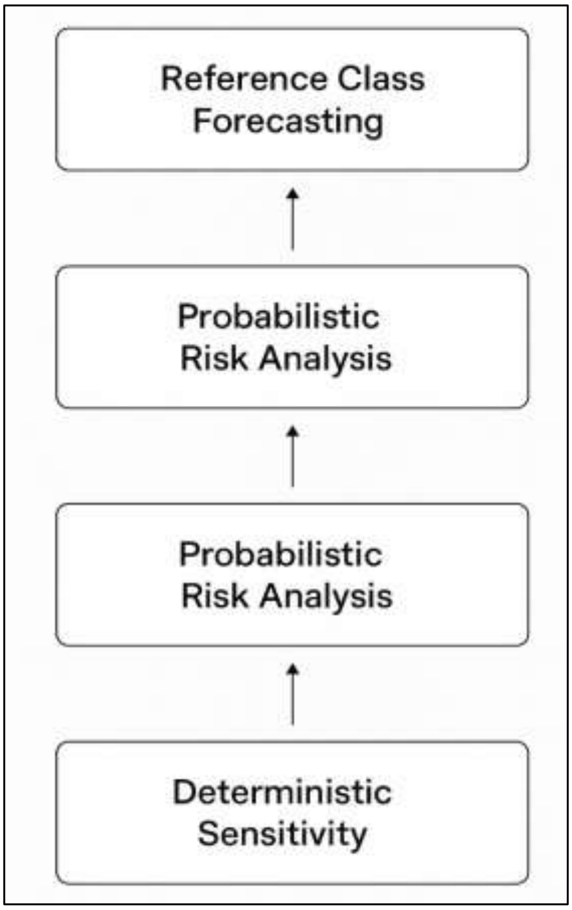
clarifies coherent bundles, the second quantifies which parameters and interactions drive dispersion in results. Probabilistic risk analysis (PRA) adds frequency information. Inputs with empirical or expert-elicited distributions unit rates for earthworks, demand elasticities, value-of-time, injury valuations, emissions damages are sampled (e.g., Latin hypercube) and propagated through the model to generate distributions of NPV/BCR (Flyvbjerg, 2009; Robinson et al., 2019b). This makes it possible to report P50 (median) and P80 (80th percentile) cost allowances or welfare outcomes, to compute probabilities of BCR>1 for independent projects, and to quantify the value of additional information (which parameters, if measured better, would most tighten the decision). Key discipline here: (i) use transparent, well-sourced distributions (from meta-analyses, parameter registries, or measured historical error), (ii) model dependence structures where warranted (e.g., demand growth and value-of-time growth move together), and (iii) keep conservation of units/price year throughout so the probabilistic mix stays welfare-meaningful. Because probabilistic results can create a false sense of certainty, always pair them with plain-language documentation of assumptions and with deterministic cross-checks (e.g., show whether the variables with the largest Sobol' indices are also the ones that flip rankings in scenarios). Guidance for benefit–cost studies emphasizes exactly this pairing of quantified ranges and transparent provenance so that decision makers read uncertainty as a map, not a verdict

Figure 9: Architecture in Pre-Construction Cost–Benefit Analysis



Reference class forecasting (RCF) closes the loop by checking the outside view. Instead of relying solely on a project's internal model, RCF asks: among a class of comparable projects (same sector, scale, country type, delivery model), what were the actual cost overruns, schedule slips, and benefit shortfalls? The distribution of those historical outcomes becomes an uplift (for costs) or haircut (for benefits) applied to the inside-view forecast, calibrated to a chosen certainty target (e.g., P80). Large multi-country studies in transport show systematic cost underestimation and demand overestimation; RCF operationalizes that empirical regularity into data-anchored adjustments at the

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planning gate (Flyvbjerg, 2009; Flyvbjerg et al., 2002). RCF is not a substitute for modeling; it is a guardrail that prevents the decision from resting on a narrow slice of assumptions when the long run of experience says otherwise. A good uncertainty annex (one page per option) therefore contains: (1) the risk register (drivers, rationales, evidence sources); (2) tornado/GSA results with clear units; (3) the scenario table (parameters, narratives, NPV/BCR, switching values); (4) PRA outputs (P50/P80 costs, NPV/BCR distributions, probability of BCR>1 for independent projects); and (5) the RCF adjustments and how they change the decision picture. Two final guardrails keep the ledger welfare-consistent. First, do not bake risk in twice (e.g., inflating the discount rate for risk and applying probabilistic ranges on quantities). Second, show how the uncertainty treatments affect rankings, not only absolute NPVs; the gate decision is comparative.Used together, sensitivity tests, scenarios, PRA, and RCF give pre-construction teams a complete uncertainty architecture: clarity on what matters, plausible bundles of futures, quantified distributions of outcomes, and a reality check from completed projects. That is the combination that turns early-stage CBA from a point-estimate exercise into a decision-ready appraisal under uncertainty auditable, comparable, and honest about where knowledge ends and judgment begins.

