THE USE OF SCENARIOS IN TRANSPORT MODELLING AND APPRAISAL: A THINK-PIECE DRAWING ON LITERATURE

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EXECUTIVE SUMMARY

Across guidance and practice, there is broad agreement that robustness across multiple plausible futures should be a core criterion for infrastructure policy, given the uncertain environment of transport planning and the asset life of infrastructure investment. Yet no single, operational definition or metric of robustness is prescribed or agreed. There is agreement on the use of scenarios for assessing robustness, but no consensus on the number of scenarios required.

In appraisal, the benefits of the intervention (Do-Something) are measured relative to the counterfactual (Do-Minimum). Both will be influenced by exogenous assumptions and therefore both must be run in each scenario to quantify the benefits of the intervention.

Disaggregating appraisal outputs across wider objectives – such as efficiency, safety, decarbonisation, etc. – could provide decision-makers with clearer insights into the trade-offs between alternative interventions and outcomes, rather than presenting aggregated outputs such as net present value (NPV) or the benefit-cost ratio (BCR).

Moreover, clear visualisation of outputs across scenarios is needed to help decision-makers understand where interventions meet their objectives and where they do not. Clear understanding of robustness across different measures, and presented in clear language, could also support decision-makers.

Finally, it is important to recognise that there are risks of double-counting uncertainty in appraisal. If uncertainty analysis using scenarios is undertaken, there may be circumstances where the use of a risk-adjusted discount rate is duplicative. In such cases, scenario analysis is preferred because it is more transparent and better incentivises design adjustments that reduce poor outcomes.

We did not observe any papers that illustrated or showed how scenario analysis impacted decision-making or the value of foresight and scenarios more generally. We think that this is an important question to answer, and this motivates the first of our recommendations which follow.

In undertaking the review, we observed the need for more evidence in this important area and thus we make a few recommendations.

Recommendation 1: There is a need to undertake further work to better understand how scenario analysis influences policy outcomes, with reference to the types of uncertainty considered, the methods through which uncertainty is represented in the

modelling and appraisal process, how uncertainty is communicated to policymakers, and how policy decisions in the context of uncertainty are subsequently reached.

Recommendation 2: Alongside such exploratory projects, there is a need for formal evaluation of the use of the CAS in modelling, analysis and decision-making.

Recommendation 3: There is a need to encourage more academic interest in representing uncertainty in transport planning, modelling and appraisal, for example through PhD research. A specific topic meriting attention would be the relative merits of simple vs. complex transport models in the representation of uncertainty.

Recommendation 4: The DfT has played a leading role internationally in formalising uncertainty guidance. As the guidance evolves, there may be benefit in convening a roundtable with other agencies (either virtually, or via a forum such as the ITF) who are exploring uncertainty in modelling and appraisal to further test and discuss findings from this paper.

1. BACKGROUND AND CONTEXT

The aim of this think-piece is to review best practice around scenario analysis and other approaches for treating uncertainty in transport modelling and appraisal (M&A). This exploration specifically focuses on learning from academic literature, international guidance and published evidence from other sectors. Specific areas of interest were identified at the start of the project:

- types of uncertainty
- techniques and tools for analysing uncertainty, including how scenarios are developed and used in modelling and appraisal, and assessment of strengths and weakness of these
- how expectations of scenario analysis are set and how scenario analysis is mainstreamed
- how proportionality of scenario analysis is determined and applied
- evidence of the impact of scenario analysis on decision-making.

1.1 Why now?

This paper is motivated by considerations relevant to transport analysis in general terms, as well as by considerations specific to analysis undertaken by the Department for Transport (DfT).

From the general perspective, transport planning is increasingly undertaken in an environment of uncertainty. The COVID-19 pandemic triggered large, heterogenous and persistent shifts in working patterns – especially the emergence of hybrid working – which have altered travel demand and commuting patterns. Technological changes, such as the transition to electric vehicles, are having significant impacts on the cost of car travel, energy requirements, urban realm and transport equity. The possible introduction of automated mobility could exacerbate these changes and introduce wider system change in terms of travel productivity, car ownership, viability of public transport services and perhaps even home and business locations. Going forward, it is impossible to predict with great accuracy the impact of climate change on factors influencing travel, including economic and income growth, population change, home and business locations and impacts to the travel network itself. These and other endogenous and exogenous changes to transport are not typically well represented in travel demand forecasting models and appraisal.

From DfT's perspective, work is ongoing to refresh Transport Analysis Guidance (TAG) on uncertainty scenarios including revisions to the Uncertainty Toolkit[1] and TAG Unit M4: Forecasting and Uncertainty[2], and changes to guidance on national level demand scenarios. The current approach uses the Common Analytical Scenarios (CAS). The CAS were originally developed to provide "'consistent, off-the-shelf, cross-modal comparators for schemes," enabling a more consistent treatment of national-level uncertainties across all transport modes. The forthcoming guidance refresh aims to strengthen how uncertainty is analysed, reported and proportionately applied in transport business cases, reflecting feedback on the use of CAS and to ensure alignment with wider strategy, for example the Appraisal, Modelling and Evaluation Strategy (AMES) and Better Connected: a strategy for integrated transport[3]. The refresh also will reflect the need to incorporate emerging and new areas of uncertainty and better represent uncertainties that may impact on active travel, new modes and freight.

Against this backdrop, the DfT has commissioned this think-piece to synthesise best practice on scenario development and its use in M&A to help inform the next iteration of TAG's uncertainty scenario guidance.

1.2 How this paper is structured

This think-piece seeks to draw learning from international transport literature and literature from other sectors on the use of scenarios in modelling and appraisal, focussing upon academic literature as well as relevant "grey" literature[4]. However, during the review of the literature, it became clear that there was also a need to clarify some of the theoretical foundations around scenarios and treatment of uncertainty. Thus, we begin by setting out the key theoretical elements of uncertainty, including definitions, where uncertainty arises within modelling and appraisal, the established typologies and levels of uncertainty, and the principal analytical methods used to explore it. We then describe the types of scenarios used in transport planning, before introducing the DfT's CAS and explaining the planned refresh of their scenario guidance. This sequencing positions DfT's approach within the broader conceptual landscape, and supports subsequent discussion on modelling, appraisal and findings from the literature.

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[1] TAG uncertainty toolkit - GOV.UK
[2] TAG unit M4 forecasting and uncertainty - GOV.UK
[3] Better Connected: a strategy for integrated transport - GOV.UK
[4] Grey literature refers to research related documents that are disseminated outside academic publishing channels. They are often published by governments, NGOs, consultancy firms, international bodies, industry groups, professional associations and research centres.

2. KEY UNCERTAINTY CONCEPTS

In this section we set out what is meant by uncertainty, the methods that are used to explore or quantify it, including scenarios, and how uncertainty is incorporated in transport planning, modelling and appraisal. We then set out the DfT's approach to uncertainty and the CAS.

2.1 Defining (deep) uncertainty

The UK Department for Transport's (DfT's) Uncertainty Toolkit describes uncertainty broadly as "limited knowledge about past, current and future events and the systems in which these events occur." Within the decision-making context, the Toolkit further defines uncertainty as the "gap between available knowledge and the knowledge decision-makers would need to make the best, most informed policy decision." It draws on the wider risk and uncertainty literature, differentiating between three different forms of uncertainty:

- "**known knowns**" (or risk) which refer to uncertainties that analysts recognise are present (are known) and can be quantified through probabilistic variability (also known as aleatory uncertainty). An illustrative example would be the probabilistic distribution of the value of travel time.
- "**known unknowns**" (also called epistemic uncertainty in the wider literature) which encompass factors that analysts recognise they do not know. An illustrative example would be the price of car travel in 2050, which is a critical assumption in future model forecasts.
- "**unknown unknowns**" (also called ontological uncertainty in the wider literature) which concern factors or developments that transport analysts have not contemplated and therefore do not appear within existing analytical framework. Examples include the emergence of a novel technology that was not anticipated or a behaviour shift entirely absent from prevailing assumptions.

The Uncertainty Toolkit is primarily oriented towards supporting analysis under conditions of "known unknowns" (as well as "known knowns"), while emphasising that awareness of "unknown unknowns" is also important for decision-makers.

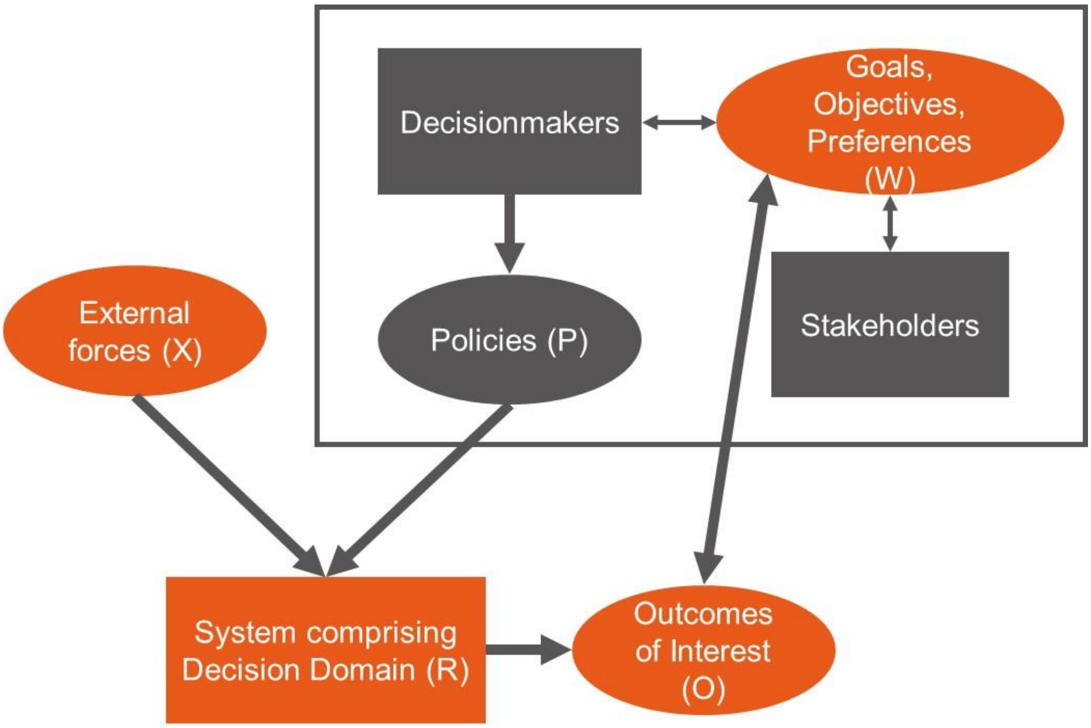
Beyond the Toolkit, a growing area of research and practice is focused on approaches collectively termed "**Decision Making Under Deep Uncertainty**" (DMDU). Within this literature, "deep uncertainty" is defined as conditions under which analysts do not know or cannot agree on: (i) models that relate key forces that shape the future; (ii) probability distributions of key variables and parameters in these models; and/or (iii) the value of alternative outcomes (Marchau et al., 2021). This formulation is analytically useful because it broadens the conceptualisation of uncertainty beyond simple knowledge deficit to encompass disagreement, contested assumptions, and alternative value perspectives. It also expands recognition of where uncertainty may arise within modelling and planning processes. We would argue that many of the uncertainties identified in section 1 of this paper fall within this category of deep uncertainty – characterised by divergent views on timing, magnitude of potential impacts on supply and demand, and the potential value of alternative outcomes.

