Department for Transport

TAG Uncertainty Toolkit

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Department for Transport

Transport Analysis Guidance (TAG)

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1. Introduction

Purpose of the Uncertainty Toolkit

1.1 There is considerable uncertainty about how the transport system will evolve in the future, particularly with the potential for emerging trends in behaviour, technology and decarbonisation to drive significant change over time. The use of transport models, a fundamental aspect of scheme appraisal, can also introduce uncertainty to transport analysis, through the data, assumptions and model specifications required. To ensure decision-making is resilient to future uncertainty, decision makers need to understand how the outcomes of spending and policy proposals may differ under varying assumptions about the future. Analysis and presentation of uncertainty enables analysts, scheme promoters, and the decision makers they support, to better recognise and account for the uncertainty they face.

1.2 The aim of the Uncertainty Toolkit is to provide practitioners with practical advice on the analysis and presentation of uncertainty. The Uncertainty 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. Further, the Uncertainty Toolkit provides a) the Department for Transport's (DfT) view of when it is appropriate to use different tools and techniques for analysing uncertainty and b) guidance on proportionality in uncertainty analysis.

1.3 Four principles underlie the guidance provided in this toolkit for the treatment of uncertainty in transport appraisal and modelling:

1. **The treatment of uncertainty is a core part of any transport analysis and is needed to inform robust decision-making.** It should be considered early in the development of a scheme.

2. **Analysis should not focus exclusively on a core scenario.** Uncertainty analysis and the consideration of wider 'what if' scenarios should be undertaken as standard. To help navigate uncertainty in transport analysis, decision makers need to be provided with analysis showing how different futures may affect the outcomes of the decisions they are taking today.

3. **Proportionate appraisal techniques for defining, measuring and accounting for uncertainty within decision making should be used.**

4. **Uncertainty should be considered holistically across the strategic and economic cases and throughout the planning process.** There are several stages of transport scheme development at which considering

uncertainty in the future may be required. Consideration of uncertainty should be built in throughout the planning process and the 5-dimension business case model.

1.4 The Uncertainty Toolkit introduces the Common Analytical Scenarios. These are central to how DfT intends to approach uncertainty in transport analysis. They are a set of seven standardised, off-the-shelf, cross-modal scenarios exploring national level uncertainties which have been developed by DfT for use in forecasting and appraisal. The Uncertainty Toolkit sets out how we intend the scenarios to be used . The application of the scenarios is supported by the publication of TEMPro datasets, alongside more detailed guidance on their use.

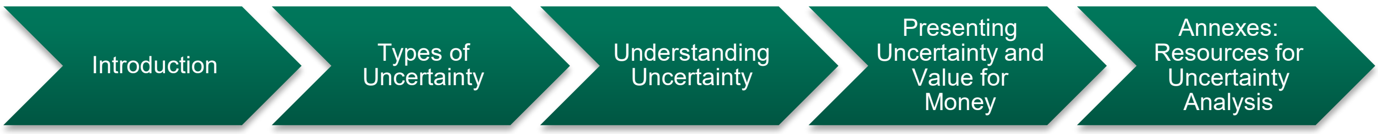
1.5 The Uncertainty Toolkit is supplementary to and sits alongside existing Transport Analysis Guidance (TAG) [note 1], especially TAG unit M4 [note 2], (which deals specifically with forecasting and uncertainty). The principles it contains can, however, be used by a wider transport audience in policy development. The Uncertainty Toolkit is intended to build on and support the application of TAG, with the intention of bringing together previously fragmented guidance on uncertainty. **The Uncertainty Toolkit will be updated and revised as necessary in the future.**

1.6 This Uncertainty Toolkit focuses on the treatment of uncertainty in a transport context, bringing together tools and techniques that are referenced in existing TAG units and exploring in greater detail how these can be applied. There is also focus on how analysis should be presented to decision makers. Other cross-Government publications such as the Cross Whitehall Uncertainty Toolkit [note 3], and the Government Office for Science Futures Toolkit [note 4] provide more general guidance on the analysis of uncertainty. The Department's Road Traffic Forecasts [note 5] and National Road Traffic Projections illustrate how our thinking on the treatment of uncertainty, and particularly the use of scenarios, has evolved over time.

The structure of the Uncertainty Toolkit

1.7 The Uncertainty Toolkit follows a five-chapter structure:

Figure 1 Chapter Structure of the Uncertainty Toolkit



1. **Introduction:** this chapter sets out what the Uncertainty Toolkit seeks to achieve and its structure.

2. **Types of Uncertainty:** this chapter sets out the different types of uncertainty pertinent to transport modelling and appraisal and specific considerations for each. It enables users to categorise and understand the uncertainties they are facing. There are signposts to existing guidance in TAG as well as cross-government publications (such as the Green Book

[note 6] and Aqua Book [note 7]). We reference some sources from a wider range of literature covering uncertainty, which will be expanded in future iterations of the Uncertainty Toolkit.

3. **Understanding Uncertainty:** this chapter sets out the different tools and techniques for understanding uncertainty, with guidance as to when and where they should be used in a proportionate manner.

4. **Presenting Uncertainty and Value for Money:** this chapter includes guidance on how schemes should present uncertainty in transport analysis to decision makers, including in value for money advice.

5. **Annexes:**

a) **Annex A: Glossary;** Defines key terminology beyond those already presented in TAG Unit M4 [note 2].

b) **Annex B: Resources for Uncertainty Analysis;** Contains assumptions for schemes to use in their analysis, including the Common Analytical Scenarios.

c) **Annex C: Techniques for Understanding Uncertainty;** Summarises the main techniques discussed in Chapter 3, highlighting the advantages and disadvantages of each.

d) **Annex D: Notes;** Contains notes referred to in the text in square brackets e.g. [note 1].

2. Types of Uncertainty

Introduction

2.1 Uncertainty can be defined broadly as limited knowledge about past, current and future events and the systems in which these events occur. In the context of decision-making, uncertainty refers to the gap between available knowledge and the knowledge decision makers would need to make the best, most informed policy decision.

2.2 An important first step for successful uncertainty analysis is understanding the type of uncertainty the scheme in question is facing. This can help analysts think about the best way of handling the uncertainty and can support scheme promoters in identifying what uncertainties are important for their scheme.

2.3 Transport infrastructure projects are exposed to considerable uncertainties. This is attributed to transport systems being complex, often interconnected and the “time consuming planning and implementation processes” and “applied [economic] and technical methodologies” [note 8] involved in their appraisal and modelling.

2.4 Further, transport analysis typically requires data and assumptions. Sources of uncertainty in transport analysis are wide-ranging: it relies on making assumptions around future economic, social, technological and environmental factors, and on model parameters calibrated to historical data. The models used to support this analysis are based on firm theoretical foundations which typically rely on the premise that the past is a good indicator of the future. Ultimately, however, they are simplifications of reality, meaning they can often fail to capture the inherent uncertainty in the future.

2.5 This chapter of the Uncertainty Toolkit will introduce different sources of uncertainty and signpost users to existing guidance within TAG. The types of uncertainty referenced are particularly pertinent to transport modelling and appraisal, and specific considerations for each are presented. These include information to enable users to categorise and understand the uncertainties they are facing. This will aid in the selection of techniques and presentational methods.

Classification of Uncertainty

2.6 Uncertainty is encountered throughout the decision-making process and the supporting analysis. Analysts need to understand and describe uncertainty to ensure their analysis is credible. There are different ways to classify uncertainty, but a common approach is to group classifications into three areas:

- **Known knowns** (or **risk**) – refers to the inherent uncertainty that is always present due to underlying probabilistic variability (also known as **aleatory uncertainty**);

- **Known unknowns** – arises from the lack of complete knowledge about the complex system being modelled (also known as **epistemic uncertainty**);

- **Unknown unknowns** – arises from factors or situations that have not previously been experienced and cannot be considered due to lack of evidence (also known as **ontological uncertainty**).

2.7 The characteristics of each are summarised in Figure 2 below on a scale from full determinism to total ignorance.

Figure 2 The Classification of Uncertainties

Statistical Determinism / Risk	**Known outcomes**	**Ignorance**
Known outcomes	**Unknown Probabilities**	**Unknown outcomes**
Known probabilities	**e.g. travel behaviour**	**Unknown probabilities**
e.g. Interest rates		**e.g. cataphoric disruption**

2.8 The focus of this chapter (and the Uncertainty Toolkit) will be on known knowns and known unknowns. However, an awareness of unknown unknowns is important for decision makers. Analysts should be ready to account for those uncertainties when they become known. Findings from models should be caveated as being a simplification of reality and, where possible, scheme design should be made robust to unknown unknowns (e.g. some of the consequences of climate change). The small probability of a national catastrophe is accounted for in the 1% per annum catastrophic risk factor in the social time preference rate recommended in the HMT Green Book [note 6].