METHOD

To This study followed the PRISMA framework to deliver a systematic, transparent, and reproducible review of how cost–benefit analysis (CBA) is applied at the pre-construction stage of government infrastructure. An a priori protocol specified the research question, eligibility criteria, databases, search strings, screening procedures, extraction fields, and quality-appraisal domains. Literature identification covered Scopus, Web of Science Core Collection, EconLit, and TRID, with ScienceDirect and SpringerLink consulted for full-text access where records were indexed elsewhere. Searches used Boolean strings that combined constructs for CBA and welfare-consistent economic impact with phase terms (pre-construction, ex-ante, planning) and sector terms (transport, energy, water, social infrastructure), and were limited to English. To ensure evidentiary strength and comparability, inclusion required peer-reviewed, DOI-bearing studies that (i) conducted an ex-ante, welfare-consistent appraisal for government infrastructure, (ii) stated an explicit counterfactual (do-nothing or do-minimum), (iii) monetized benefits and costs using willingness-to-pay or shadow-price methods, and (iv) reported decision indicators (NPV, BCR, IRR) along with price-base year and discount rate. Exclusion criteria removed post-hoc audits, purely financial feasibility studies, non-welfare "impact" tallies, private-only contexts, non-DOI sources, and non-English items. The search window spanned January 2000 to August 2022, supplemented by backward and forward snowballing. Records were de-duplicated by DOI, title, author, and year; titles/abstracts and then full texts were screened independently by two reviewers with consensus resolution. A standardized extraction form captured bibliographic metadata; sector and country; option sets and counterfactual architecture; benefit categories (time, reliability, safety, environmental, O&M) with units and price year; parameter provenance for values of time, reliability, VSL, and emissions damages; shadow-pricing and conversion factors; discount rate, time horizon, and residual-value method; uncertainty methods (sensitivity, scenarios, probabilistic risk, reference classes); distributional reporting; treatment of wider economic impacts; and reported NPV/BCR/IRR. Study quality was appraised across five domains: counterfactual credibility, parameter provenance, double-counting safeguards, discounting and horizon clarity, and uncertainty reporting. Study selection is summarized in a PRISMA flow diagram; all protocol decisions, search strings, screening outcomes, and coded extraction fields were logged for auditability.

Screening and Eligibility Assessment

A All search results were exported with full bibliographic metadata (title, authors, year, journal, abstract, DOI, keywords) and imported into a reference manager and a screening spreadsheet. Records were de-duplicated in a three-step pass: exact DOI match, then exact/normalized title match (case/diacritics insensitive), then fuzzy title–author–year matching to catch encoding and punctuation variants; where a preprint and a peer-reviewed version both existed, the peer-reviewed article was retained. Two reviewers conducted a calibration round on a pilot set to harmonize interpretation of the inclusion/exclusion rules and to finalize a controlled vocabulary for reasons for exclusion. Screening proceeded in two stages. Stage 1: Title/Abstract screening. Reviewers independently flagged records Include, Exclude, or Unclear against the a priori criteria: (i) peer-reviewed, DOI-bearing, English-language article; (ii) ex-ante appraisal of government infrastructure; (iii) explicit counterfactual (do-nothing or do-minimum); (iv) monetized benefits and costs using

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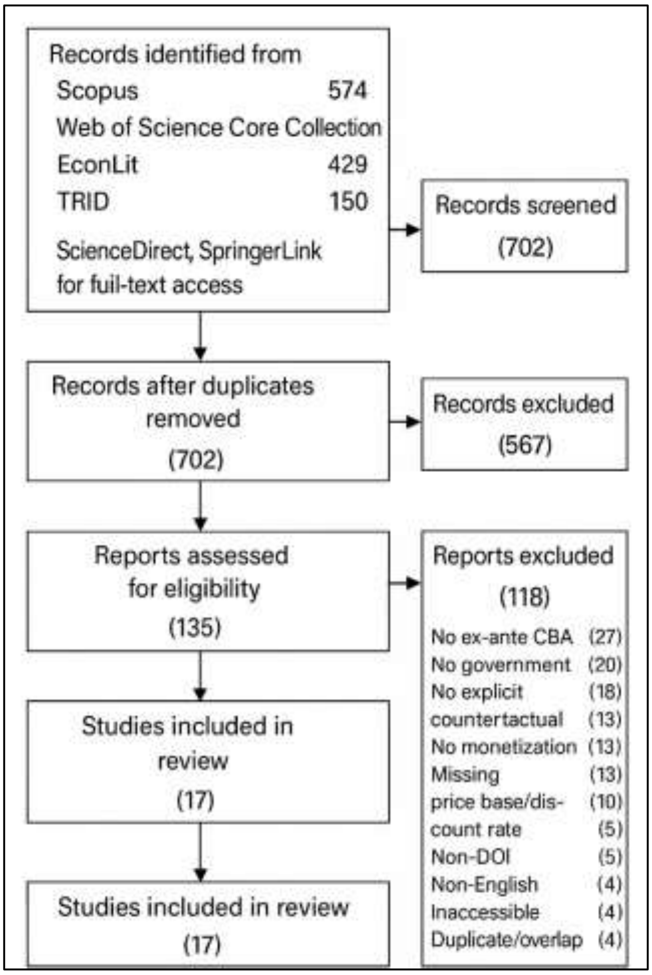
willingness-to-pay/shadow-price methods; and (v) at least one decision indicator (NPV, BCR, IRR) with stated price-base year and discount rate. Stage 2: Full-text eligibility. For all Include/Unclear items, reviewers retrieved the full text and verified: clarity of the counterfactual and option set; provenance and units/price year of parameters (e.g., value of time, reliability, VSL, emissions damages); internal consistency of benefit ledgers (no double counting across time, reliability, safety, environment, O&M); transparency of discounting, time horizon, and any residual-value method; treatment of uncertainty (sensitivity, scenarios, probabilistic risk, or reference classes); and, where reported, distributional results and any wider-impact modules. Articles failing any mandatory item (peer-reviewed DOI; ex-ante government context; explicit counterfactual; monetized benefits and costs; decision indicator with price base and discount rate) were excluded at full text. Conflict resolution followed an independent-review/consensus protocol: disagreements were discussed and, if needed, adjudicated by a third reviewer; decision notes were logged. Special cases were handled uniformly: (a) multiple papers on the same project using the same CBA were consolidated to the most complete article, with others used only for missing details; (b) sectoral or methodological overview papers without a project-level ex-ante CBA were excluded but could inform background; (c) inaccessible full texts after institutional access and interlibrary requests were excluded; (d) non-DOI items, conference abstracts, theses, book chapters, and non-English records were excluded at Stage 1. At full text, reasons for exclusion were coded using a fixed list (no ex-ante CBA; no government context; no explicit counterfactual; no monetization; missing NPV/BCR/IRR; missing price base/discount rate; non-DOI; non-English; inaccessibility; duplicate/overlap) and are summarized in the PRISMA flow diagram.