In contrast to these forms of uncertainty, **risk** is conventionally defined as an outcome or event to which a **measurable probability can be assigned** (Harvey et al., 2021). This distinction underscores why traditional risk-based approaches are insufficient when confronting the profound and pervasive uncertainties that increasingly characterise long-term planning in the transport domain.

2.2 Where uncertainty arises in transport modelling and appraisal

Walker (2000) sets out a helpful conceptualisation of the wider planning system in the deep-uncertainty literature, reproduced below, viewing decision-making as choosing among alternatives to change system outcomes in a desired way[5].

Figure 1: Decision-making domain and uncertainty (Walker, 2000)



This diagram aligns well with the transport modelling and planning environment, where uncertainties arise from:

- external forces (X), reflecting exogenous drivers such as population and GDP growth, new technologies and climate change.
- the system comprising the decision domain ('R'), reflecting system response and causal mechanisms.
- the importance placed on the outcomes ('W'), which may be contested, for example future values of carbon, safety outcomes and/or values of time.

[5] The Walker (2000) diagram is also contained in Marchau et al. (2019) and the DfT's Uncertainty Toolkit.

Together these mean that there is significant uncertainty in the outcomes of interest 'O', from all of the above.

2.3 Types (and levels) of uncertainty and implications for planning, modelling and appraisal

Drawing on the DMDU literature (Marchau et al., 2019), and incorporating the X-R-W-O structure of Walker (2000), we distinguish four broad "levels" of uncertainty and their implications for the approach to planning, modelling and appraisal in Table 1.

Table 1: Types of uncertainty and what it means for planning and analysis

System level uncertainty	**Level 1: Deterministic**	**Level 2: Futures with probabilities**	**Level 3: A small set of plausible futures; probabilities unknown**	**Level 4: Deep uncertainty**
Future uncertainty (X)	Single well-specified future	Alternative futures with known/assumed probabilities	Alternative futures with unknown probabilities	Unknown futures and unknown probabilities
Models and analysis (R)	Deterministic models, point estimates	Stochastic models, expected values with confidence intervals, sensitivity analysis	A limited set of system models and outcomes	A wide set of models and outcomes
Most closely aligned policy planning approach	Predict and provide	Predict and provide	Decide and provide, stress testing with a small scenario set	Decide and provide, stress testing with many scenarios; adaptive pathways
Appraisal assessment criteria	Optimum solutions	Optimum solutions	Robust across a few futures	Robust across many futures

Levels 1 and 2 describe contexts in which future conditions can be characterised with confidence and, crucially, where uncertainties can be **credibly quantified with probabilities**. Under these conditions, conventional "predict and provide" planning remains valid and optimal solutions can be identified.

In contrast, Levels 3 and 4 represent environments of deep uncertainty, with known (Level 3) or unknown (Level 4) future uncertainties, but with **unknown probabilities**. In these deeply uncertain environments, "predict and provide" approaches are untenable. Instead vision-led or "decide and provide" approaches are required, which begin with explicit articulation of objectives and identification of strategies that meet these objectives across a broad range of future conditions. Robustness becomes the central evaluation criterion. Lempert et al. (2021) define robust strategies as those that perform satisfactorily across a wide range of plausible futures – rather than optimal ones which are fragile to assumption failure. These strategies tend to trade optimum performance for less sensitivity to broken assumptions and failure. Robust strategies can also be **adaptive**, incorporating contingent or mitigation actions trigged by the indicators that signpost when future action may be required.

In its document on managing uncertainty in the second National Infrastructure Assessment, the National Infrastructure Commission (NIC, 2022) also emphasise the importance of robustness, arguing that infrastructure should be designed to perform well across multiple possible futures, thereby increasing the likelihood that assets remain useful and effective throughout their lifecycle.

The present paper focuses primarily on the forms of uncertainty represented in Level 3, which reflects use of a small scenario set to stress test options and plans and is aligned with the DfT's CAS (which are discussed in further detail in Section 1.1.5). However, we also explore Level 4 approaches where they offer insights that can strengthen the practical use of Level 3 scenario approaches.

2.4 Methods for exploring and characterising uncertainty

There are a number of analytical approaches used to explore and quantify uncertainty that can be incorporated in transport analysis, modelling and appraisal. These methods differ in the types of uncertainty they address, the assumptions they require, and the insights they provide. Table 2 summarises the principal approaches, their applications, advantages and limitations. Although this paper focuses primarily on **scenario analysis**, insights from other methods are drawn upon where appropriate.

2.5 Types of scenarios and their use in transport planning

The scenarios literature (Lempert et al., 2022; Norconsult, 2024) commonly distinguishes three broad types of scenarios – **predictive**, **exploratory** and **normative** – corresponding to the questions "What will happen?", "What might happen?", and "How can we reach a goal?", respectively. In transport planning, predictive scenarios underpin forecasting and align with "predict-and-provide" approaches. Normative scenarios set out goal-seeking plans that are then appraised. Exploratory scenarios are used to stress test policies and investment strategies against structural uncertainties. In this context, stress testing involves a structured assessment of how well a policy, strategy, or intervention meets its objectives across multiple plausible scenarios, with particular attention to scenarios that expose weaknesses, trade-offs, failure points, or conditions under which the policy no longer performs as intended.

Throughout this paper, the term "**scenarios" refers to exploratory scenarios,** unless otherwise specified. Exploratory scenarios enable the systematic examination of interventions across a range of plausible futures. The futures are defined by differing assumptions concerning exogenous factors (Xs), behaviour responses (Rs), societal value judgements (Ws) and outcomes (Os), following the X-R-W-O framework introduced by Walker (2000).

Table 1: Different approaches to explore and characterise uncertainty and their pros and cons

	What is it?	How is it used?	Pros	Cons	Best for…
Sensitivity testing	Varying one (or a few) inputs at a time	Tests dependence of outcomes on key input and parameter assumptions	Simple and widely understood; identifies influential assumptions	Ignores interactions; not suited for deep / structural uncertainty	Parameter or input uncertainty around a central case
Monte Carlo analysis	Running a model many times to produce a distribution of outcomes	Generate distributions of outcomes, expected values and confidence ranges	Shows spread of outcomes; handles multiple uncertainties simultaneously; supports probabilistic interpretation	Requires credible probability distributions for uncertainties; risks false precision under deep uncertainty; remains 'predict-and-provide'	Quantifiable uncertainty with defensible probabilities
Scenario analysis	Small set of contrasting plausible futures	Stress tests policies and interventions against uncertainties in exogenous drivers / behaviour	Handles deep uncertainty; can reveal vulnerabilities; strategic insight	Stress tests incorporate limited scenarios and factors; may be too focused on central case; unclear how to interpret outputs	Structural / deep uncertainty; strategic planning
Decision Making Under Deep Uncertainty (DMDU) methods	Family of methods to test strategies across many uncertainties to identify robust options / strategies	Exploratory modelling to stress test strategies across multiple objectives and a wide range of uncertainties to identify strategies that perform well across a wide range of uncertainty	Stress tests over a wide range of uncertainties; analysis identifies critical uncertainties and trade-offs; helps identify robust policies and strategies; different formulations of robustness available	Computationally and resource intensive, particularly alongside existing travel demand models; emerging approach in transport (although used in other sectors)	Planning in highly uncertain contexts; designing robust and adaptive plans
Real Options Analysis (ROA)	Values flexibility by treating decisions like financial options	Quantifies the value of keeping options open in staged/irreversible investments	Values flexibility explicitly; mitigates risk of lock-in or stranded assets	Methodologically demanding; requires assumptions about decision triggers	Large, irreversible, stageable projects with high uncertainty and genuine decision flexibility

Stress testing through exploratory scenarios serves two primary functions:

- to identify conditions under which an intervention achieves its aims and those under which it does not, thereby informing the development of more robust strategies, as well as allowing analysts to understand potential intervention vulnerabilities and to seek design improvements.
- to enable comparison across possible interventions as a means of exploring and demonstrating the robustness of these across a range of plausible futures.

The DfT's CAS are a Level 3 exploratory scenario set designed to stress test interventions.

2.6 The DfT's current approach: Common Analytical Scenarios

The DfT recognises that transport planning and analysis take place under conditions of significant uncertainty driven by technological change, behavioural shifts, economic disruption and climate-related risks. The TAG Uncertainty Toolkit positions scenario analysis as a central technique for handling uncertainty and provides guidance on the use of alternative futures within M&A. It explicitly states that the Toolkit "sets out techniques for exploring uncertainty as part of transport modelling and appraisal, with a focus on the use of scenarios for assessing uncertainty around future travel demand." This approach is aligned with the Level 3 uncertainty assessment set out in Table 1 earlier.

A core element of the DfT's approach is the use of the Common Analytical Scenarios (CAS). Developed to ensure consistency across business cases, the CAS consist of quantified sets of alternative (national) futures that vary key drivers such as population, economic growth, technology adoption, energy prices and behavioural trends. The CAS are specifically designed to be used within transport models to produce alternative forecast outcomes. By altering underlying assumptions, set out in the TAG Data Book, they enable practitioners to stress test proposed interventions across the different CAS to present decision-makers with evidence on the robustness of schemes under uncertainty. This modelling-based scenario testing supplements TAG Unit M4, which provides further requirements for analysing future uncertainty within forecasting.