2.9 Risk can be treated as a kind of uncertainty – a low level of uncertainty that can be quantified using probabilities. Probabilities cannot reliably be associated with the remaining uncertainties, because uncertainty is a broader concept than risk [note 9]. Whether schemes are facing readily quantifiable *risks* or less quantifiable *known unknowns* is a distinction for scheme promoters to understand - the terms are often conflated and different analytical techniques can be used for each.

2.10 Key features of risk are as follows:

- Risk describes the situation in which there is a chance of a specific outcome; uncertainty refers to a condition where future events are unknown.

- Potential outcomes are known in risk. For known unknowns, outcomes can only be estimated or are unknown.

- Risk is, to an extent, controllable and can be mitigated through thorough planning and intervention where necessary. Control and mitigation in the traditional sense is unviable for general uncertainty.

2.11 Risks can materialise in transport and infrastructure projects due to their long-term and complex nature: managing interfaces between the actors involved introduces operational risk and there could also be financial risk, especially if the project spans several years and budgets. **Annex 5** of the **Green Book** [note 6] and **TAG Unit A1.2** [note 10] contain guidance on the classification and management of scheme risk.

2.12 In the case of known unknowns and unknown unknowns, there will not be enough information to assign probability distributions to potential outcomes. Situations where experts cannot agree on probabilities and how the system works are generally characterised as in “deep uncertainty” [note 11]. In extreme unknown unknowns, nothing is known and analytical techniques are of limited value. In section 3.80 we cover techniques specifically for understanding deep uncertainty.

2.13 Chapter 3 Understanding Uncertainty of this toolkit describes techniques for exploring the impacts of both risk and uncertainty within a transport context. Some require an understanding of the risk probability distribution (such as Monte Carlo) and others can be used to understand a broader range of uncertainty (such as scenarios and sensitivities).

Existing Coverage of Uncertainty in Transport Analysis Guidance

2.14 The Uncertainty Toolkit builds on and supports the application of existing, fragmented uncertainty guidance across TAG. Laid out below is the uncertainty coverage within TAG, broken down by stage in the modelling and appraisal process:

- **Modelling**: specialist modelling units outline different sources of modelling risk and discuss parameter uncertainty (associated with estimation and/or specification error);

  - **M1.1**: Modelling Risk [note 12]
  - **M4**: Model parameter error [note 2]

- **Forecasting**: modelling units outline different sources of forecasting risk and discuss national and local sources of uncertainty on both the demand and supply side;

  - **A1.2**: Scheme costs via Quantified Risk Assessment and optimism bias [note 10]
  - **A2.2**: Private Sector Investment [note 13]

  - **A3**: Environmental impacts [note 14]
  - **A5.3**: Rail Demand Cap [note 15]
  - **M1.1**: Forecasting Risk [note 12]
  - **M4**: National / local uncertainty [note 2]

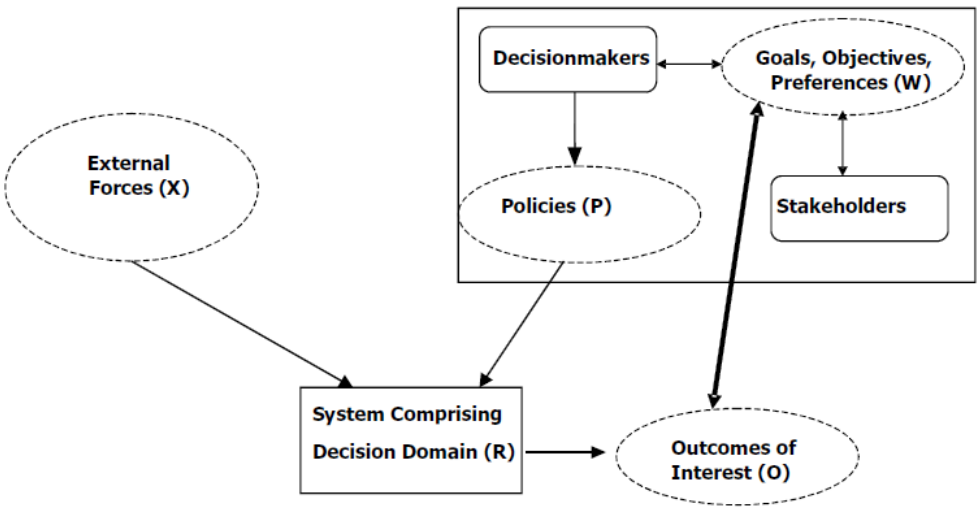
- **Appraisal**: this stage brings together the modelling and forecasting sections with evidence based assumptions concerning user costs and benefits.

  - **A1.1:** Interpolation and extrapolation over the appraisal period and beyond [note 16]
  - **A1.3**: Value of Travel Time savings uncertainty [note 17]
  - **A2.1**: Wider Economic Impacts [note 18]
  - **A4.1**: Option and non-use values [note 19]

Sources of Uncertainty

2.15 Walker [note 11] provides a framework for decision support which identifies several locations in which uncertainty arises in decision analysis. Policies (P) are used to influence the behaviour of the system (R) to achieve goals. Other external forces (X) act on the system of interest (i.e. transportation system along with policies). The results of these interactions are the outcomes of interest (O) which give a value of outcomes (W).

Figure 3 A framework for decision support [note 11]



2.16 Broadly, there are two sources of uncertainty: uncertainty in the inputs to the system (X and P); and uncertainty in the system model parameters and specification (R). Within transport analysis, the propagation of uncertainty through the system model can be a significant driver of uncertainty.

2.17 Section 2.19 shows a classification of different sources of transport uncertainty, presented in pairs. It is important to note that these groups are not mutually exclusive. For example, demographic changes could be considered an exogenous, national, demand-side uncertainty.

2.18 Mutual exclusivity should not be assumed within pairings either. Demographic changes which impact the national population will intuitively impact on local populations as well (although the inverse is not necessarily true).

2.19 Classification of sources of uncertainty

Input Uncertainty

- **Endogenous Inputs** – Inputs in which decision makers have influence on the future system outcomes through policy interventions (P)
- **Exogenous Inputs –** External forces outside of the decision maker's control which may influence the system significantly (X)
- **Supply –** Uncertainties associated with the existing and future transport network or the provision of transport services.
- **Demand –** Uncertainties due to current and future economic, demographic, technological, and behavioural change, policy led demand and proposed developments.
- **National** – Uncertainties that influence the whole of the country e.g. demographic, technological, behavioural.
- **Local** – Uncertainties that are specific to the area in which schemes are being developed e.g. population distribution.

Model Uncertainty

- **Parameter** – Model Specification and Propagation uncertainties (R) including elasticities, sampling errors and limited precision in input values.

Input Uncertainties

Endogenous and Exogenous inputs

2.20 Inputs which can be influenced using tools or policies at the decision maker's disposal are classed as endogenous to the scheme. Uncertainties with a significant decision-making input (e.g. policies to support decarbonisation or autonomous vehicles) therefore tend to be more endogenous. Inputs outside the influence of those deciding on a transport intervention are classified as exogenous factors (e.g. population growth).

2.21 This simplified, binary distinction between endogenous and exogenous fails to capture situations where uncertainties contain elements of both. The level at which decisions are made is a determining factor in this: classification will differ according to the perspective of the practitioner. Compared to local authorities or transport operators, central government will classify a larger set of uncertainties as endogenous, owing to their nationwide policy making remit.

Supply side uncertainties

2.22 Endogenous factors often relate to supply-side measures – national decision makers have influence over supply-side capacity (e.g. the development of new infrastructure projects). The presence of endogenous factors may lend itself to a more visionary approach to uncertainty analysis, whereby scenarios can be used to explore how policies might help achieve desirable end states (see paragraph 3.35 for more details).

2.23 Supply side uncertainties relate to scheme development and are often associated with the development of new capacity and the capital costs of transport projects. There is also uncertainty around the intended value resulting from schemes – will the project deliver the intended increase in supply capacity? Will service quality improve? Will fare levels change across the sector? These questions are illustrative but demonstrate how supply side uncertainties can have a significant impact on expected Value for Money. Technological disruptors such as transport modes that do not exist now but may in the future can be classified as supply-side uncertainties.