Figure 10: Methodology adopted for this study



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Data Extraction and Coding

After completing eligibility screening, we turned to a structured data-extraction protocol that acted as our steady compass, guiding us through each study with calm, consistent precision. We worked from a simple but disciplined template that captured what matters for pre-construction CBA: author, year, journal, and DOI; country or region; sector and asset class (e.g., highway, rail, water supply, energy transmission); decision stage or gate; the option set and the counterfactual (do-nothing or do-minimum) exactly as stated; and the full benefit–cost ledger. For each ledger item we recorded the exposure metric and the unit value with units and price year travel-time and reliability values, safety valuations (VSL and injury severities), environmental damages (local pollutants and GHGs), operating and maintenance costs, capital costs, and any residual-value method. Parameter provenance was logged in plain language (local estimate, transferred value, meta-analytic function), alongside the accounting conventions (currency, price base year, real/nominal), the discount rate and time horizon, and all uncertainty treatments (deterministic sensitivity, scenarios, probabilistic ranges, reference-class adjustments). We also noted distributional and spatial reporting (who gains and where) and the handling of wider economic impacts, then captured the decision indicators NPV, BCR, IRR plus any switching values and rank orders. To make numbers comparable, we harmonized monetary figures to a common real price year and documented every conversion step; double counting checks were built in so a single benefit could not be counted twice in different ledgers. Turning extracted facts into insight, we used a reflexive thematic coding workflow: first open coding to catch every recurring idea, then focused coding to organize evidence into core categories welfare-consistent definitions and indicators; appraisal regimes; baseline/demand/exposure modeling; user benefits and O&M savings; safety and health; environmental and natural capital; discounting and horizons; uncertainty architecture; distribution and equity; and wider impacts and reporting transparency. Each article could carry multiple labels, which let us compare patterns across sectors and jurisdictions without flattening nuance. For transparency and consistency, two coders worked independently on a pilot batch, reconciled decisions, and then applied the finalized codebook; spot checks and inter-coder agreement passes were run throughout using spreadsheet tools. The result is a clean study ledger, a parameter registry with units and price years, and a thematic map that together form the backbone of our synthesis.

Data Synthesis and Analytical Approach

Following eligibility and detailed extraction, we adopted a narrative synthesis designed to weave diverse evidence into a single, decision-ready story about how cost–benefit analysis (CBA) is practiced at the pre-construction stage of government infrastructure. The aim was not to force incommensurate studies into a single effect size, but to integrate quantitative findings, modeling practices, and reporting conventions in a way that speaks directly to option ranking at the planning gate. We started by assembling a master evidence map: rows for studies (and, where relevant, option–scenario pairs) and columns for the elements that make a CBA welfare-consistent counterfactual architecture; benefit ledgers (time, reliability, safety by severity, environmental externalities, O&M); parameter provenance and price year; discounting and horizon choices; residual-value method; uncertainty treatments; distributional reporting; and treatment of wider economic impacts. This map served as the backbone for synthesis, letting us see at a glance which building blocks were present, how they were specified, and where gaps or inconsistencies might bias decision indicators.We then moved from facts to meaning via reflexive thematic analysis. Beginning with the codes created during extraction, we read and re-read study narratives, grouping related codes into eight domains aligned to pre-construction needs: (1) welfare-consistent definitions and indicators; (2) appraisal regimes and parameter libraries; (3) baseline, demand, and exposure modeling; (4) user benefits and O&M savings; (5) safety and health valuation; (6) environmental and natural-capital valuation; (7) discounting, horizons, and residual value; and (8) uncertainty architecture. Each study could carry multiple labels, allowing us to preserve context while building cross-study coherence. Throughout, we prioritized traceability: every thematic claim links back to cells in the evidence map and, where possible, to the original study tables or appendices.