Across the guidance, the principle of proportionality is emphasised, meaning that uncertainty analysis should reflect the magnitude of the decision, the role of modelling in the business case, and the degree of uncertainty relevant to the intervention. Likewise, the guidance on CAS stresses that scenarios should be applied proportionately to avoid unnecessary analytical burden, while still ensuring that modelling outputs reflect a reasonable envelope of future conditions.

The DfT's approach to uncertainty scenario analysis is undergoing substantive transition. According to the DfT's *Summary of Upcoming Changes to Uncertainty Scenario Guidance*[6], the final CAS release (December 2025) marks the end of the

[6] Summary of upcoming changes to uncertainty scenario guidance - GOV.UK

CAS in their current form, with the DfT transitioning towards a more flexible modular scenario framework (as opposed to updating a fixed set of scenarios) for use by all projects. The new approach aims to build on the usefulness of having a set of scenarios, whilst allowing projects to adopt a more bespoke approach where helpful.

3. HOW UNCERTAINTY IS TYPICALLY INCORPORATED IN TRANSPORT MODELLING AND APPRAISAL

Having introduced key uncertainty concepts that potentially affect transport planning and analysis, we now describe how uncertainties are currently treated in M&A specifically to help to position the insights emanating from the evidence review which follow in later sections of this paper. We focus on practice in the UK, noting that many other countries adopt similar approaches. To set the scene, we note Tveter et al.’s (2025) observation that: *‘CBA [cost-benefit analysis] results are often presented to decision-makers as point estimates. However, such results rely on numerous forecasts, parameters, and unit values, which introduce uncertainty’* (p137).

3.1 Model development

The modelling and appraisal process typically commences with the estimation of a transport model for a base year without the scheme, typically pertaining to a prior year for which data on actual recorded journeys and flows exist or can be straightforwardly extrapolated.

According to the traditional ‘four-stage’ transport model, model development begins with its spatial definition, through delineation of the study area, its subdivision into zones, and the definition of zone centroids. The model is then developed incorporating the following responses:

- Trip Generation: the key inputs are volumes of trip productions and attractions by zone for the base year. In practice, these inputs are themselves based on models (e.g. TEMPro), which are increasingly challenged by emerging behavioural phenomenon such as digital substitution, e.g. people working from home, online shopping.
- Trip Distribution: trip origins are matched to trip destinations using a gravity model, which derives zone-to-zone trip frequencies as a function of location attractiveness and the generalised costs of travel – the output is an estimated trip origin-destination (O-D) matrix.
- Mode Choice: the share of trips by each mode is estimated using a logit model, as a function of generalised cost and possibly other measures of mode attractiveness – the output is an estimate of the volume of trips by mode for each O-D pair.
- Trip Assignment: Finally, O-D trips by road or public transport are assigned to paths through the network using equilibrium principles (such as Wardrop’s), where travel time is a function of demand – the outputs are estimates of link and path flows and associated generalised costs.

The model is calibrated by adjusting its parameters until estimated travel behaviour (e.g. mode choice, link flows, and realism tests, including out-turned elasticities and trip length distributions, etc.) match those observed in the base year – in effect minimising **model error in the base year**. Often mode choice and trip distribution responses are estimated simultaneously using logit models, allowing for quantification of the relative sensitivity of both responses to changes in transport costs and times.

3.2 Forecasting

Having developed the transport model for the base year, the model is typically applied in a forecasting context for the **opening year** of the scheme, for a minimum of two scenarios to quantify the value of the scheme:

- The "without-scheme" scenario – which is commonly referred to, as appropriate, as the Do-Nothing or **Do-Minimum scenario** (Do-Min).
- The "with-scheme" scenario – which is commonly referred to as the **Do-Something scenario** (Do-Some).

The model is further applied to a future **design year**, again for both the **Do-Min** and **Do-Some**. TAG advises that the design year should be as far into the future as possible.

TAG also prescribes that the above forecasts (i.e. for the Do-Min and Do-Some for the opening and design years) should be generated for a further range of scenarios, to explore the impact of **uncertainty in exogenous factors**, as follows:

- **Core scenario**, which entails central assumptions for the exogenous drivers of demand together with 'firm and funded' government policy commitments. With reference to Table 1, there is a temptation to interpret this as Level 1, but this practice has provoked contention in the literature (e.g. Lyons and Marsden, 2021), for its tendency to incite a false sense of certainty. Section 5.1.1 below will elaborate on this issue.
- **Alternative scenarios**, which entail different background assumptions – especially High growth and Low growth scenarios. These are based on official forecasts developed by the likes of the Office for Budget Responsibility (OBR) and the Office for National Statistics (ONS). These forecasts are themselves underpinned by a range of methods straddling Levels 2 and 3 (e.g. OBR reports real GDP growth forecast with confidence intervals, whilst ONS population forecasts are scenario-based), but DfT assimilates these into a series of scenarios.
- **Common Analytical Scenarios (CAS)**, a set of seven cross-modal scenarios exploring national level uncertainties which have been developed by DfT, reflective of Level 3 uncertainties. At the time of writing this think-piece, these scenarios are being reviewed by DfT in the context of a wider refresh of guidance on the use of uncertainty scenarios.

In developing a model along the above lines, TAG recommends the use of an **uncertainty log** recording the assumptions which could lead to variations in demand and supply, noting that such uncertainties can typically be classified into the following categories:

- **Model parameter errors** – exposed by sensitivity testing.
- **National uncertainty in travel demand** – due to uncertainty in demographic projections and traveller's behaviour and tastes.
- **National uncertainty in travel cost** – due to uncertainty in fuel prices or government policy.
- **Local uncertainty (within the vicinity of the scheme) in travel demand** – due to uncertainty around other proposed developments (e.g. housing, employment, schools, or retail).
- **Local uncertainty (within the vicinity of the scheme) in travel supply/cost** – due to uncertainty around other transport projects.

3.3 Appraisal

Having applied the model to a range of forecast years under a range of exogenous scenarios, the impacts of the scheme are calculated as the difference in the net benefits between the Do-Min and Do-Some over the standard 60-year transport infrastructure appraisal period, interpolating and extrapolating as necessary for years not explicitly modelled. Net benefits are then discounted over the 60-year period, subtracting the construction costs at year zero, to derive the **net present value of the scheme**.

Scheme costs

Whilst uncertainty in travel demand and costs have been highlighted above at the forecasting stage, a key source of uncertainty arising at the appraisal stage is that associated with scheme costs. In this regard, TAG includes guidance on the following approaches:

- **Quantified Risk Assessment (QRA) –** this is a process for calculating an expected value – or risk-adjusted estimate – of the scheme cost, based on the probabilities of different outcomes.
- **Risk mitigation plans** – to support a systematic approach to responding to risks.
- **Optimism bias** – TAG sets out a four-stage approach to deal with the systematic tendency for scheme promoters to be unduly optimistic about their ability to deliver on time and budget. The approach involves the application of uplift factors to the base capital cost, in combination with sensitivity analysis.

Asset life

Another potential source of uncertainty is the degree of alignment between the appraisal period and the engineering life of the asset. TAG advises that, where the asset life is significantly longer than 60 years, an **extended appraisal period could be presented as a sensitivity test**. On the other hand, for schemes with asset lives less than 60 years, TAG advises that the residual asset value should be included within the appraisal.

Discounting

More generally, uncertainty can be accommodated into the appraisal process through one or more of three broad approaches:

1) **By invoking the Arrow-Lind theorem:** which argues that if idiosyncratic[7] risk-bearing is shared throughout a large enough population then it becomes insignificant, so that projects can be appraised in terms of expected net benefit alone.

2) **By accommodating variability into modelled forecasts** of demand, supply and their associated unit costs and benefits: for example, using alternative scenarios as detailed above, and/or via specific uncertainty techniques such as sensitivity analysis, stochastic risk analysis and scenario analysis.

3) **By adjusting the discount rate:** for example, through representing variability in future income growth and/or through the introduction of an explicit risk premium to proxy for systematic risk.

DfT (and HM Treasury) has in essence adopted approach 2) in combination with a **risk-free discount rate**.

3.4 Uncertainties arising through the modelling and appraisal process

As well as setting out a reasonably conventional approach to modelling and appraisal, the above discussion has highlighted various actions which can be taken to manage uncertainties which arise.

Table 3, reproduced from Nellthorp et al. (2021), provides a useful typology of such uncertainties and potential mitigations. An important point to stress is that M&A represents a **process.** There is the possibility that errors or uncertainties arising at an earlier stage of the process could propagate through the process and indeed be compounded by other sources of error arising at a later stage.

To position the present paper, we have highlighted the rows of Table 3 which we consider most relevant to scenario analysis – which are those pertaining to Nellthorp et al.'s notion of 'inherent uncertainty'. The latter is conceptually distinct from the notion of (statistical) 'error' which manifests in various ways through M&A. At the same time, the process nature of M&A means that scenarios will not be independent of those

[7] Idiosyncratic (or unsystematic) risk is specific to an agent or asset. This contrasts with systematic risk, which affects a market or economy.

errors, and indeed scenarios could serve to amplify those errors. For example, the formulation of a future scenario around autonomous vehicles would place particular emphasis on assumptions of the value of travel time, in a situation where travel time can in principle be used productively. If these estimates are biased and/or imprecise, then this will be reflected in the modelled scenarios.