2.24 There are identifiable factors that may influence scheme costs, leading to over- or under-spends. ‘Optimism bias uplifts’ should be applied to account for practitioners’ tendency to be over-optimistic about capital or operating costs. Where relevant, adjustments should also be made to benefits, to account for the possibility of over-optimistic calculations. Section 3.84 provides more detail on optimism bias. In addition, **TAG Unit M4** [note 2] sets out the requirement for an Uncertainty Log to record all assumptions made when modelling demand and supply.

Demand side uncertainties

2.25 Where factors are classified as exogenous, this implies a lack of influence over uncertain aspects of the future which may affect the outcome of transport investment made now, such as future income or employment levels. Demand side uncertainties are generally associated with the key drivers of transport demand such as trip rates, income, population change, employment and car ownership. There is inherent uncertainty in the forecasts of these factors, which constitute model inputs.

2.26 Exogenous uncertainties are often related to demand-side factors, which are the predominant focus of the Common Analytical Scenarios (presented in section 3.44). **TAG Unit M4** [note 2] provides guidance on national growth in demand, which is complemented by the Common Analytical Scenarios (see Chapter 3 Understanding Uncertainty and Annex B: Resources for Uncertainty Analysis).

2.27 To help practitioners explore the uncertainty within their schemes, section 2.28 presents a list of some common to transport analysis. These were collated following interviews with DfT policy teams, and are grouped by overarching themes. This list is not exhaustive and we encourage practitioners to consider sources of uncertainty relevant to their schemes in a long list. This can form part of the short-listing process for the generation of new scenarios - see section 3.35.

2.28 Common Transport Supply and Demand Uncertainties

Technology

- Range of road vehicle types, and extent of technological standardisation;
- Take-up of Connected Autonomous Vehicles and Electric Vehicles;
- Nature, sufficiency and cost of energy supply;
- Connecting energy supply to vehicle energy demand.

Economy

- Economic performance;
- Composition of labour market, different ways of working and changing business models;
- Level of automation;
- Patterns of spatial development and changes in regional distribution.

Behaviour

- Use of digital infrastructure and services;
- Level of car ownership and extent of licence holding;
- Level of vehicle occupancy;
- Demand for active travel;
- Adoption of new technologies.

Social

- Changes in demographic composition (e.g. ageing population);
- Changes in public health;
- Importance of equity;

- Climate change impacts and response;
- Potential disruption to transport systems.

Political

- Regulatory influence (e.g. road-pricing);
- Decisions on national infrastructure projects;
- Roles, responsibility and interconnectedness of the public and private sectors;
- International action on decarbonisation.

Transport Supply

- Other transport investments;
- Availability of and demand for public transport;
- Carrying capacity of the rail network;
- Digital vs. physical connectivity for access;
- Production to consumption supply chains.

National versus Local Uncertainties

2.29 Uncertainties can be specific to the spatial level at which they are experienced. National level uncertainties in travel demand can relate to demographic projections and aggregations on population, households, employment, GDP growth and changes in traveller's behaviour and tastes. Similarly, there are national uncertainties around travel costs, related particularly to potential technological developments.

2.30 Simultaneously, schemes could be exposed to a level of local uncertainty specific to the areas in which they are developed. These local uncertainties typically will depend on whether developments (such as housing or schools) or other planned transport schemes go ahead within the vicinity of the scheme in question. Uncertainty around costs can also be specified at a local level (e.g. whether other transport construction projects materialise).

2.31 **TAG Unit M4** [note 2] provides definitions of these spatial level uncertainties, and requires practitioners to record both national and local uncertainties in travel demand and cost in an uncertainty log.

Model Specification and Parameter Uncertainties

2.32 The use of transport models is a fundamental aspect of scheme appraisal. This introduces another important type of uncertainty: model specification. Primarily, scheme promoters should be aware of the extent to which transport models can accurately represent real life relationships and trends. Historical relationships are often used in model calibration for future forecasting – whilst this is usually the most appropriate and proportionate approach, this can introduce uncertainty into analysis.

2.33 Uncertainty arises from a multitude of sources within transport models, including: data collection limitations (e.g. use of surveys which might only be performed on certain days or on a limited percentage of each cohort); using parameter estimates instead of true values (e.g. a parameter estimated from historical data which might not accurately reflect the future); or specification error in model equations. It will never be possible to have a model completely free from uncertainty, but it is important for scheme promoters to recognise this fact and understand how this affects model outputs and economic assessments.

2.34 When an input or parameter is estimated from a separate model, this will most likely rely on statistical methods, theory and assumptions. Aggregation of data within and across models can result in uncertainty. It is not simply the prevalence and magnitude of individual sources of uncertainty, but the interaction between these sources that is pertinent here. This can lead to propagation of uncertainty throughout modelling and appraisal systems. In the context of transport modelling, propagation refers to the case where the final forecast depends on a series of sub-models 'in which the output of the previous sub-model in the chain is used as input to the next sub-model, [and where] errors in any sub-model may be amplified or reduced in the next sub-models' [note 20].

2.35 Sensitivity testing (discussed in Section 3.64 in more detail) is crucial, particularly around key parameters upon which the model is most dependent for forecast production, and where practitioners are aware model specification is uncertain.

2.36 **TAG Unit M1.1** ('Principles of Modelling and Forecasting') [note 12] issues guidance on mitigating modelling and forecasting risks. This Unit (and section 3 specifically) acknowledges that transport models may "not be realistic or sensible due to the error around the model parameters used, or limitations in the extent to which the model can represent human behaviour". This TAG Unit issues the following guidance:

- *Validation* – comparing model outputs with independent, observed data;
- *Realism testing* - checking model response to changes in inputs is realistic based on independent evidence;

- *Sensitivity testing* – rerunning the model with changes to model parameters, to check model results are robust to changes, and to check the model responds appropriately;
- *Input transparency* – ensuring inputs to transport models are transparent and easy to audit, in order to mitigate the risk of errors;
- *Appropriate model use* - using models in accordance with their design and underlying theory, as a model designed for one purpose may not be suitable for a different situation.

2.37 Section 2 of **TAG Unit M4** [note 2] identifies errors in the model parameters and specification (i.e. how these inputs propagate through the model) as a key source of forecast error in transport modelling. It requires practitioners to record model parameter errors within an uncertainty log.

2.38 HM Treasury's (HMT) 'Aqua Book' [note 7] provides guidance on quantifying uncertainty around use of data in analysis in Chapter 8 'Analysing Uncertainty'. Caution is advised around uncertainty propagation, discussed above. Some of the limitations of data use more generally are also presented. Datasets are rarely perfect for analysis, for reasons including availability, issues of definition and coverage gaps. Guidance advises that proxy or extrapolated datasets can, within reason, be used, although this will inevitably introduce further uncertainty into the analysis. More detail on these topics can be found in the Aqua Book.

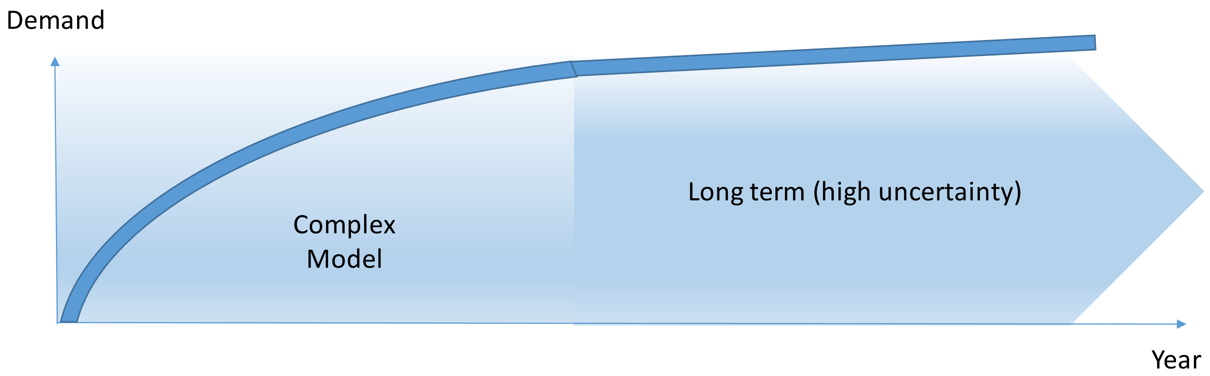
Appraisal Period

2.39 **TAG Unit A1.1** [note 16] provides guidance on appraisal periods, and the appropriate length that should be applied. The length of the appraisal period has an impact on the level of uncertainty. Over a longer appraisal period the key drivers of transport demand and supply become increasingly uncertain including:

- Exogenous input assumptions such as economic growth, fuel costs, population and employment;
- Modelling parameters which convert these exogenous drivers into forecasts of travel demand, such as demand elasticities and mode choice parameters;
- Appraisal values, such as forecast values of time, health impacts and agglomeration elasticities.