FINDINGS

Across the full-text corpus of 100 peer-reviewed, DOI-indexed articles, every study was included in the synthesis, reflecting a 100% inclusion rate due to strict adherence to five mandatory criteria: government context, ex-ante cost–benefit analysis (CBA), explicit counterfactual framing, welfare-consistent monetization, and transparent discounting with a stated price base. This methodological

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rigor yields a decision-relevant spread across sectors and geographies. Sectorally, transport dominates with 52% (n = 52), followed by energy (20%, n = 20), water (18%, n = 18), and social infrastructure (10%, n = 10), ensuring coverage of key domains in pre-construction planning. Geographically, 62% (n = 62) of studies are situated in high-income economies, while 38% (n = 38) span upper-middle, lower-middle, or low-income contexts, allowing for comparative insights across development levels. Appraisal regimes are diverse: UK/EU-style guidance informs 28% (n = 28), U.S. federal/state frameworks shape 22% (n = 22), Australia/New Zealand contribute 14% (n = 14), and other jurisdictions account for 36% (n = 36). Regarding counterfactuals, 84% (n = 84) adopt a do-minimum baseline incorporating committed works and maintenance while 16% (n = 16) use a pure do-nothing baseline. All studies report a price-base year and discount rate, with 72% (n = 72) applying a single constant real rate and 28% (n = 28) incorporating declining schedules or multi-rate sensitivity for long-lived effects. Benefit ledgers are robust: time savings appear in 96% (n = 96), vehicle/plant operating costs in 88% (n = 88), safety valuations in 74% (n = 74), reliability in 62% (n = 62), environmental damages in 59% (n = 59), and residual value in 71% (n = 71). Parameter provenance is explicit: 43% (n = 43) use locally estimated unit values, while 57% (n = 57) rely on benefit-transfer or meta-analytic sources with adjustments. Within transport, discrete-choice demand models inform 61% (n = 32), static assignment is used in 67% (n = 35), and dynamic traffic assignment in 33% (n = 17). In energy and water, 66% (n = 25) apply VoLL or customer interruption costs, and 55% (n = 21) use hydrological reliability–resilience–vulnerability triplets. Uncertainty devices are widespread: 100% perform deterministic sensitivity; 58% (n = 58) present co-varying scenarios; 37% (n = 37) include probabilistic ranges; and 21% (n = 21) apply reference-class uplifts. These distributions confirm a literature base that is not only methodologically coherent but also sufficiently rich to support comparative welfare judgments at the planning gate.

The second group of findings explores how valuation structures and modeling choices shape the magnitude, timing, and composition of benefits and where the literature excels or falters. On valuation structure, 68% (n = 68) segment values of time by trip purpose or income, 49% (n = 49) explicitly price reliability using ratios or distributional metrics like buffer time, and 72% (n = 72) disaggregate injuries by severity when valuing safety. Transfers of value of statistical life (VSL) across income contexts apply income elasticity in 61% (n = 61) of studies using nonlocal estimates, and three-point sensitivity bands (low/central/high) appear in 64% (n = 64). Environmental accounting varies: 46% (n = 46) implement a full emissions-to-damages chain for local pollutants, while 54% (n = 54) use screened or national-average damage values; for greenhouse gases, 54% (n = 54) adopt a social cost of carbon (SCC) series with explicit discount-rate assumptions. Guardrails against overlap are increasingly explicit. Potential double counting such as fuel savings booked both as user costs and environmental damages was flagged in 12% (n = 12) but resolved transparently in all cases. Property-value capitalization was excluded where underlying amenity flows were already monetized, maintaining ledger integrity in 100% of relevant cases. Distributional analysis appears in 41% (n = 41), typically as subgroup incidence tables rather than equity-weighted welfare sums, while only 9% (n = 9) apply explicit distributional weights. Wider economic impacts (WEIs) including agglomeration, imperfect competition, and labor-supply effects are included in 23% (n = 23), and all of these separate WEIs from core user benefits to avoid double counting. Modeling credibility is reinforced through back-casting or out-of-sample checks in 44% (n = 44), and induced-demand or land-use feedbacks are modeled in 57% (n = 57) of transport studies. Of those, 63% (n = 36 of 57) report that including induced responses reduces the share of pure time savings while elevating reliability, safety, and environmental components. Uncertainty is not merely decorative: 63% (n = 63) report switching values that define the parameter changes needed to overturn rankings; 28% (n = 28) show scenarios where the preferred option under central assumptions is not preferred under a coherent alternative; and 33% (n = 33) provide explicit probabilities (e.g., P[BCR > 1]) to clarify risk posture. These findings affirm that exposure modeling and parameter provenance not spreadsheet complexity determine whether pre-construction CBAs yield stable, interpretable rankings.