Table 3: An indicative typology of uncertainties arising through the modelling and appraisal process (Nellthorp et al. 2021)

Stage of analysis	Type of uncertainty/error	Definition	Mitigation
ESTIMATION	Data error	Error could arise in defining and/or measuring both input/stimulus and output/response variables.	Improving the quality and quantity of data, through standardising definitions/labelling, increasing measurement precision, enhancing data capture/storage/retrieval, and expanding the scale/scope of data collection using new data sources, for example the digital traces generated by the use of devices such as mobile phones.
	Specification error	Error could arise in specifying appropriate relationships between input/stimulus variables and output/response variables.	Seeking guidance from known theoretical relationships and/or empirical evidence from prior studies, as well as through statistical procedures to inform model selection. However, a model is always a simplification of reality valid only if the future behaviour and challenges are similar to those of the base year
	Estimation error	For any given relationship between stimulus/response variables, error may arise in estimating/calibrating that relationship.	Such error can be measured through statistical procedures, and could potentially be mitigated through model re-specification and/or through improving data quality.
	Propagation error	In a model system comprising of several components, there could be the potential for error in any individual component – arising from specification and/or estimation error – to be compounded as it proceeds through the system.	Follows from the above two entries.
FORECASTING	Forecast error	In applying the model to forecasting, error will arise if theoretical relationships which held in the base year break down in the future year. Another potential source of error is the accuracy of Future Year forecasts of the exogenous input variables (e.g. socio-economic variables).	Model re-specification and/or through improving the accuracy of the input variables. Again, this requires the assumption that no major and unexpected disruptions will materialise in the future.
	Inherent uncertainty	Ultimately, the future is inherently uncertain, and a further source of error could be structural breaks in previous relationships and trends which undermine both the model and input variables.	Sensitivity analysis of key inputs and scenario analysis of alternative states of the world. Synthesising the results into a manageable set of performance indicators to advise decision-makers
APPRAISAL	Valuation error	Independent of forecasts of demand/supply, error could arise in unit valuations of benefit/cost (e.g. estimates of the value of travel time savings).	Improving the quality and quantity of data giving underpinning unit valuations.
	Optimism bias (aka cost error)	The Green Book 2020 refers to optimism bias as *'the proven tendency for appraisers to be optimistically biased about key project parameters, including capital costs and operating costs, project duration, and resulting benefits delivery'* (p9).	Adjusting cost estimates (upward) accordingly.
	Inherent uncertainty	The practice of discounting is motivated by several considerations as to why the realisation of a given net benefit at different points in time may carry different value. One consideration is the risk that a forecasted net benefit may not fully materialise – which would introduce error into forecasts of NPV.	Factoring risk into the discount rate is a partial, and some would say misleading, solution. Incorporating costed intervention flexibility in the decision and identifying mitigation measures must complement this. This conundrum is at the centre of this paper.

4. OUR APPROACH TO THE LITERATURE REVIEW

The aim of the literature review was to identify best practice around scenarios analysis and other approaches to treating uncertainty in transport M&A. We adopted a systematic approach to the literature review, covering published academic papers and "grey" literature[8] in three domains:

1. International transport guidance, focussing on nations outside the UK that have comparable structures to the UK and face similar uncertainties.
2. Governmental guidance in other sectors, focussing on organisations that produce macroeconomic forecasts or face similar types of uncertainty to DfT.
3. Academia, encompassing papers published in English in peer-reviewed journals.

We developed a four-pronged search approach to identify a long-list of relevant literature across these three areas: (i) a search of papers using academic databases and Google Scholar, (ii) a search using Co-pilot, (iii) reaching out to relevant experts in countries with similar institutional structures to the UK and those which face similar uncertainties, and (iv) literature identified by the client in the brief. We adopted different searching strategies for each approach, as is summarised in Figure 2 below.

In total, the academic search identified 60 possibly relevant papers, the Co-pilot search 14 papers, experts provided 36 reports and papers, and the client identified 7 papers in the project brief providing a longlist of 117 possible papers and reports for review. It is noted that a substantial number of the report and papers provided by experts were not written in English and therefore the exclusion criteria were revised to allow non-English reports to be in scope. Co-pilot was used to produce summaries of these papers for the short-listing of papers for review.

[8] Grey literature refers to research related documents that are disseminated outside academic publishing channels. They are often published by governments, NGOs, consultancy firms, international bodies, industry groups, professional associations and research centres.

Figure 2: Summary of literature search process

	Academic search	Co-pilot search	Networks	Client / Brief
Identification	'Scenario analysis' AND 'transport appraisal' 'Scenario analysis' AND 'transport modelling' 'Scenario analysis' AND 'CBA' Web of Science and Google Scholar	What are the best papers exploring the use of scenario planning in transport modelling and appraisal?	Contacted 23 experts across relevant countries 17 experts responded	Documents identified in brief
Longlist	• 60 papers • English • Country similar to UK • Title/abstract must include mention of (uncertainty or scenarios) and (modelling and appraisal)	• 14 papers	• 43 reports and papers • Not all reports/papers are in English • Produced summaries of reports in English (using Co-Pilot) for assessment of short-list	• 7 papers
	Scoring of relevance of papers for scenario development, modelling and appraisal by assessment of abstract / summary by transport experts using scoring scale of 1-5 scale. Accepted papers that scored > = 4 from both reviewers.			
Shortlist	• 6 papers	• 0 papers	• 11 papers, some not in English (translated using Google Translate)	• 5 papers

Both authors reviewed the abstracts and summaries for all 117 papers and assessed the relevance of the paper in terms of their use of scenarios for modelling and appraisal. Specifically, papers were scored on a scale of 1 through 5, as follows:

1. Not relevant, do not review
2. Unlikely to be relevant
3. Not sure, may be relevant
4. Moderate relevance
5. Highly relevant, must review

Papers were included on a short-list for review if they scored 4 or better by both authors. In total 22 papers were identified on the short-list for review. This was judged to be at the higher end of what was feasible within the specific timescales and budget. These papers are listed in Appendix A. This list includes a couple of papers providing a broader perspective on the importance of incorporating uncertainty in appraisal (Tveter et al., 2025; Asplund and Eliasson, 2016). It was felt that these papers would help position the importance of uncertainty in appraisal and the need for methods like scenario analysis. We included one (recent) paper on DMDU methods, which we consider a scenario approach, but have also referenced the book "Decision Making Under Deep Uncertainty: From Theory to Practice" when this expands on a particular area of interest (Marchau et al., 2019).

The short-listing process identified that:

- **Relatively few papers explore scenario development alongside modelling and/or appraisal and therefore few papers were deemed to be highly relevant for the review;** only two papers were scored a five by both authors and one received a score of 4 and 5. The rest received scores of 'moderate' relevance.

- **Most of the documents from experts came from the UK, the Netherlands, Norway, the USA, Australia and New Zealand.** They mostly reflect grey literature, i.e. project reports commissioned by government agencies, appraisal guidance documents and studies on treatment of uncertainty by think-tanks or international agencies, such as the International Transport Forum (ITF) of the Organisation for Economic Co-operation and Development (OECD).
- We were **not able to identify much literature in this area from other sectors**, despite exploring a number of avenues, e.g. the Government Office for Science and our networks outside of transport.
- There were **few academic papers published in this area that were judged to be directly relevant;** most of the papers came from academic networks and the brief.
- Co-pilot did not identify any relevant papers (and many of the papers identified were quite old).

A template was developed to ensure information was collated in a systematic manner from the papers. Papers that were not written in English were translated using Google Translate.

5. FINDINGS

Before setting out learning from the review, it is worth emphasising that, in general, we have found the **literature around the use of scenarios for transport M&A to be limited and piecemeal**. There is more literature covering the development and use of scenarios for planning in transport (and presumably in other sectors). But the focus of this review was on literature evidence on the **use of scenarios for modelling and appraisal** and there was much less literature on these specific topics. Secondly, most of the identified literature is grey literature. Some of this comes in appraisal guidance from other countries, some from international organisations, and some from reports of project work. It must be recognised that grey literature may have lower levels of formal peer-review and therefore may contain errors. The use of Google Translate to translate non-English documents may also lead to errors. Reporting of erroneous findings in the grey literature may be mitigated by the experience of the reviewers. Thirdly, given the piecemeal nature of the literature, the authors also draw on their own expertise and knowledge of the topic and may draw on literature not specifically identified in the review.

5.1 Approaches to developing scenarios

There are many approaches to developing (exploratory) scenarios (see Lyons et al., 2021). Most approaches involve the identification of critical (exogenous) uncertainties (sometimes called 'factors' or 'drivers'), specification of how these factors may change in future (making projections for each factor), and then integrating these projections into scenarios considering consistency between different factor projections. Stakeholder engagement is a critical part of the process, providing guidance on critical uncertainties, the values they may take in future and to validate the plausibility and credibility of scenarios. Typically, a small number of scenarios (between 4-6) are defined. Scenario narratives may be provided to bring the scenarios to life for stakeholders and policymakers.

The DMDU literature describes scenarios in a similar way – a plausible, internally-consistent representation of a possible future "state of the world" reflecting combinations of relevant uncertainties, e.g. uncertain drivers (or factors), model assumptions and parameter values (Marchau et al., 2022). However, unlike traditional scenario planning, in DMDU analysis scenarios are frequently generated computationally using experimental designs to combine the factor projections across all uncertainties – generating sometimes thousands of scenarios – for extensive exploration of uncertainty. These scenarios form the basis of robustness analysis, not storytelling. Scenario discovery methods are used to identify which combinations of uncertain factors lead to a strategy failure or success. The identification of the most critical uncertainties is therefore an **output** of the analysis, not an **input assumption**, as in traditional scenario analysis.

Contrasting with the above characterisations, the NIC (2022) argues that developing a wide range of reasonably simple scenarios is more important than the precise combination of inputs that generate each scenario.

Arguably, the DfT's Common Analytical Scenarios (CAS) do not align exactly with any of the preceding characterisations. Rather than being predominantly narrative-driven, the CAS specify numerical variations in key drivers (economic growth, population, fuel prices, travel behaviour and technology adoption). Some of the CAS only consider changes in one factor at a time, more akin to a sensitivity test. They are intended to provide a practical tool to assess uncertainty around future travel demand and provide a standardised set of quantified alternative futures to stress test policy interventions in terms of Value-for-Money (VfM). Alongside the CAS, the DfT's Futures Team employs a broader set of visioning and scenario techniques to inform the Department's policy work beyond TAG.

It is noteworthy that no other countries have developed anything like the CAS for modelling and transport appraisal. Indeed, two of the Norwegian scenario studies reviewed for the present paper concluded that it would be beneficial to have a set of common scenarios (like the DfT's CAS) to provide a systematic framework across municipalities, saving them time and resource in the delivery of analysis (Norconsult, 2024; Numerika and Norconsult, 2024). On the other hand, DfT has found that delivering a set of common scenarios can be both time and resource intensive and are factoring this learning into the development of their scenario guidance refresh.

5.1.1 The value of a central forecast

In practice, there is often disagreement about the value of a central forecast or "business-as-usual" scenario.

In the broader literature (e.g. see Lyons and Marsden (2021) for a discussion of the issue), advocates argue that that a central forecast can provide a reference point or anchoring device for exploring uncertainty, helping analysts identify departures from expected trends and offering a common baseline against which competing projects can be compared. Such arguments typically emphasise the communicative and organisational value of a baseline rather than its predictive reliability.

Conversely, critics contend that under conditions of deep uncertainty a central forecast lacks empirical foundation and can be actively misleading, anchoring decisions to a future with an unjustified sense of likelihood. From this perspective, DMDU approaches are designed precisely to avoid reliance on a single expected future; analysis is instead structured around stress testing strategies across a wide range of plausible futures, identifying vulnerabilities, and developing robust and adaptive options. Within such frameworks, the notion of a central forecast becomes redundant.