2.40 Established transport models are typically used to forecast travel demand for the next twenty years or so (using evidence-based assumptions) over a period termed the 'complex model phase'. These models cannot be used indefinitely and at some point, a final forecast needs to be made. Where longer-term forecasts are required further demand may be projected using a simpler approach, such as extrapolating in line with population growth.

Figure 4 Illustration of the typical long-term demand forecasting approach with a simpler projection in the longer term



2.41 The impacts of transport schemes are typically estimated with transport models run for the scheme opening year and at least one other forecast year (see TAG unit M4 [note 2]). Interpolation is used between the modelled years. Analysts need to carefully consider the trajectory of the magnitude of impacts after the final modelled year when deciding on the appropriate approach to extrapolation beyond this point. Further modelled years, where proportionate, are a useful means of testing whether congestion or capacity limits may curtail benefits growth in the future.

2.42 Over the longer term there is an increased risk of assets becoming economically obsolete due to, for example, major technological or behavioural change. New technology such as autonomous vehicles may radically shift both demand and supply for certain modes of travel. Similarly, climate change may render some assets unusable. A risk allowance of 1% per annum is included within the HMT Green Book [note 6] discount rate. This is intended to capture, for example, "disruptions due to unforeseeable and rapid technological advances that lead to obsolescence or natural disasters that are not directly connected to the appraisal" (paragraph A6.10).

2.43 However, there are a wide range of uncertainties surrounding future travel demand and scheme benefits, as discussed elsewhere in this document, which should be assessed on a project-by-project basis. These cannot be reasonably captured within a uniform adjustment to the discount rate. The use of scenarios (described in Chapter 3 Understanding Uncertainty and Annex B: Resources for Uncertainty Analysis) offers a means to stress test schemes against these sources of uncertainty.

2.44 As better evidence becomes available, uncertainty in input assumptions and modelling parameters can be reduced with the corresponding range of uncertainty narrowing [note 21]. Analysts need to be aware of emerging uncertainties which should be incorporated, generating a continual process of improvement. Decisions should therefore incorporate the best depiction of the full range of uncertainty at that point in time.

2.45 Regardless of the appraisal period used, a range of scenarios should be explored (as discussed in Chapter 3 Understanding Uncertainty). Uncertainty over the entire appraisal period must be considered, not only within the complex model phase. Although benefits will be extrapolated for a large portion of the appraisal period in most cases, it is vital that a range of trajectories for any post-final modelled year extrapolation are tested.

2.46 Beyond the NTEM forecasting horizon, currently 2061, population growth should be considered the key driver of growth in total exogenous travel demand. As set out in Annex B: Resources for Uncertainty Analysis, the Common Analytical Scenarios use varying ONS population growth projections, and this should be reflected in the approach to both demand forecasting and benefits extrapolation over the full appraisal period. For example, if population-based extrapolation is used from the final modelled year, this should be based on the ONS 'low' and 'high' population projection variants in the 'Low Economy' and 'High Economy' scenarios respectively.

Conclusion and Key Takeaways

2.47 This chapter has made explicit distinctions between different types of uncertainty as a first step in helping scheme promoters judge the proportionality of their uncertainty analysis. The key takeaways should be:

- It is highly likely transport proposals will be subject to uncertainty: however, this is broadly defined. There are different types of uncertainty scheme promoters may need to analyse and bring to the attention of decision makers;

- An important initial distinction is between uncertainty and risk. Under risk, potential outcomes are known and can be quantified. In the case of uncertainty, potential outcomes can only be estimated;

- From here uncertainty in transport modelling and appraisal can predominantly be categorised as either a) input uncertainty or b) model specification uncertainty:

  - Within a), scheme promoters should determine whether this input uncertainty could be classed as endogenous, and whether it is at the local or national spatial scale;
  - Within b), scheme promoters should, to the best of their ability, determine whether uncertainty is introduced through either the estimation of parameter estimates or through model specification (or both). If the final forecast depends on a series of successive sub-models, scheme promoters should be conscious of the fact uncertainty can be propagated throughout the modelling process.

3. Understanding Uncertainty

Introduction

3.1 The previous chapter looked at the types and sources of uncertainty. This chapter sets out different tools and techniques for understanding the uncertainty pertinent to transport modelling and appraisal. The selected approaches are determined by the additional value which they provide in understanding uncertainty, which can be used to improve decision-making. This value will be higher when there is greater uncertainty or when the impact is higher. A framework in which to assess proportionality of the different techniques is introduced below. This toolkit places emphasis on the use of scenarios for testing uncertainty, and in this chapter, we introduce the Common Analytical Scenarios.

Benefits of including uncertainty analysis

3.2 Effective decision-making about the future depends on anticipating change. The application and presentation of uncertainty analysis enables officials, analysts, planners and the decision makers they support to better recognise and confront uncertainty and operate more effectively. Reduction in uncertainty is welcome, but decisions that ignore uncertainty ignore reality. Substituting single value assumptions for uncertainty ranges might simplify choices in the short term but may come at a much higher price in the longer term.

3.3 Excluding consideration of uncertainty is not realistic. Explicitly accounting for it makes planning choices more appropriate, such as making the choice between solutions that are high expected value, high uncertainty versus low expected value, low uncertainty transparent to a decision maker. There is benefit in knowing whether:

- The likely outcome of a proposal is similar whatever happens;
- The result is unstable with outcomes readily changing with small input variations;
- Some uncertainties are key to outcomes and thereby imply scope for hedging.

3.4 Schemes and polices can then be designed to mitigate against uncertainty (see section 4.13). However, including uncertainty analysis can add additional complexity to the modelling process. Depending on how uncertainty is presented, it can make the results harder to understand. Furthermore, carrying out uncertainty analysis can add to the time and resource costs of analysis. A proportionate approach is required to strike an appropriate balance.

Proportionality Framework

3.5 This Chapter introduces several ways in which practitioners can address uncertainty in their analyses which vary in analytical complexity. Within a proportionate approach, the value additional analysis adds in avoiding costs and maximising benefits should outweigh the costs of the analysis itself. In addition, the type of analysis should be suited to the type of uncertainty. The sophistication of the techniques employed can vary, ranging from qualitative assessments and ready reckoners through to full model runs.

3.6 This Uncertainty Toolkit recognises that the scope of uncertainty analysis should be reflective of the **impact of the uncertainty** and the **level of uncertainty**. Considerably more weight should be placed on understanding uncertainty for schemes with higher impacts, greater revenue risk and more uncertain outcomes.

3.7 There are several factors that can increase the **impact of the uncertainty**:

- The financial cost of a proposal and the cost to the public purse;
- The scale of the project's projected social benefits and costs;
- If the decision maker takes revenue risk;
- Whether there is corporate risk (which considers how novel, contentious or repercussive the intervention is);
- The degree of interdependency between the proposal and other policies and investments;
- The marginality of the value for money case (i.e. whether the value for money rating is close to a changing category).

3.8 The **level of the uncertainty** also affects its impact, and will be influenced by factors such as:

- The stage of project development;
- The lifetime of the project influencing the extent of uncertainty (i.e. the longer the lifetime the greater the uncertainty - see section 2.39 on Appraisal Periods);
- National level uncertainties to which the project is sensitive (see Section 2.29 on scenarios);
- Specific local uncertainties that are applicable.

3.9 There are a number of frameworks that can help consider the impact and likelihood of the uncertainty, such as the Cabinet Office standard Business Impact Levels [note 22] and the Department for Transport's Business Case

Approval Framework [note 23] that defines projects by Tier. In Table 1 below, we recommend considering the various influences listed in determining an indicative impact / uncertainty category. Three broad categories of impacts can be identified: Low, Medium and High.

3.10 Schemes are unlikely to fit into one single impact level in Table 1. **Practitioners will need to use their judgement**, combined with the guidance above and this table, to determine the impact level. A scheme does not have to meet all of the criteria (rows in the table) in order to attain a given impact level – for example, if there was a substantial 'corporate risk' then high impact may be justified even if the cost was much lower than £500m. The impact levels can be used to help determine the selected uncertainty analysis techniques. Note the scale and scope of analysis may evolve as the project develops.