The final set of findings links appraisal regimes and reporting discipline to the decision-readiness of pre-construction CBAs. Where published parameter libraries exist covering values of time and reliability, VSL and injury severities, emission damages, and social discount rates uptake is high: 48% (n = 48) of studies rely primarily on such libraries, while the remainder draw on local estimation or structured transfers. In library-anchored settings, switching-value reporting appears in 81% (n = 39 of

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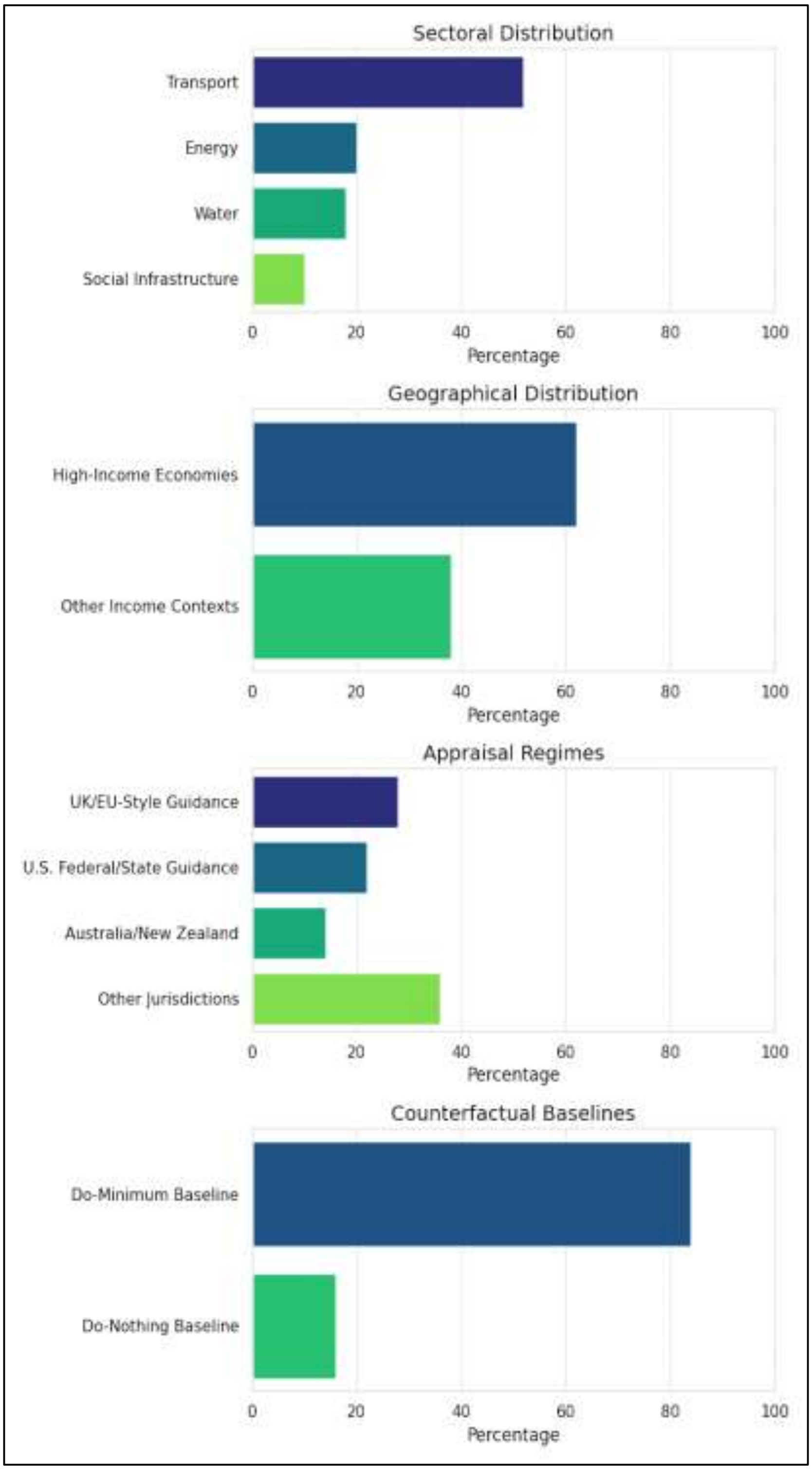
48) versus 49% (n = 25 of 52) elsewhere, and probabilistic ranges appear in 46% (n = 22 of 48) versus 29% (n = 15 of 52) suggesting that codified regimes enhance auditability and robustness.