Among the documents reviewed, only the Bernanke (2024) assessment of Bank of England forecasting practices directly addresses the role of a central forecast. Bernanke recommends that the Bank should publish alternative scenarios alongside the central projection and, importantly, should place **less emphasis** on the central forecast. This suggests a possible middle ground in which a baseline is retained for communication while its dominance is reduced.

5.1.2 Using scenarios for stress testing

The Government Office for Science's Futures Toolkit[9] explicitly endorses **qualitative** stress testing of policies using scenarios as a core component of robust long-term decision-making. This involves assessing **"whether a policy would work under different conditions"**, to challenge assumptions and reveal vulnerabilities in policy design. Within this framework, scenarios help analysts and policymakers probe how trends and uncertainties could interact, thereby exposing weaknesses, identifying hidden assumptions, and generating insights into how policies might be adapted to remain resilient across a range of plausible futures. The Toolkit positions qualitative scenario-based stress testing as a key method for ensuring that policies are robust in the face of uncertainty.

There is little guidance for quantitative stress testing using scenarios, outside of DMDU methods that tend to use models to stress test policies and interventions.

5.2 The role of transport models for scenario analysis

In principle, transport models can be used to support quantitative stress testing of policies and interventions. This requires expressing scenarios as coherent sets of

[9] The Futures Toolkit HTML - GOV.UK

quantitative inputs to the transport model, so the model can generate scenario-specific outcomes. The sub-sections below summarise insights from national-level forecasting and backcasting, scheme-level modelling, and relevant lessons from other sectors, regarding scenario testing using transport models.

5.2.1 National-level transport forecasting

Scenario analysis at the national level typically entails formulating several plausible futures and representing them through explicit modelling inputs – most often exogenous drivers, but also alternative model parameter assumptions or valuation assumptions. Models are then used to develop forecasts of the national demand for travel (and potentially also correlates of travel, such as carbon usage and pollutant emissions). The DfT's approach to National Road Traffic Projections exemplifies this practice through use of the CAS.[10]

The Uncertainty Toolkit recommends that the CAS be applied – in a proportionate manner, depending on the stage of analysis and expected size of impact of the scheme – to stress test schemes in terms of VfM. Supporting the implementation of these scenarios in transport models, DfT also publishes a CAS Databook that provides the underpinning quantitative assumptions and inputs (e.g., demographics, technology, costs). In their refreshed scenario guidance, DfT will recommend a similar process, but allowing for more bespoke scenarios beyond the CAS.

Another example of national level transport forecasting is the work of Ives et al. (2017), which informed the National Infrastructure Commission's (NIC)[11] assessment of the UK's major infrastructure needs to 2050. Their analysis used a "system-of-systems" model called the National Infrastructure Systems Model (NISMOD)[12] to represent interdependencies across infrastructure sectors, including energy and transport.

The NISMOD system was developed between 2011 and 2015 by the Infrastructure Transitions Research Consortium to model key infrastructure sectors including energy, transport, waste and water in a system-of systems framework incorporating key interdependencies between sectors such as transport's demand for energy, the demand for water by the energy sector and the production of energy from waste. In NISMOD, demand forecasts are driven primarily by scenario assumptions about population, demographic change and regional economic growth, with sector-specific demand then modified by factors such as land use, technology, behaviour, climate, prices, journey times and policy interventions. The transport model element reflects passenger and freight transport on highways, railways, air, sea and local public transport networks (for further details of the transport model see Lovrić et al 2017). The model predicts future demand for each mode on individual flows using an elasticity-based simulation approach. Origin and destination flows (at local authority level) are then assigned to transport networks to assess infrastructure capacity

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[10] National road traffic projections - GOV.UK
[11] NIC has since been reconstituted as the National Infrastructure and Service Transformation Authority (NISTA).
[12] ITRC - NISMOD

utilisation and obtain estimates of inter-zonal travel times. The model explicitly considers cross-sectoral interdependencies with other infrastructure networks, including the energy sector (where transport is the largest consuming sector), digital communications (which can reduce or increase demand for transport, and transport can increase demand for digital services), waste management (which requires transport services) and water supply (where flooding poses a major risk of transport disruptions).

For purposes of benchmarking, NISMOD results were compared against those from more standard and more detailed transport models. Specifically, the DfT applied a subset of the NIC's scenarios to the National Trip-End Model (NTEM) and the National Transport Model (NTM) in the case of road, and the Exogenous Demand Growth Estimator (EDGE) in the case of rail.

The NIC's scenarios combined alternative assumptions for key drivers: economic growth and productivity (specifically three variants of GDP per capita), population and demography (four variants of ONS projections), climate change and environment (three variants of UKCP09 emission projections), and technology (two different speeds of technology development and adoption). Ives et al. noted that consideration of all permutations of the scenarios was beyond the available analytical resources. Therefore, a smaller set of scenarios were chosen based on three criteria: **diversity** of scenarios to test robustness; **plausibility** in terms of realism and internal consistency; and **relevance** to the Commission's objectives. Interestingly, the process for choosing the most critical scenarios involved removing both very extreme and very central scenarios. Ives et al. (2017) emphasised that no scenario was considered more likely than any other, and scenarios were chosen to span the range of plausible outcomes.

Baseline strategies developed for the National Infrastructure Assessment (NIA) were run in each of 12 scenarios. These 'Do-Minimum' baseline strategies corresponded to the level of road and rail capacity associated with the status quo plus investments included in the Autumn 2016 National Infrastructure and Construction Pipeline (NICP). They served as a counterfactual against which to compare the NIC's "Do-Something" policy options (although these comparisons were not presented in the paper reviewed).

Across a 25-year horizon, the different models generated broadly comparable, but not identical, results. For road, the DfT models projected a 21-34% increase in vehicle kilometres, compared with 30-45% in NISMOD. For rail, the models were more similar with projected growth in passenger journeys ranging from 11-33% in the DfT model and 11-27% in NISMOD. The reasons given for these discrepancies were speculative, but included different treatments of income elasticity, population growth and, in the case of roads, assumptions surrounding connected and autonomous vehicles (which were not included in the DfT models but were included in NISMOD).

Ives et al. (2017) concluded that the DfT and NISMOD model results were broadly comparable, particularly when differences in input variables and elasticities were controlled. They concluded that "at a national scale there is thus some evidence for a diminishing return from increased model complexity" (Ives et al, 2017).

Reflecting on these issues in work for the second National Infrastructure Assessment, NIC (2022) argues that a wider range of simpler scenarios has significant advantage in comparison to complex modelling of only a few – on the grounds that it is a more efficient use of analytical resource. This discussion makes a distinction between the concepts of **'bias'** and **'measurement error'**, which they define as follows:

'Bias occurs when information is available but interpreted incorrectly or ignored entirely. Simple models suffer from bias because they exclude many details captured in more complex models. Error occurs because samples of data inevitably vary in some way from the true data they seek to represent and the underlying relationships between variables may not be fully understood. Complex models suffer from greater errors, particularly when there is high uncertainty, as they include more sources of possible error and less well understood relationships' (p13).

Reconciling these arguments, NIC concludes (without giving specific evidential attribution):

'Measurement error, or errors in the choice of modelling assumptions, can compound rapidly in complex models and provide misleading conclusions, whereas carefully chosen simplifications can perform better. Where uncertainty is high, the errors introduced by complex modelling can outweigh the biases that are eliminated by trying to take account of more factors' (p14).

5.2.2 National-level transport backcasting

Whereas the previous section considered the application of scenario analysis to national-level transport forecasting, this section will consider its application to the 'inverse' exercise of "backcasting". Backcasting, in a futures context, is a futures and policy-design method that works backwards from a desired long-term goal, to identify the actions and interventions needed to reach it. It is aligned with the decide-and-provide approach to transport policy.

Statens vegvesen et al. (2025) report a two-phase study in Norway that applied backcasting to develop a robust pathway for decarbonisation. Phase 1 assessed the suitability of models and planning approaches and highlighted the need to treat uncertainty more explicitly. Phase 2 undertook a proof-of-concept study: setting goals for decarbonisation consistent with the national transport plan – in terms of travel demand, emissions and the economy – and then backcasting to identify robust policy pathways to reach these goals. Four strategic pathways were tested: a **technology pathway**, assuming emission reduction could be achieved through technological development and innovation, with no restriction on travel; a **reduce pathway**, where emphasis is put on restrictive measures to save energy, land, the environment and capital; a **cost-effectiveness pathway**, through continuous introduction of measures to cost-effectively reduce emissions, paid for by transport users; and a **balanced approach** combining the above pathways, again paid for by transport users.

To enable the Phase 2 work, enhancements were made to a suite of models, including:

- the official national passenger model (NTM6), for journeys longer than 70km;
- a set of regional passenger travel models (RTM) covering regional travel, for journeys up to 70km;
- a model of freight travel (a set of base matrices of goods flows between Norwegian zones and external zones); and
- a general equilibrium model (NOREG2).

All four models were judged necessary to quantify the impact of the wide range of policy interventions, including taxation, across the outcomes of interest, including freight and the economy. As regards the specific model enhancements, run times of the passenger model were reduced and the structure simplified to accommodate new modes, whilst the freight model was updated to better reflect imports/exports, and NOREG2 was enhanced to better capture cross-sector emissions. The modelling suite was then used to evaluate alternative policy pathways across outcomes (travel volumes, emissions, costs, macroeconomic effects) relative to a reference trajectory.

Reported insights included the following: (i) strategic planning should 'seek robustness'; (ii) backcasting provided a structured way to identify policy measures within alternative pathways, conditional on a credible reference trajectory; (iii) combining passenger, freight and general equilibrium models allowed quantification of transport and economy-wide impacts, though many measures (e.g. digitalisation, sharing economy, emergent behaviours) were represented via assumptions; (iv) faster, more flexible models would have better supported "deliberation with analysis", allowing analysts to assess model outcomes and amend pathways in a more iterative fashion; and v) scenario analysis enabled robustness testing of policy pathways against critical uncertainties, but this had to be done qualitatively (because of timescale and budget constraints). The authors highlighted the resource intensity of building a suitable modelling framework and the importance of allocating time for iteration and interdisciplinary reflection.