Table 1 Table of Indicative Impact

	Indicative Impact		
	Low	**Medium**	**High**
Impact on public finances through budget cost or revenue risk	Tier 3 e.g. < £50m	Tier 2 e.g. £50 - 500m	Tier 1 e.g. > £500m
Corporate risk	Limited / risk of minor embarrassment	Risk of minor loss in confidence	Risk of major loss in confidence
Value for Money	Solidly within a value for money category	Close to a value for money category boundary	Bordering two value for money categories
Level of uncertainty	Input assumptions low range of uncertainty. Short lifetime e.g. <5 years	Input assumptions medium range of uncertainty. Medium lifetimes 5 – 50 years	Input assumptions high range of uncertainty. Long lifetimes e.g. > 50 years

Proportionate Analysis Technique Selection

3.11 There is no single approach for analysing uncertainty. Multiple approaches may be appropriate for some schemes and this should be considered on a case by case basis. The choice of approach should depend on the nature of the uncertainties. Different methods have varying technical requirements and resource implications – intuitively, sophisticated methods require more resource to complete.

3.12 **As a rule of thumb, the potential benefits gained or costs avoided by improved decision-making should be greater than the costs of doing the uncertainty analysis.** Figure 5 below shows a possible technique selection flowchart.

3.13 In this chapter we introduce various techniques for a proportionate understanding of uncertainty:

- **Judgement-based**; simple judgement-based approaches (Section 3.30) are introduced.

- **Scenarios**; the use of scenarios (Section 3.35) and the Common Analytical Scenarios (Section 3.44) provide significant insight into the impacts of key national level uncertainties for transport analysis. Horizon Scanning (Section 3.53) is useful as part of scenarios development.

- **Sensitivity studies**; Sensitivity studies (Section 3.64) and local scenarios are also powerful tools to reveal project specific uncertainties to decision makers.

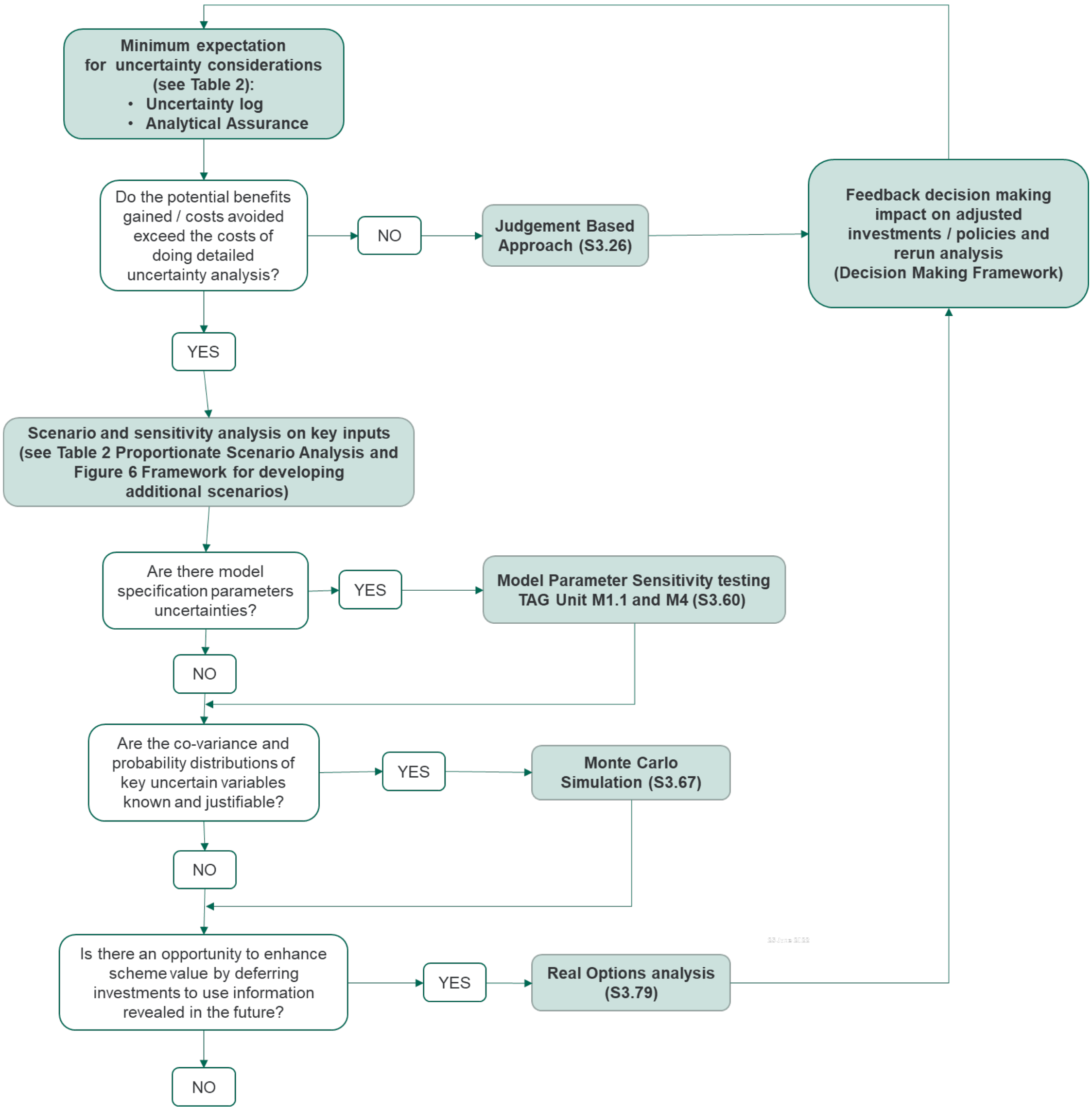
- **Monte Carlo**; We cover certain risk analysis techniques such as Monte Carlo analysis (Section 3.71).

- **Other decision-making approaches**; These techniques (Section 3.80) are useful for decision-making under deep uncertainty. When there is a significant learning-over-time component Real Options analysis can be used.

- **Optimism Bias;** (Section 3.84) is a technique focused on cost and benefit uncertainty.

3.14 Whenever additional analysis is performed its value is in providing insight that can be used in decision-making and iterating improved schemes, options and policies. This feedback loop is a crucial aspect of realising the impact of the analysis. Different approaches may be appropriate at different stages of analysis, for example more judgement-based approaches may be useful in very early stage design.

Figure 5 Uncertainty Analysis Technique selection



Proportionate Scenario Analysis

3.15 In section 3.8 the stage of project development is given as a factor that influences the level of uncertainty. Earlier stages will likely be more uncertain. However, at earlier stages of project, there may be less capacity for advanced modelling techniques to consider uncertainty. Therefore, it may be proportionate to consider a judgement based or qualitative assessment (see section 3.30). Conducting a high-level assessment of key uncertainties will ensure the initial scheme design is robust to uncertainty and will help inform the subsequent more detailed uncertainty analysis at later stages. If multiple design options are being considered it could be considered proportionate to only perform the scenario analysis on a subset of options.

3.16 In all cases the scenario analysis should be clear about which scenarios enhance/weaken the scheme's viability and needs case. Schemes should consider what impacts are associated with each of the scenarios. e.g. freight impacts, emissions impacts, distributional impacts, congestion and feedback loops (see Annex B: Resources for Uncertainty Analysis section 5.20). Explicit evidence should be stated of what mitigations are in place to make recommendations robust to the range of scenarios and risks.

3.17 We require that all schemes consider at the minimum consider the Common Analytical Scenarios qualitatively. Guidance on how to conduct this assessment is given in section 3.19, section 3.30 on Judgement-Based Approaches and Annex B: Resources for Uncertainty Analysis section 5.20. Table 2 provides guidance on what the Department for Transport considers the minimum standard to exemplify best-practice analysis using the Common Analytical Scenarios, at varying stages of business case and impact level. It should be used as a guide, and where proportionate additional analysis should be undertaken. If a practitioner wishes to deviate from Table 2's guide of best practice, justification should be provided in the business case.