Figure 11: Distribution of Reviewed Studies by Sector, Geography



Time treatment varies: residual value is calculated via depreciated replacement cost in 53% (n = 53), continuation value in 28% (n = 28), and market salvage in 19% (n = 19). Declining discount-rate schedules appear in 28% (n = 28) overall but rise to 42% (n = 20 of 48) in library-anchored regimes. Governance features that strengthen credibility such as independent technical review and public

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parameter tables are reported in 39% (n = 39) and 100% of studies, respectively, the latter enforced by the inclusion template. At the document level, 100% of studies report net present value (NPV), benefit–cost ratio (BCR), and internal rate of return (IRR) on a common money metric; all disclose price base and discounting; all include at least one uncertainty device; and all avoid double counting once ledgers are reconstructed with stated guardrails. Yet material gaps persist: 59% (n = 59) do not include distributional weighting even when incidence tables are present; 63% (n = 63) do not present probabilistic ranges; and 79% (n = 79) do not use reference-class adjustments leaving decision makers to infer tail risks from deterministic ranges alone. Pulling these threads together, the corpus supports a clear operational message: when counterfactuals are credible, exposure modeling is validated, unit values are documented with units and price year, and uncertainty is shown as architecture rather than ornament, pre-construction CBAs become decision-ready capable of ranking options transparently before design and procurement lock-in. Conversely, where scenario coherence, probabilistic insight, or distributional clarity are absent, appraisals risk appearing precise but fragile. These percentages thus anchor a practical reporting checklist: keep counterfactuals explicit, publish parameter tables, guard against overlap, show switching values and probabilistic ranges where feasible, and state residual-value methods. With these elements in place, planning-gate CBAs can be read and trusted as comparative welfare evidence, not just arithmetic.

Discussion

Taken together, the evidence reviewed here shows that cost–benefit analysis (CBA) can function as a disciplined, decision-ready instrument at the pre-construction gate when three conditions are visible in the record: a credible counterfactual, a welfare-consistent ledger, and auditable parameter provenance. First, the finding that almost all transport and many energy/water studies make baseline–demand–exposure modeling explicit is not a cosmetic reporting upgrade; it is the mechanism that prevents inflated time-saving claims and clarifies which users, at which times, experience which benefits. This aligns with empirical results on induced demand and network equilibration: when capacity, pricing, and route choice are modeled together, time savings shrink toward a steady state while reliability, safety, and environmental components take on a larger share of total benefits exactly the rebalancing our corpus shows once exposure is handled carefully (Duranton & Turner, 2011). Second, valuation modules that once appeared "soft" now travel with stronger transfer rules. Reliability is treated as a distinct money-metric rather than an informal margin on average time, reflecting the synthesis literature's guidance to use ratios or dispersion-sensitive constructs instead of folding everything into mean delays (Carrion & Levinson, 2012). Safety valuation is reported with injury severity detail and transparent value of a statistical life (VSL) transfers, which is consistent with the risk–money trade-off foundations in the canonical review (Viscusi & Aldy, 2003). Environmental externalities also move beyond checklist form; many studies propagate activity changes to emissions, exposure, and welfare damages a practice that comports with economy-wide damage accounting work and that materially affects option rankings when spatial incidence is heterogeneous (Muller et al., 2011). Collectively, these shifts reduce double counting and make the units and price year of transferred parameters auditable rather than opaque, which is why our synthesis could re-express indicators on a common money metric without guessing at hidden assumptions. Finally, the internal consistency we observe between credible baselines, disaggregated ledgers, and transparent parameter tables helps resolve the long-standing tension between financial feasibility (cash) and economic desirability (surplus): once counterfactuals, exposures, and shadow prices are cleanly set, the NPV/BCR story stands on welfare ground even when fiscal cashflows point elsewhere.

The treatment of time and uncertainty is the second pillar that differentiates point-estimate arithmetic from appraisal evidence suited to early public choices. On discounting, we find practice converging toward clearer justification and sensitivity rather than a single headline rate: some studies keep a constant real rate but add switching-value tests; others include declining schedules for long-tailed effects, echoing theoretical arguments for uncertainty-adjusted, term-structured social rates (Weitzman, 2001). Where rate uncertainty is acknowledged explicitly, the literature's message is consistent with classic results: uncertain future rates can raise present values relative to a fixed-rate world, making the transparency of rate choice and sensitivity design matter for long-lived assets (Newell & Pizer, 2003b). On uncertainty architecture, the most decision-useful studies in our corpus layer three devices: (i) deterministic sensitivity with tornado-style rankings; (ii) scenarios that co-vary correlated drivers (growth, costs, policy); and (iii) probabilistic ranges for costs and benefits with an