5.2.3 Transport modelling at scheme vs. strategy levels

Whereas the previous two sub-sections have considered national-level modelling, another potential application of scenario analysis is to transport modelling at the scheme level. As has already been discussed in section 1.2, transport M&A is conventionally focussed on comparing Do-Minimum (i.e. without-scheme) and Do-Something (i.e. with-scheme) scenarios. In this context, scenario analysis entails the development of further scenarios based on exogenous (to the scheme) factors, to reflect local dependencies which could influence **both** the Do-Min and Do-Something. Again, DfT promote this kind of approach through the Uncertainty Toolkit, but a similar approach has been explored in Norwegian transport policy. No evidence of applications such as these were however found for the review.

5.2.4 Insights from other sectors

As part of our review, we also sought insights from other sectors which employ scenario analysis in official modelling and forecasting but were able to uncover only a small amount of material in this regard.

The most notable example was the Bernanke (2024) assessment of the Bank of England forecasting practices. This report observes that the accuracy of forecasting has been declining, alongside other central banks – largely due to large shocks that are ‘difficult to forecast’, e.g. the pandemic, Russia’s invasion of Ukraine, impacts on oil prices and global supply chains, etc. The report makes suggestions for a number of modelling improvements, but also recommends that *‘policymaking could be made more systematic and coherent by supplementing the central forecast with additional information and analysis, notably insights drawn from alternative scenarios (including forecasts made based on alternative paths for the standard conditioning assumptions)’*.

Bernanke (2024) remarks that the *‘expanded use of alternative scenarios would facilitate comparisons of possible policy choices, more accurately quantify the risks to the forecast, and help the* [Monetary Policy] *Committee (MPC) learn from past forecast errors’*. More specifically, he argues that: *‘To improve the MPC’s policy discussion, the central forecast should be regularly augmented by alternative scenarios, with the specific scenarios ideally decided upon at an early stage of each forecast round by the MPC and staff’*.

The report also contains an interesting discussion about the communication of model forecasts to external audiences, recommending that the presentation of selected alternative scenarios alongside the central forecast would help the public to better understand policy decisions and the inherent uncertainties. However, there is specific criticism of fan charts as a presentational device, on the basis that they *‘have weak conceptual foundations, convey little useful information over and above what could be communicated in other, more direct ways, and receive little attention from the public’.*

5.2.5 General observations

Transport models can: (i) expand the range of futures tested beyond trend projections, (ii) enable stress testing of strategies and measures under varying future assumptions, and (iii) improve understanding of robustness of investments and policies. However, running multiple scenario-based model simulations can be time consuming and costly, and explaining outputs and difference across scenarios can be challenging (Norconsult, 2024).

The DMDU literature (Lempert et al., 2022) echoes the challenges of using transport travel demand models for undertaking exploratory analysis, noting that such models are typically computationally intensive and require laborious construction of data files for each run. They suggest that less-detailed and faster-running models should be developed for stress testing, perhaps drawing on outputs from more detailed demand models. They suggest two alternatives for developing fast-running models:

- Creating a fast-running meta-model using machine learning techniques, to approximate model outputs quickly in situations where multiple runs are computationally expensive, for example using the publicly-available Travel Model Improvement Program – Exploratory Modelling and Analysis Tool (TMIP).[13]
- Creating a fast-running strategic level model, for example using the VisionEval software.[14]

They also recommend that methods like DMDU, involving approximate models, are more appropriate in early-stage planning.

Ives et al. (2017) also highlight the value of simpler fast-running models, based on scenario testing using both traditional four-stage transport models and the more approximate "systems of systems" NISMOD model. They found the results from the two model types to be broadly comparable, although NISMOD offered the greater flexibility for analysing uncertainty.

NIC (2022) builds on these findings, proposing the use of simple models to test the robustness of interventions across scenarios. They acknowledge that simple models may suffer from bias because they exclude many details, but suggest that complex models may ultimately be subject to greater error, particularly when there is high uncertainty.

In contrast to the desire for simpler and faster-running models, Numerika & Norconsult (2024) observe that many proposed developments in transport models are focussed on increasing model precision, e.g. increasing the number of zones, segments, time periods, which have the effect of increasing run times (and complexity). They argue that such developments alone will not elicit the required insights on new forms of mobility and societal trends. They undertook a RAG assessment of the suitability of three types of transport models – standard four-stage models, activity- and agent-based models (AABMs) and simplified models – against various criteria which underpin what they refer to as 'foresight analysis'. The criteria considered were:

- Development needs
- Timeliness
- Level of detail
- Transparency
- Geographical and temporal coverage

[13] TMIP-EMAT is an exploratory modelling and analysis toolkit developed under the USA TMIP Programme that integrates with transport modelling to run large numbers of scenario experiments, analyse uncertainty, build meta-models and support DMDU analysis, see: TMIP-EMAT documentation — TMIP-EMAT 0.6.4, January 2025 documentation

[14] VisionEval is an open-source strategic transport modelling framework designed for long-range scenario planning. It was created jointly by American transportation agencies (FHWA, Oregon DOT and others) to help planners test large numbers of future scenarios. It was not designed for scheme appraisal and contains no explicit network assignment but is recommended for stress testing in early-stage strategic work.

- Data needs

Their analysis (reproduced in Table 4 below) shows no outright winner or loser, but the standard four-stage model was judged to be reasonably well-suited for use in foresight analysis. It is noteworthy that their assessment considered work undertaken in 2024 to explore how run times of the Norwegian National model could be improved, finding that it could be reduced by 70-90%[15]. They argue that while AABMs might appear to offer potential in this regard, the additional model complexity, impacting upon data, run times and analysis, means that they are less appropriate for uncertainty analysis. They also make the case for simplified quick-running models which can be run for multiple scenarios.

Table 4: RAG assessment of suitability of different models for foresight analysis (reproduced from Numerika and Norconsult (2024))

Model type / criteria	Development needs to become operational	Characteristics					Suitability for foresight analysis
		Timely, ability to undertake analysis in reasonable time frames	Level of detail, ability to represent complex and detailed relationships in a reasonable way	Transparency, ability to understand underlying assumptions	Coverage, ability to cover broad geographies, time, issues	Data needs	
Four-step models							
AABM							
Simplified models							

Broader “systems of systems” models like NISMOD, which tend to have less detail of transport networks than traditional transport models, but incorporate links to a wider range of sectors, may also better support uncertainty analysis across multiple and wider planning objectives. It is noteworthy that the backcasting work of Statens vegvesen et al. (2025) involved running four types of models – long-distance passenger models, regional passenger models, freight models and a general equilibrium model – to assess the impact of a wide range of interventions and a number of outcomes, including travel demand, emissions, cost of travel and the economy.

Outside of these examples, little evidence was found of using transport models to undertake uncertainty analysis. While the DfT’s CAS are set up to do this, there is very little published work in this area. Ives et al. (2017) comment that the 12 scenarios developed in the course of their work could serve as a counterfactual to test policies and investments, but the paper does not provide any findings from such analysis. Statens vegvesen et al. (2025) aimed to use quantitative scenarios to test different policy pathways for decarbonisation but given time and budget constraints this work had to be done qualitatively.

[15] This point was also discussed in section 5.2.2.

Given the lack of literature in this area, it was not possible to find evidence on the proportionality of analysis. Proportionality is a critical consideration of the DfT's Uncertainty Toolkit, influencing the choice of technique and complexity of modelling depending on the potential impacts and the stage of analysis. But it is worth noting that faster running more approximate models could influence proportionality requirements, allowing for more quantitative modelling work up front to explore the robustness of policy options in the strategic analysis phase.

5.3 The use of scenarios in appraisal

In this section, we summarise findings and insights around how scenarios are used in appraisal, the potential for double-counting sources of uncertainty, and insights from other agencies and sectors.

5.3.1 How scenarios are used in appraisal

Very few countries explicitly prescribe scenario use within appraisal, but some emerging practices offer insights. In a comparative study of Dutch CBA practices against four other countries (UK, Norway, Sweden, Denmark), Mouter (2014) remarks that, whilst official Dutch appraisal guidelines (encompassing various ministries including transport) require that at least two exogenous scenarios are considered, this goes beyond typical practices in other countries.

Whilst not an explicit requirement, Infrastructure Australia (2021) sets out a staged process for incorporating scenarios into appraisal, as follows:

- **Stage 1:** Where resilience is identified as a driver for a scheme, it may be appropriate to identify scenarios around key uncertainties.
- **Stage 2:** Employ plausible extreme ('lowest' vs. 'highest') future scenarios to help identify scheme options that are robust across scenarios in the relevant timeframe and consider robustness when shortlisting[16].
- **Stage 3:** Based on the identified uncertainties and materiality of their impacts, determine the appropriate tools for analysing and responding to them. Interestingly, Infrastructure Australia argues that, whereas sensitivity analysis may be sufficient for a 'low' level of impact, a combination of sensitivity and scenario analyses will be more appropriate for a 'moderate' level of impact, potentially also undertaking real options analysis for a 'high' level of impact. Whilst considerations around proportionality would be helpful, no direction is given on what constitutes 'low' vs. 'high' impact.

The discussion is then developed further by setting out the following steps to incorporating scenario analysis in CBA. Most of these appear reasonably standard, but the discussion does introduce some additional considerations – pertaining to scenario analysis – under some of the steps.

[16] In this context, the guidance gives a transport example: 'How do different transport options perform if there is a behavioural shift to working from home and digital services, or a shift to driverless cars?'. No specific guidance is given on the interpretation of 'plausible' or 'robust'.

- **Step 1:** Articulate the problems and opportunities being addressed – how is this affected in the least and greatest plausible future change scenarios?
- **Step 2:** Identify the base case and project case options – consider the performance of options under the least and most plausible scenarios; consider at least one future, alternative scenario as an alternative base case.
- **Step 3:** Identify costs and benefits and how they are measured – under the different scenarios
- **Step 4:** Forecast the demand and impacts over the life of the investment – under the different scenarios.
- **Step 5:** Monetise the costs and benefits.
- **Step 6:** Identify non-monetised impacts.
- **Step 7:** Discount costs and benefits to determine the net benefit under each scenario; also determine value of additional features to better manage uncertainty potentially using real options analysis.
- **Step 8:** Analyse risks and test sensitivities – under each scenario; also use break-even analysis to see whether additional risk mitigation is affordable.
- **Step 9:** Report on CBA results.

A brief example is discussed of using scenarios to consider the uncertainty surrounding COVID-19.