Table 2 Technique selection for a proportionate approach to scenarios analysis

	Low Impact Projects	Medium Impact Projects	High Impact Projects
Requirement for all schemes at all stages	Qualitative discussion of how the options developed could be impacted by the different Common Analytical Scenarios		
Recommended for Strategic Outline Cases	Qualitative discussion of Common Analytical Scenarios as described in the 'requirement for all schemes'	Proportionate quantitative analysis of scenarios critical to decision making	Proportionate quantitative analysis of scenarios critical to decision making on a subset of longlisted options
Recommended for Outline Business Cases	TAG M4 Low/High or envelope of Common Analytical Scenarios to be run and VfM reported	Critical Common Analytical Scenarios to be run, with reported VfM. Alongside this, any relevant local scenarios could be run. For scenarios not critical to decision making, there should be proportionate quantitative analysis	Critical Common Analytical Scenarios to be run, with reported VfM. Alongside this, any relevant local scenarios could be run. For scenarios not critical to decision making, there should be proportionate quantitative analysis
Recommended for Full Business Cases	TAG M4 Low/High or envelope of Common Analytical Scenarios to be run and VfM reported	Critical Common Analytical Scenarios to be run, with reported VfM. Alongside this, any relevant local scenarios should be run. For scenarios not critical to decision making, there should be proportionate quantitative analysis	Critical Common Analytical Scenarios to be run, with reported VfM. Alongside this, any relevant local scenarios should be run. For scenarios not critical to decision making, there should be proportionate quantitative analysis.

3.18 Note that, in order to consider a wide breadth of uncertainty, the range of scenarios examined in greater depth for appraisal should cover a range at least as stretching as the TAG M4 Low/High growth scenarios, unless the TAG M4 Low/High growth scenarios themselves are used (in line with the proportionate approaches set out in Table 2).

3.19 Qualitative analysis could consider how the different assumptions used within each CAS will impact on scheme objectives and potential solutions. This should inform sifting and also inform which CAS to focus on when doing quantitative analysis in later stages.

3.20 There should be a qualitative discussion as to how the options developed could be impacted by the different CAS. This discussion should reflect the complexity and impact of the scheme considered. There should be a discussion as to the risks and opportunities facing the strategic objectives of the scheme under each of the CAS. For example, a decarbonisation scheme may perform poorly on decarbonisation objectives under the High growth scenario.

3.21 This qualitative discussion should include a discussion on the direction the VfM would move under every scenario, and an explanation as to why.

3.22 A scenario might be critical to decision making for a scheme because it presents high adverse risks to the scheme as well as scenarios that are particularly advantageous to a scheme. Additionally, a scenario may be critical if a scheme promoter wishes to show resilience under that scenario – that the value for money does not fall.

3.23 The decision as to which CAS scenarios are critical for a scheme should be documented together with appropriate qualitative and quantitative analysis undertaken to inform the decision. The decision should be reviewed and updated as necessary at each stage of scheme development.

3.24 Any downstream analysis using CAS traffic model outputs (e.g. TUBA, COBALT, noise, air quality, DI assessments) should as a minimum be undertaken for core (Level 1) benefits and be proportionate to scheme. The level and type of analysis should consider scheme stage, scheme objectives and relevant CAS scenario. For example, undertaking DI analysis for the Regional CAS where a shortlisted scheme has levelling-up objectives; or re-assessing air quality impacts when considering a Decarbonisation scenario. Another approach could be to conduct a sensitivity test on TUBA or Level 1 benefits, and then apply an uplift or downlift to Level 2 or 3 benefits.

3.25 The 'core scenario’ (as defined in TAG Unit M4 [note 2], section 3) is expected at all impact levels should represent best basis for decision making given current evidence. The existence of a core scenario focuses decision makers and prevents cherry picking scenarios. The TAG Data book [note 24] provides a library of central assumptions and large parts of the guidance are built around having a Core scenario. The core scenario is also used to develop scenarios in NTEM and then in NTM by varying modelling levers away from the default central values.

3.26 **Lower Impact Schemes**: examples of low impact schemes are smaller scale, local transport policies or schemes. For lower impact analysis it is proportionate to use the High and Low demand growth scenarios as presented in TAG Unit M4 [note 2], thus keeping the number of scenarios and associated costs to a minimum. However, this should not preclude the use of the Common Analytical Scenarios for considering relevant national level uncertainties. Other key sensitivities and uncertainty techniques should be used where relevant. A risk analysis of key quantifiable variables such as cost and elasticities would typically be performed.

3.27 **Medium Impact schemes**: examples of medium impact schemes are large DfT approved projects. The Common Analytical Scenarios, which provide assumptions on national level trends, should be used in place of the TAG Unit M4 [note 2] High and Low growth scenarios wherever possible. The Common Analytical Scenarios provide far greater insight into the impacts of uncertain trends on transport schemes which can be used to better inform decision makers. Some of the Common Analytical Scenarios may not be wholly relevant to certain schemes, nor would it be proportionate for smaller, more localised projects to assess all seven scenarios. For this reason, schemes will have to justify their decision to not select and discount scenarios. Other key sensitivities and uncertainty techniques should be used where relevant. A risk analysis of key quantifiable variables such as cost and elasticities would typically be performed.

3.28 **Higher Impact schemes**: examples of higher impact schemes are high impact investment programmes e.g. Roads Investment Strategy or strategic national transport studies. The Common Analytical Scenarios should be used. Justification should be provided if certain scenarios are discounted e.g. they have already been considered at an earlier phase of work. Other sensitivities and uncertainty techniques should be used to communicate the range of uncertainties. A comprehensive risk analysis of all quantifiable variables that feature in the forecasting and appraisal such as cost and elasticities should be performed.

3.29 More detail of the different approaches to consider uncertainty follows.

Judgement-Based Approaches

3.30 In some cases, advanced uncertainty analysis techniques will be unfeasible due to time, resources or data constraints. It may be the case that there is too little time or too little information to perform a quantified analysis. In the absence of rigorous uncertainty analysis, the cross Whitehall Uncertainty Toolkit for government analysts [note 3] suggests “a subjective estimate of the overall uncertainty” be made.

3.31 This should be a group discussion and formal elicitation methods are advised (e.g. Delphi). This should eliminate the possibility of ‘group-think’ and allow a consensus agreement or an average (depending on the technique used).

3.32 Whilst this approach is highly subjective and relies on input from knowledgeable experts, there are some clear advantages. It should require little to no data or computations, and thus be relatively quick to produce. However, time lags could be expected if formal elicitation methods and/or software is used.

3.33 Attention should be focussed on the major sources of uncertainty. If one source of uncertainty has a much greater impact than all others, then the uncertainty due to this one factor might be a reasonable proxy for the overall uncertainty of the project.

3.34 **Summary of Judgement-Based Approaches**

Description – A subjective estimate of the overall uncertainty using expert elicitation techniques

Advantages

- Requires little to no data;
- Based on real-world performance, so avoids optimism/ pessimism bias;
- Do not need to mathematically combine uncertainties.

Disadvantages

- Highly subjective;
- Requires expertise to reasonably grasp the range of possible outcomes.

When should this technique be used?

- When quantitative uncertainty analysis is unfeasible due to time, resource or data constraints.

Scenarios

3.35 Scenario analysis is a process of analysing future events by considering several alternative possible outcomes. Each scenario outcome and pathway should, however, be plausible, and scenario analysis itself observes the impact of different possible futures on a scheme's strategic goals and overall Value for Money.

3.36 It is not possible to predict the future of transport with any certainty. Questions around digitalisation, behaviour, climate change and the outturn of key metrics such as Gross Domestic Product (GDP) only serve to compound uncertainty in the sector. Scenario analysis is a process of analysing future events by considering a wide set of plausible outcomes, each with an associated narrative. These should not necessarily be based on extrapolation of past trends nor should they expect past observations to remain valid in the future.

3.37 The use of scenario analysis should enable the robustness of investment decisions to be appraised against a range of possible futures and help decision makers consider potential future outcomes. Scenarios can be used in a number of decision frameworks including investment analysis, dynamic adaptive planning and policy stress testing as set out in the Government Office Science Futures Toolkit [note 4]. The technique is one of the best recognised methods of analysing uncertainty. It stems from the premise that "if the future is uncertain there are, in fact, multiple equally plausible futures, which we call scenarios" [note 25]. Scenarios should be credible, coherent and challenge the status quo.

3.38 As described, this technique demonstrates how divergent, feasible futures can emerge. They are a helpful tool if there are many sources of uncertainty and the likelihood of them occurring cannot be quantified easily. Overall, it is a flexible and proportionate approach to analysing a variety of uncertainties.

3.39 In the Government Office for Science Futures Toolkit [note 4], scenarios are defined as: "stories that describe alternative ways the external environment might develop in the future". Each scenario should explore how different conditions might support or constrain the delivery of transport schemes and wider strategic objectives. A scenarios approach can, therefore, be used to explore significant behavioural, technical, economic and political uncertainties which could affect the success of a transport scheme.