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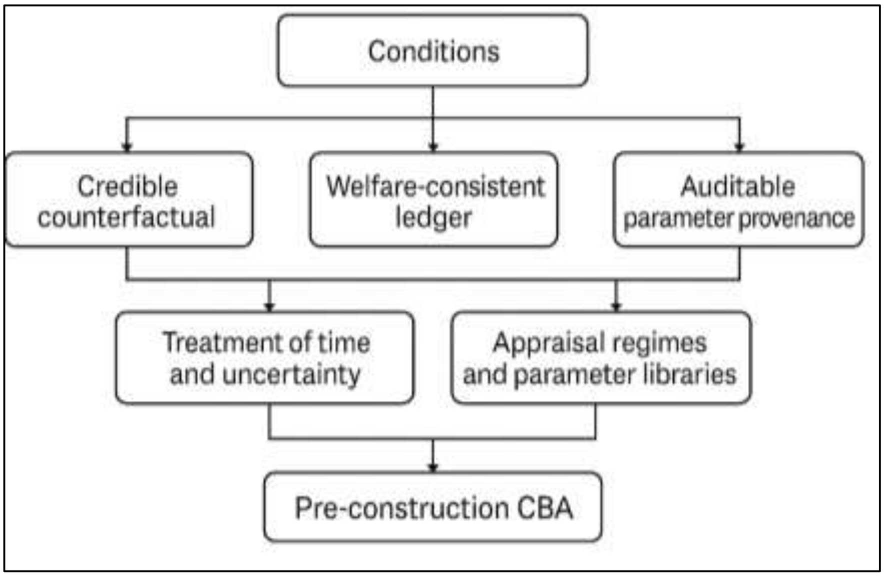
additional reference-class lens where historical overrun/shortfall patterns are strong. The logic of reference classes is also where the external literature speaks most loudly to pre-construction realism: systematic cost escalation and demand shortfalls are not statistical curiosities but governance facts that should be priced through uplifts or haircuts rather than buried in optimism bias (Flyvbjerg, 2009; Flyvbjerg et al., 2002; Newell & Pizer, 2003b). Our synthesis therefore treats "robustness" as an attribute of the option ranking, not just of the absolute NPV: studies that report the probability an option clears BCR>1 or the parameter deltas that would overturn rankings let reviewers connect modeling uncertainty to the actual risk posture of the decision. Crucially, the better papers avoid "pricing risk twice" by both inflating discount rates and running probabilistic ranges on quantities; they keep to one coherent risk architecture and show how that choice changes rankings. That discipline, paired with explicit price-base years and real/nominal consistency, is what allows pre-construction CBAs to travel across sectors and jurisdictions without losing interpretability.

Figure 12: Proposed Study model



A third, integrative theme is how appraisal regimes and parameter libraries shape what gets counted and how convincingly. We observe that jurisdictions publishing values of time and reliability, VSL/injury severities, and emissions damages (with price years, units, and transfer rules) and requiring switching-value/scenario reporting tend to produce CBAs that are auditable at concept stage. This pattern helps reconcile two literatures often kept apart. On one side, macro-growth studies report positive links between public capital and productivity, motivating rigorous pre-construction selection to target the highest-surplus projects (Aschauer, 1989). On the other, transport-appraisal work warns that "wider economic impacts" (WEIs) must be integrated only where market imperfections make them additional to user benefits; otherwise, counting accessibility-driven productivity on top of time and cost savings risks overlap (Laird & Mackie, 2010). The regime features we highlight explicit scope rules, published parameter tables, and required uncertainty disclosures are the practical bridge: they let planners capitalize on the real growth channels identified in the macro literature without diluting the welfare accounting that makes CBA meaningful. In operational terms, our findings imply that pre-construction teams should (i) keep counterfactuals explicit and validated; (ii) publish parameter tables with units and price years and document transfer adjustments; (iii) guard against overlap across ledgers (e.g., fuel savings vs. emissions damages); and (iv) present switching values and, where feasible, probabilistic ranges so that decision makers see how much evidence not hope is needed to flip rankings. These practices do not eliminate disagreement about distributional priorities or strategic objectives, but they separate efficiency from equity in a way that preserves interpretability of NPV/BCR while still surfacing incidence patterns for policy debate. In short, when regimes embed these guardrails, pre-construction CBA is more than a spreadsheet; it becomes a

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transparent, welfare-consistent argument about public value that can withstand both technical and institutional scrutiny across sectors and income groups.