Nellthorp et al. (2021) also give specific direction on the implementation of scenario analysis in scheme appraisal. This is in the context of a White Paper (WP) commissioned by Transport for Greater Manchester (TfGM), to consolidate knowledge on the topic of uncertainty, determine the implications for transport planning and policy, and identify what actions could be taken to better account for uncertainty within its strategic thinking. Having introduced the basic concepts, the WP considers tools and techniques for modelling and appraisal under uncertainty, separating these into two groups – the first concerning stochastic risk analysis and the second concerning scenario analysis.

The paper argues that 'deep' or 'scenario' uncertainty is best dealt with using scenario analysis, setting out a staged approach for scenario analysis, as follows:

- Decide drivers for change/assumptions.
- Bring these drivers together into a viable framework.
- Produce 7-9 initial mini-scenarios.
- Reduce to 2-4 scenarios that can be described in detail.
- Convert the scenarios into quantitative inputs to the model plus qualitative considerations for the interpretation of outputs.

- Run the full model under each scenario and produce the key outputs, costs and benefits.
- Identify the issues arising and how they affect decisions – especially whether the risks of going ahead outweigh the rewards, or vice versa.

The paper argues that, in practice, the future is likely to be a blend of different scenarios – and on that basis, a meta-model could be used to better define the 'solution space'. It is also argued that projects could be more adaptable to uncertainties arising in delivery, which could be informed by real options analysis.

5.3.2 Double-counting sources of uncertainty

Sections 1.1 and 1.2 of this paper set out a range of analytical methods to better understand and possibly mitigate for sources of uncertainty in M&A. However, an issue to be wary of is the possibility that deploying multiple methods in tandem could be duplicative. Citing De Zeeuw et al. (2008), Mouter (2014) highlights a specific case of duplication in relation to scenario analysis, as follows:

'Estimating welfare effects using multiple scenarios that vary in macroeconomic growth has the advantage of making the sensitivities of effect estimates to varying economic development clearly visible to readers. I conclude that problems can arise if the effect estimates are simultaneously adjusted for non-diversifiable macroeconomic risk (systematic risk) by applying a mark-up to the discount rate. For this reason, Norway, Sweden, and the United Kingdom also choose to describe risks surrounding effect estimates due to systematic risk through scenarios (or other methods) or a mark-up to the discount rate' (p82)[17].

In this context, Mouter (2014) recommends scenario analysis over the risk premium for two reasons: first, scenario analysis is more transparent for policymakers, and second, a risk-adjusted discount rate does not incentivise scheme promoters to reduce uncertainty through project design. Nellthorp et al. (2021) make a similar point (see the final entry in Table 3). An important caveat however is that De Zeeuw et al.'s (2008) advocacy of scenario analysis is specific to the case where probabilities can be assigned to scenarios (i.e. Level 2). In short, the three authors all advocate scenario analysis over a risk-adjusted discount rate, but De Zeeuw et al. restrict this guidance to the case where scenarios are assigned probabilities, whereas Mouter and Nellthorp et al. do not.

[17] In other words, the UK employs a risk-free discount rate, and deals with uncertainties via other analytical methods.

5.3.3 Transferable insights from other agencies and sectors

In the course of our review, we sought to identify other public sector organisations, both in the UK and elsewhere, which demonstrated good practice in terms of the use of scenarios in economic appraisal. Unfortunately, we were able to identify few organisations which openly prescribe or recommend this practice, but two organisations which do are the UK Financial Conduct Authority (FCA) and the European Investment Bank (EIB).

Chapter 6 of the FCA's official appraisal guidance includes a section entitled 'How we handle uncertainty in our estimates', which is motivated as follows (FCA 2024):

'When we do a CBA we are trying to estimate future impacts of a policy. This is inherently uncertain as we often have to make several assumptions about the way markets will develop and the way consumers and firms will respond'.

They highlight several specific sources of uncertainty including the impacts of FCA interventions when these relate to new markets and technologies, errors in data and models, uncertainties in demand and supply responses, the future macroeconomic environment, concurrent policy interventions and other factors outside the FCA's control, and imperfect or incomplete information more generally.

Several methods are then introduced which could be deployed to address the above uncertainties, which largely align with those considered earlier in this think-piece (i.e. sensitivity analysis, Monte Carlo analysis and scenario analysis), but they also mention the use of Delphi methods[18], as well as ranges and central estimates.

Little guidance is given on the specifics of scenario analysis, aside from the comment that: *'For instance, where a market is currently new, we may assume high growth in a market compared to low growth. The scenarios used may also form a 'best' and 'worst' case scenario range, reflecting the upper and lower bound of what we reasonably expect* (p28).

The EIB's appraisal manual states (EIB, 2023): *'When lacking sufficiently sound data to construct probability distributions, the analyst must judge the range and likelihood of possible values for each variable. In these circumstances, it may be more transparent to base the risk assessment on scenario building, where the assumptions used are immediately apparent and visible, than to run Monte Carlo simulations with assumed probability distributions, where the underpinning assumptions are less easily appreciated by the decision maker'* (p65).

An interesting aspect of the EIB's guidance is the prescription of three scenarios:

- "Base case" scenario – constituting the base expected rate of return (ERR) reported for the project;

[18] The Delphi method is a process of iterative surveying used to arrive at a group opinion from a panel of experts.

- "Pessimistic" scenario – values for the main input variables depicting a probable bad outcome, based on previous adverse experience;
- "Switching scenario" – input values that would cause the project to miss the acceptable return threshold.

Based on the above analysis, the EIB manual advises that the analyst should form a judgement on project riskiness based on the three scenarios, but acknowledges that:

'Inevitably, scenario-based analysis is more reliant on analyst judgement than a Monte Carlo simulation based on known probability distributions. The analyst needs to judge whether there is sufficient available information on probability distributions to merit performing a Monte Carlo simulation. Moreover, scenario-based analysis may complement or replace Monte Carlo analysis' (p65).

Whilst rather succinct, the above gives a clear position on the potential for combining stochastic risk analysis with scenario analysis as a basis for informing appraisal decisions.

Finally, it is worth noting that the latter three sections of Chapter 12 of EIB's manual are devoted to real options analysis, motivated as follows:

'When uncertainty is particularly high and investments are irreversible, flexibility to adapt in the future is especially valuable. Moreover, if project components can be delayed and if waiting would resolve uncertainty, the promoter may design and phase the project to leave options open on future actions. Measuring the full economic value of such projects requires the valuation of such options using real options analysis (ROA)' (p66).

5.3.4 General observations

From the material reviewed, there is a reasonable consensus that in an environment of (deep) uncertainty the use of multiple future (exploratory) scenarios is an appropriate way to test for the robustness of interventions. Thus, it is necessary to quantify the performance of intervention options – measured as the difference between including the intervention (Do-Something) and the counterfactual (Do-Minimum) – for a range of future scenarios, noting that both the Do-Some and Do-Min could be impacted by exogenous assumptions. There is no agreement on the number of such scenarios that should be tested: guidance ranges from one other scenario (Infrastructure Australia, 2021), to two other scenarios (Mouter, 2014; EIB, 2023), to 2-4 in Nellthorp et al. (2021). Standard appraisal analysis is then undertaken to quantify the key outputs – costs and benefits – to quantify the net benefit under each such scenario.

However, while many agencies recommend that good infrastructure policy should be robust across a range of futures and recommend the use of scenario analysis (for example, NIC (2022), Infrastructure Australia (2021)), no agency explicitly sets out how to measure robustness.

So how then should analysts and decision-makers judge what is the best option?

As noted earlier, DMDU researchers (Lempert, 2019) define a robust strategy as one that performs well compared to the other alternatives across a wide range of plausible futures. They go further and set out different robustness criteria, noting that selecting a specific quantitative criterion to judge robustness is non-trivial and that the choice of criterion can give a different ordering of interventions. For example, Robust Decision Making (RDM), one of the specific DMDU methodologies, draws on a number of robustness criteria:

- Maximum (expected) utility, choosing the option with the highest expected value when probabilities over futures are available.
- Wald (maximum), choose the option with the best worst-case outcome.
- Savage (minimax regret), choose the option that minimises the maximum regret.
- Hurwicz (α-criterion), choose the option that maximises a weighted average of the best and worst outcome.
- Laplace, maximise expected value assuming equal probabilities across futures.
- Starr / Domain (satisficing), identify an acceptable outcome domain and choose strategies that stay within it most often.

Both the Wald and Savage criteria are conservative, seeking to avoid poor outcomes. In practice, RDM typically applies several criteria to identify options that are consistently strong across measures, rather than relying on a single metric.

Kwakkel and Haasnoot (2019) emphasise the distinction between ‘regret’ and ‘satisficing’ metrics, where:

- the regret of a policy option is measured as the difference between the performance of the option in a specific state of the world and the performance of the best possible option;
- and satisficing metrics that aim to maximise the number of states of the world in which the policy alternative meets minimum performance thresholds.

They also emphasise the idea of vulnerability analysis, which identifies where policies fail to meet (satisficing) outcomes. This analysis is critical to determine the conditions under which a policy or investment may fail to meet outcomes, and inform possible mitigations.

Importantly, robustness analysis in DMDU is inherently multi-objective. Moreover, analysts strongly recommend the reporting of disaggregated outcome metrics, rather than collapsing these into single aggregated metrics, such as a benefit-cost ratio (BCR). Disaggregating outputs provides decision-makers with clearer insights into the trade-offs between alternative interventions and outcomes (if no strategy dominates across all objectives). For example, if one policy performs better on efficiency (i.e. VfM) while another performs better on equity, reporting outcomes separately allows stakeholders to better understand these trade-offs. This emphasis on disaggregation reflects a core premise in DMDU that analysts and stakeholders may not know or agree on how to weigh and value desirable outcomes, making multi-objective, disaggregated reporting essential for transparent and value-explicit decision-making.

Lastly, visualisation of outcomes is also a critical element of DMDU to help decision-makers understand the robustness of interventions, their vulnerabilities, and trade-offs between outcomes.

Otherwise, visualisation of results is an issue that has attracted little discussion in the reviewed literature. One study which did pick this up was Bernanke's (2024) review of the Bank of England's forecasting performance. He expressed a dislike of using fan charts to present uncertainty, on the basis that they have weak conceptual foundations, convey little useful information over and above what could be communicated in more direct ways, and have little salience with the public or media.

Finally, an important point is the potential for double-counting uncertainty if scenario analysis is undertaken alongside marking up the discount rate as a risk premium. Here we agree with Mouter (2014) and Nellthorp et al. (2021) who advocate the use of scenario analysis over the risk premium approach, on the basis that it is more transparent to policymakers and incentivises scheme promoters to reduce poor outcomes through project design.