3.40 Scenarios can be used to evidence a scheme's performance against different objectives. What are termed 'business as usual' or 'do minimum' scenarios should be included amongst the set against which policies or schemes can be tested. However, scenarios with a significant decision-making input (e.g. decarbonisation or autonomous vehicles) can be used to understand how national or local government transport policies and targets may support (or detract from) the achievement of desirable or visionary end states.

3.41 For investment appraisal, scenarios are primarily used to ensure transport schemes are robust to exogenous uncertainties. A limited number of scenarios and policy options tend to be modelled due to constraints on modelling resources. Exogenous scenarios are useful in appraisal to ensure that policies are robust in the face of objective outside uncertainty (e.g. population change).

3.42 Scenarios can contain both pessimistic and optimistic elements, but objectivity and a balanced approach should be maintained. Optimistic scenarios (or scenarios which are beneficial to the proposal under consideration) should not be considered in isolation. For example, in parallel to more optimistic assumptions, downside economic assumptions should be assessed in a separate scenario. It is useful to implement a multi-disciplinary approach into this task to avoid considering the unfamiliar improbable.

3.43 It is important that scenarios cover as full a range of possible outcomes as is proportionate and feasible. As mentioned above, an equal weighting should be given to each to ensure objectivity in analysis.

Common Analytical Scenarios

3.44 Forecast travel demand is a key driver of benefits in scheme appraisal. For this reason, value for money is particularly sensitive to assumptions around future travel demand. The uncertainty around this should be explored and presented as a core part of scheme appraisal. To support practitioners in this, DfT has developed a set of seven analytical scenarios for use in forecasting and appraisal (please find detailed descriptions of the scenarios in Annex B: Resources for Uncertainty Analysis).

3.45 The Common Analytical Scenarios provide a consistent off-the-shelf set of scenarios for use across modes to cover key areas of national transport uncertainty, including:

- Growth in the population and the economy;
- Distribution of economic activity across the regions;
- Technological advances and uptake;
- Social and behavioural change;
- Level of decarbonisation and fleet mix ambition.

3.46 The provision of these scenarios makes standard uncertainty analysis less costly for scheme promoters; brings consistency to the assumptions used in the appraisal of major schemes coming to investment committees in DfT; and avoids the selection and presentation of solely favourable scenarios in any particular business case. Consistency in the assumptions used enables DfT to assess the resilience of the departmental portfolio as a whole.

3.47 The Common Analytical Scenarios provide a narrative around the evolution of key drivers of uncertainty rather than taking an arithmetic approach to demand uncertainty as per **TAG Unit M4** [note 2] High and Low Growth scenarios. They provide greater insight into the impacts of changes in future travel demand which can be communicated to decision makers. The **TAG Unit M4** [note 2] High and Low growth scenarios are still useful for sensitivity testing and certain smaller schemes (see discussion on proportionality in section 3.15).

3.48 For guidance on how to communicate the results of analysis using the Common Analytical Scenarios, please see Chapter 4 Presenting Uncertainty and Value for Money (specifically section 4.8).

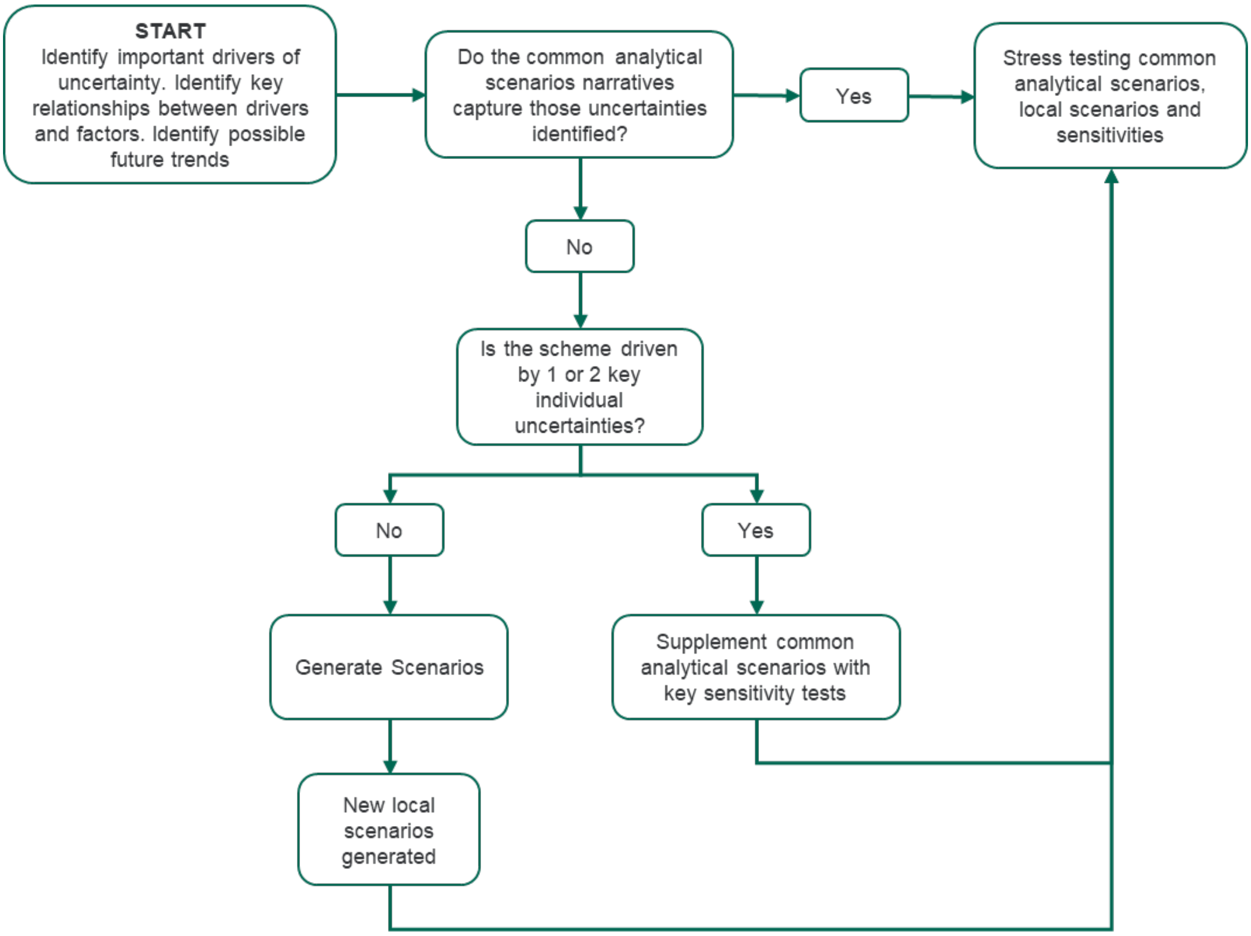
Developing Additional Scenarios

3.49 Due to the variety of uncertainty which may be relevant to individual investment proposals, it may be proportionate for schemes to develop their own analytical scenarios. These would focus around the additional uncertainties that may be important to their scheme. These should be in addition to the Common Analytical Scenarios, and depend on the impact level of the scheme (as discussed in section 3.15).

3.50 Figure 6 presents a logical framework within which practitioners can assess whether additional scenarios would be needed in their appraisal (e.g. to reflect local uncertainties such as housing developments). If there are uncertainties above and beyond those captured in the Common Analytical Scenarios, scheme promoters can either look to a) account for additional uncertainty using supplementary sensitivity testing (see section 3.64) or b) develop their own local scenarios . It can be helpful to consider other published modal specific scenarios such as those set out in the Road Traffic Forecasts [note 5] and National Road Traffic Projections.

3.51 Combining the Common Analytical Scenarios in different permutations is possible. Whilst we do not suggest that combining elements of the scenarios creates a more likely scenario, and whilst we encourage the use of scenarios beyond the provided set of Common Analytical Scenarios, the expectation is that DfT investment committees will require a consistent benchmark (i.e. the use of the Common Analytical Scenarios), in order to be able to compare across schemes and programmes.

Figure 6 Framework for developing additional scenarios



3.52 The process of developing scenarios is flexible. Broadly though, the following stages (consistent with the GO Science Futures Toolkit [note 4]) can be implemented to create a set of potential future scenarios:

1. **Gathering intelligence about the future** – identify relevant uncertainties, factors of future change and collate current baseline data for trends;

2. **Identification of drivers of future change** - develop a consensus on the key uncertainties in a transport-specific context for the scheme in question;

3. **Describing what the future might look like** - explore the dynamics of change by a) developing an underpinning narrative and b) assembling and modelling the scenarios.