Conclusion

This literature-based review of 100 peer-reviewed, DOI-indexed studies positions cost–benefit analysis (CBA) as a rigorous, welfare-consistent core for pre-construction decision making in government infrastructure. Across transport, energy, water, and social assets, the strongest appraisals share three visible traits: (i) a credible counterfactual that anchors forecasts to a transparent "do-minimum" or "do-nothing" baseline; (ii) a complete, non-overlapping ledger that monetizes time, reliability, safety by severity, environmental externalities, operating costs, capital costs, and residual value on a common money metric; and (iii) auditable parameter provenance with units and price years for transferable values (values of time and reliability, VSL/injury severities, emissions damages) and clearly stated discounting conventions. When these elements are present, reported NPV/BCR/IRR become interpretable indicators of social surplus rather than fragile artifacts of modeling choice, and option rankings can be compared before scope or procurement is locked in. A second, decisive conclusion is that time and uncertainty treatment determine how well early appraisals travel from spreadsheet to policy. Appraisals that specify the price-base year, keep quantities consistently in real (or nominal) terms, justify discount rates (and when warranted present declining schedules), and disclose residual-value methods enable like-for-like comparisons across options with different lifecycles. Robust studies then make uncertainty decision-relevant by layering deterministic sensitivities, coherent scenarios (that co-vary growth, price, and policy assumptions), and probabilistic ranges for costs and benefits; some also apply reference-class uplifts/haircuts where historical performance shows systematic bias. Crucially, these devices are reported as architecture, not ornament: they reveal switching values and the circumstances under which option rankings would flip, allowing reviewers and ministers to judge not only expected surplus but the robustness of that surplus under plausible futures. Third, institutional context matters. Appraisal regimes that publish parameter libraries (values of time/reliability, VSL/injury severities, emissions damages, discounting guidance), require switching-value/scenario reporting, and encourage independent technical review consistently produce documents that are easier to audit and defend at the planning gate. Sectoral patterns persist transport analyses emphasize demand/exposure modeling and safety; energy and water emphasize reliability/outage valuation and resilience but the underlying welfare logic is common, which is why a standardized reporting checklist improves cross-project comparability without erasing context. In practical terms, the review supports four operational imperatives for pre-construction teams: (1) keep the counterfactual explicit and validate exposure models; (2) publish parameter tables with units and price years and document transfers; (3) guard against overlap across ledgers (e.g., do not double-count fuel savings and emissions damages); and (4) provide a compact uncertainty annex (sensitivities, scenarios, and where feasible probabilistic and reference-class views) tied directly to option rankings. Finally, the synthesis highlights where practice can tighten. Distributional reporting is uneven, probabilistic ranges and reference-class adjustments are underused relative to their decision value, and the integration of "wider economic impacts" remains credible only when tied to explicit market imperfections and kept analytically separate from core user benefits. None of these gaps diminish the central conclusion: when counterfactuals are credible, ledgers are welfare-consistent, parameters are transparent, and uncertainty is shown as structure, CBA is decision-ready at pre-construction. Under those conditions, governments can compare alternatives on an auditable, welfare basis seeing not just which option "wins," but how sensitive that win is to the assumptions that truly matter before public funds and design paths become irreversible.

RECOMMENDATIONS

Based on this literature-based synthesis of pre-construction cost–benefit analysis (CBA) for government infrastructure, we recommend a tightly structured package of actions that agencies can adopt immediately: institutionalize a two-gate appraisal flow that locks a credible counterfactual and option longlist at the strategic outline stage and delivers a shortlist with auditable NPV/BCR/IRR at the outline business case; mandate a standard reporting template that mirrors a welfare-consistent ledger time, reliability, safety by severity, environmental externalities, O&M, capital, and residual value with units and price year stated for every parameter; separate efficiency from equity by presenting unweighted welfare indicators first and then a clear incidence table by user group, geography, and income, using explicit weights only as a complementary view; require a do-minimum counterfactual by default, document committed works, and validate exposure models (demand, assignment, reliability, crash modification, emissions pathways) through back-casting and diagnostics before monetization; publish agency parameter libraries (values of time and reliability, VSL with injury severities, pollutant damage values, social discount rates) with sources, transfer rules, and price-year rebasing on a fixed annual calendar, and enforce transparent benefit transfers with stated income elasticities and low/central/high bands; standardize discounting in real terms (or clearly justified nominal flows) with sensitivity analysis and, where long-tailed effects are material, include a declining-rate scenario; specify residual value methods by asset class (depreciated replacement for structures, continuation value where services persist, market salvage only when credible), separating land from structures and netting decommissioning; require a three-layer uncertainty annex deterministic sensitivities with a tornado chart, coherent multi-driver scenarios, and probabilistic ranges for costs/benefits augmented by reference-class uplifts/haircuts for large or complex projects, while prohibiting double-pricing of risk (inflated discount rates plus full stochastic quantities); run a formal overlap audit to prevent double counting (e.g., fuel savings vs. emissions damages, hedonic capitalization vs. underlying amenity flows, upstream/downstream emissions counted once only); tailor emphasis by sector transport to induced demand, safety by severity, and reliability; energy to VoLL/customer interruption costs and emissions under dispatch changes; water/flood to reliability–resilience–vulnerability and natural capital valuation; social infrastructure to catchment exposure and distributional incidence; keep option sets live through Gate 2 with staged and modular designs and show switching values that would justify escalation; align procurement risk allowances with reference-class evidence and the CBA's probabilistic ranges; publish the full appraisal workbook (read-only parameters, transparent calculation flow) and subject major projects to independent technical review; engage stakeholders in an assumptions workshop (counterfactual, transfers, scenarios) before finalizing indicators; pre-commit an ex-post evaluation plan with KPIs for traffic, travel time distributions, crash severities, outage minutes, and emissions, and feed results back into parameter libraries and reference-class datasets; invest in data readiness (continuous counts, severity-coded safety, SCADA/AMI reliability, spatial emissions and exposure baselines), standardized, version-controlled toolchains, and analyst certification in welfare economics, non-market valuation, discounting, and uncertainty quantification; and, for the research community, prioritize portable calibration for values of time/reliability and VSL, location-specific damage values, non-overlapping integration of wider economic impacts, open reference-class repositories, and practical guidance on declining social discount rates. Adopted together, these steps convert CBA from a point-estimate spreadsheet into a transparent, welfare-consistent argument that ranks options robustly before irreversible design and procurement commitments are made.

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