6. CONCLUSIONS AND NEXT STEPS

Below we present conclusions and possible next steps.

6.1 General conclusions around uncertainty and scenarios

There is broad agreement that transport is an environment of (deep) uncertainty and that strategic planning should therefore seek to instil as much robustness as possible in terms of policies and interventions. Furthermore, there is reasonable consensus that if one accepts this characterisation of transport, then scenario analysis presents an appropriate means to assess robustness.

It has been noted that language around foresight and scenarios can be confusing, for example in Norconsult (2024). We have therefore attempted to clarify key concepts around uncertainty – including what is meant by uncertainty, where it may occur, the methods that are used to explore or quantify it, including scenarios, and how uncertainty is incorporated in transport planning, modelling and appraisal.

While there is a growing literature around the use of scenarios for transport planning, there is relatively little literature exploring the use of scenarios for transport modelling and appraisal specifically. Moreover, most of the literature is 'grey' literature, i.e. project reports commissioned by government agencies, appraisal guidance documents and studies on treatment of uncertainty by think-tanks or international agencies, such as the International Transport Forum (ITF) of the OECD. We identified very few academic papers on the specific use of scenarios for modelling and appraisal. Furthermore, we were unable to identify much literature in this area from other sectors.

Our review finds that the UK is a leader in providing guidance on the treatment of uncertainty. This is demonstrated by the UK being one of the first countries to have implemented a set of “Common Analytical Scenarios” (CAS) and associated data book setting out the detailed quantified assumptions that go along with these, to support assessment of the robustness of transport policy and interventions. While the use of scenarios to assess uncertainty is picked up in a few other guidance documents, for example in the Netherlands, Infrastructure Australia, and by the EIB, it is not as detailed and developed as that produced in the UK. Indeed, work in Norway concluded that it would save time and resource to have a set of common scenarios supporting analysis across municipalities (Norconsult, 2024; Numerika and Norconsult, 2024). It has already been noted that the DfT is presently refreshing its guidance on the CAS, with a view to encouraging scheme promoters to develop more bespoke scenarios as appropriate.

There is debate in the broader literature over the value of a central forecast or “business-as-usual” scenario (e.g. Lyons and Marsden, 2021). Proponents view it as an organisational and communicative anchor that enables comparison across projects and highlights deviations from expected trends. Critics argue that under deep uncertainty such scenarios lack evidential grounding and risk anchoring decisions to an unwarranted sense of likelihood. There was limited discussion of this point in the material reviewed for this think-piece, aside from Bernanke’s (2024) suggestion that a pragmatic compromise may be to retain a central forecast for communication, whilst deliberately reducing its prominence.

6.2 General conclusions around scenarios and modelling

Transport models can play a constructive role in uncertainty analysis by (i) widening the range of futures examined beyond trend-based projections, (ii) enabling systematic stress tests of strategies and measures under divergent assumptions, and (iii) clarifying the **robustness** of investment and policy choices. Yet, many practical constraints remain: multi-scenario runs are often time- and resource-intensive, and the interpretation and communication of differences across scenarios can be non-trivial.

Where modelling of scenarios has been undertaken, the authors point towards the benefits of simpler and faster running models (including metamodels or strategic models) for early-stage exploratory analysis, reserving detailed demand models for targeted, later-stage appraisal and design. Benefits were found in two studies of using multiple modelling approaches (Ives et al., 2017; Statens vegvesen et al., 2025).

The evidence base on **proportionality** in scenario-based modelling remains limited; nonetheless, continued efforts to streamline runtimes and develop approximate tools should enable more quantitative exploration of robustness in the strategic phases, with detail scaled up as materiality and decision stage require.

6.3 General conclusions around scenarios, modelling and appraisal

Across guidance and practice, there is broad agreement that robustness across multiple plausible futures should be a core criterion for infrastructure policy, given the uncertain environment of transport planning and the asset life of infrastructure investment. Yet no single, operational definition or metric of robustness is prescribed or agreed. There is agreement on the use of scenarios for assessing robustness, but no consensus on the number of scenarios required.

In appraisal, the benefits of the intervention (Do-Something) are measured relative to the counterfactual (Do-Minimum). Both will be influenced by exogenous assumptions and therefore both must be run in each scenario to quantify the benefits of the intervention.

Disaggregating appraisal outputs across wider objectives – such as efficiency, safety, decarbonisation, etc. – could provide decision-makers with clearer insights into the trade-offs between alternative interventions and outcomes, rather than presenting aggregated outputs such as net present value (NPV) or the benefit-cost ratio (BCR).

Moreover, clear visualisation of outputs across scenarios is needed to help decision-makers understand where interventions meet their objectives and where they do not. Clear understanding of robustness across different measures, and presented in clear language, could also support decision-makers.

Finally, it is important to recognise that there are risks of double-counting uncertainty in appraisal. If uncertainty analysis using scenarios is undertaken, there may be circumstances where the use of a risk-adjusted discount rate is duplicative. In such cases, scenario analysis is preferred because it is more transparent and better incentivises design adjustments that reduce poor outcomes.

We did not observe any papers that illustrated or showed how scenario analysis impacted decision-making or the value of foresight and scenarios more generally. We think that this is an important question to answer, and this motivates the first of our recommendations which follow.

6.4 Recommended next steps

In undertaking the review, we observed the need for more evidence in this important area and thus we make a few recommendations.

Recommendation 1: There is a need to undertake further work to better understand how scenario analysis influences policy outcomes, with reference to the types of uncertainty considered, the methods through which uncertainty is represented in the modelling and appraisal process, how uncertainty is communicated to policymakers, and how policy decisions in the context of uncertainty are subsequently reached.

Recommendation 2: Alongside such exploratory projects, there is a need for formal evaluation of the use of the CAS in modelling, analysis and decision-making.

Recommendation 3: There is a need to encourage more academic interest in representing uncertainty in transport planning, modelling and appraisal, for example through PhD research. A specific topic meriting attention would be the relative merits of simple vs. complex transport models in the representation of uncertainty.

Recommendation 4: The DfT has played a leading role internationally in formalising uncertainty guidance. As the guidance evolves, there may be benefit in convening a roundtable with other agencies (either virtually, or via a forum such as the ITF) who are exploring uncertainty in modelling and appraisal to further test and discuss findings from this paper.

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Appendix A: Short-listed papers for detailed review

Search method	Reference
Academic search	Hickman, R., Saxena, S., Banister, D. and O. Ashiru (2022) Examining transport futures with scenario analysis and MCA, Transportation Research Part A, 56, pp 560-575.
Academic search	Soria-Lara, J.A. and D. Banister (2018) Evaluating the impacts of transport backcasting scenarios with multi-criteria analysis, Transportation Research Part A: Policy and Practice, Volume 110, pp 26-37.
Academic search	FCA (2024) How we analyse the costs and benefits of our policies, available at: How we analyse the costs and benefits of our policies - 2024
Academic search	Tveter, E., M. Welde and J. Odeck (2025) Accounting for uncertainties in cost-benefit analyses of road projects: A procedure illustrated by real-world projects, Transport Policy, Volume 170, pp 137-146.
Academic search	Asplund, D. and J. Eliasson (2016) Does uncertainty make cost-benefit analyses pointless?, Transportation Research Part A: Policy and Practice, Volume 92, pp 195-205.
Academic search	Miller, M. and E. Szimba, How to avoid unrealistic appraisal results? A concept to reflect the occurrence of risk in the appraisal of transport infrastructure projects, Research in Transportation Economics, Volume 49, pp 65-75.
Experts	Norconsult (2024) Use of scenarios in strategic transport planning, for Norwegian Public Roads Administration, Report R-52308914-1 (translated into English).
Experts	Numerika and Norconsult (2024) Using methods and models to assess future demand with foresight methods: Knowledge base and path choice, available at: https://norconsult.no/media/ifbhbx2m/r-52407323-1_kunnskapsgrunnlag_v2.pdf
Experts	Statens vegvesen, Avinor, Bane NOR, Jernbanedirektoratet, Kystverket and Nye Veier (2025) Improving the scientific basis for assessing target achievement and future transport demand, available at (in Norwegian): Statens vegvesen
Experts	Romijn, G. and G. Renes (2013) General guidelines for social cost-benefit analysis, prepared for the Central Planning Bureau, Netherlands Environmental Assessment Agencies (translated)
Experts	PBL (2025) Future Exploration WLO: Four Scenarios for the Netherlands in 2040, 2050 and 2060, prepared for the Netherlands Environmental Assessment Agency (PBL).
Experts	Koopmans, C. and N. Mouter (2020) Chapter One – Cost-benefit analysis, in Advances in Transport Policy & Planning, Editor Niek Mouter, Academic Press, Volume 6, pp 1-42.
Experts	Mouter, N (2014) Lessons from a comparison of Dutch CBA practice with four other CBA practices, commissioned by the Netherlands Environmental Assessment Agency.
Experts	Lempert, R.J, Popper, S.W. and C. C. Hernandez (2022) Transportation Planning for Uncertain Times: A Practical Guide to Decision Making Under Deep Uncertainty for MPOs, for details see: Transportation Planning for Uncertain Times: A Practical Guide to Decision Making Under Deep Uncertainty for MPOs | RAND
Experts	Nellthorp. J., Willumsen, L., and R. Batley (2021) Handling increased uncertainty in transport forecasting, appraisal and investment decision making, White Paper for TfGM.
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Brief	An Roinn Iompair Department for Transport (2024) Transport Appraisal Framework, Appraisal Guidelines for Capital Investments in Transport, Module 7 – Detailed Guidance on Appraisal Techniques, available at: taf-2024-module-7-detailed-guidance-on-appraisal-techniques-abca0078-f2d7-4d5f-bd48-52.pdf
Brief	Harvey, M., Jones, M., McGeehan, E. and P Tisato (2021) Australian Transport Assessment and Planning Guidelines, T7 Risk and uncertainty assessment, Commonwealth of Australia, available at: t7-risk-and-uncertainty-assessment.pdf
Brief	Infrastructure Australia (2021) Guide to risk and uncertainty analysis, Technical guide of the Assessment Framework, Commonwealth of Australia.
Brief	Bernanke, B. (2024) Forecasting for monetary policy making and communication at the Bank of England – A Review, available at: Forecasting for monetary policy making and communication at the Bank of England: a review | Bank of England
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