1) Gathering intelligence about the future

3.53 The Horizon Scanning approach proposed in the Government Office for Science Futures Toolkit [note 4] is defined as "the process of looking for early warning signs of change in the policy and strategy environment". Horizon Scanning can be used to gather intelligence, identify the drivers and trends that form scenarios and can feed into the list of uncertainties.

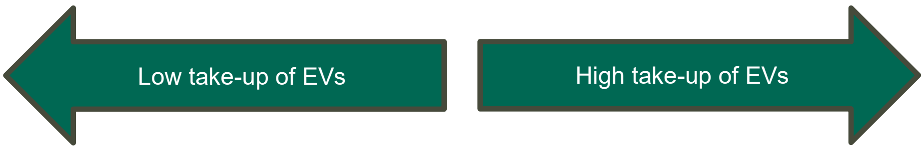
3.54 Horizon scanning involves gathering information about emerging trends and developments that could have an impact on the implementation of a scheme. Trends and developments might have compounding effects, so consideration should be given to how combined impacts might materialise. This can be achieved mainly through desk research, although a workshop-style discussion could be warranted. In this sense, it is a relatively straightforward process, but requires thought, insight and intuition.

3.55 Long- and short-listing relevant uncertainties enables practitioners to identify key uncertainties. Short lists can be generated using criteria such as likelihood and impact. System maps and diagrams can also help identify critical uncertainties. A benefit of these approaches is their flexibility – it is an open-ended process and should be approached iteratively.

2) Axes of uncertainty

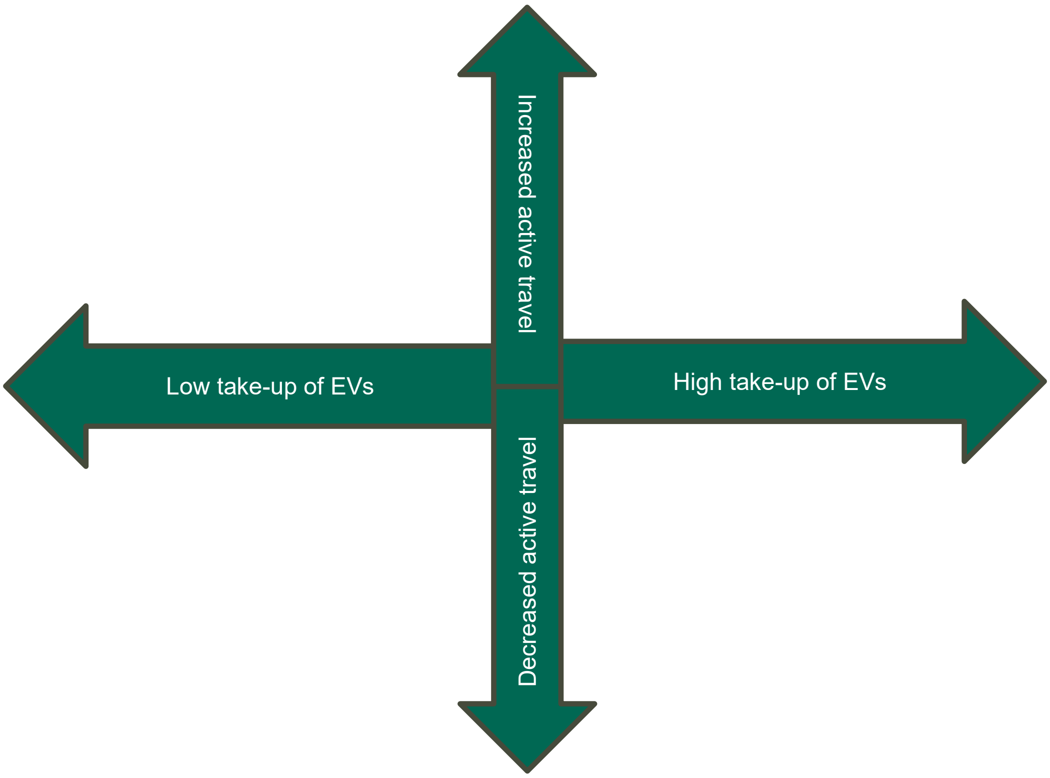
3.56 As part of the scenario generation process, it can be helpful to use a workshop to explore '**Axes of Uncertainty**', as per the GO Science Futures Toolkit [note 4]. The aim is to define the critical uncertainties for the scheme in question, within which practitioners can frame the scenario(s). Scheme promoters could define many axes describing alternative ways critical uncertainties could play out. For example, uncertainty around take up of electric vehicles (EVs) is demonstrated in Figure 7:

Figure 7 Uncertainty Axis Example



3.57 Different axes can then be overlaid to arrive at a scenario matrix (an example is demonstrated below in Figure 8), combining different aspects of uncertainty. It's important that scenarios are sufficiently different from one another, as this will reflect the full span of relevant uncertainty. Scenarios could also highlight trade-offs between potentially competing long-term objectives.

Figure 8 Overlaid uncertainty axes example



3) Describing what the future might look like

3.58 Permutations of the uncertainty axes provide the basis for the scenarios. A process of filtering for permutations that are testing but plausible and interesting to the practitioner should be performed. The narratives around the scenario pathway and the outcome should be built up.

3.59 Analytical assumptions should then be fitted to the scenarios. It is likely that the exercise of finding modelling levers to translate the scenarios into the model will require an element of iteration in the scenario selection above.

3.60 For more guidance on developing Scenarios please refer to:

- TAG Unit M4 – Forecasting and Uncertainty [note 2]
- Uncertainty Toolkit for Analysts in Government [note 3]
- Government Office for Science Futures Toolkit [note 4]

TAG Unit M4 Core, High and Low Scenarios

3.61 The core scenario as detailed in TAG Unit M4 [note 2] should continue to be modelled in all analysis as it is an important element of the Appraisal Summary Tables (ASTs). TAG Unit M4 [note 2] sets out the High and Low growth scenarios. For lower impact analysis it is proportionate to use these arithmetically defined scenarios. For higher impact analysis (see the Proportionality Framework in section 3.5) the Common Analytical Scenarios should be used in place of the TAG Unit M4 High and Low. The Common

Analytical Scenarios provide greater insight into the impacts of uncertain trends on transport schemes which can be used to better inform decision makers.

3.62 A significant proportion of transport models will rely on models underpinned by the trip end forecasts generated using the National Trip End Model and made available through TEMPro. It is intended that the Common Analytical Scenarios will be released as TEMPro datasets to facilitate consideration of national level uncertainty. However, there are certain modelling assumptions such as income, value of time, car occupancy and electric vehicle mileage splits that will need to be applied to transport models to generate the scenarios in addition to the trip ends from TEMPro (see section 5.3).

3.63 **Summary of Scenarios**

Description – Rich narratives that describe alternative ways in which the external environment could potentially develop in the future. These narratives should be accompanied by corresponding input data to which transport model results will potentially be sensitive.

Advantages

- Can be consistently applied across many schemes;
- Gives ‘real-world’, narrative-rich explanations to the range of possible outcomes, which can increase buy-in from decision makers;
- Enables the inclusion of low-probability, high-impact events, without needing to define their probability.

Disadvantages

- The choice of scenarios can be subjective, and may not cover the full range of plausible future outcomes;
- Provides no information about the likelihood of each scenario occurring;
- Scenarios will not be evenly distributed around the most likely outcome, risking optimism / pessimism bias.

When should this technique be used?

- Refer to Proportionality Framework (see Figure 5 and Table 2)

Sensitivity Testing

3.64 Sensitivity analysis is used to assess how robust a decision is to changes in specific inputs. This is particularly useful where there is a high level of uncertainty around key inputs and model parameters. Sensitivity analysis alters the assumptions and parameters used in the initial analysis and observes the impact on the scheme’s strategic goals and overall Value for Money (VfM).

Sensitivity testing around the model should be performed against variation in parameters which are judged to have a) a substantial effect on the model's prediction and b) be uncertain in their calibration.

3.65 Sensitivity testing can also be used to gauge model quality or to explore model capability. **TAG Unit M2.1** ('*Variable Demand Modelling*') [note 26] highlights that sensitivity tests should be used to ensure that the models are fit for purpose. The approach aims to identify the "relative effects of various parameters on the outcome of a scheme appraisal". Conducting sensitivity analysis is especially important when model parameter values (e.g. model elasticities) are uncertain – it is important to know exactly how sensitive appraisal and modelling results are to these uncertainties. This will help establish confidence in results.

3.66 **TAG unit M4** ('*Forecasting and Uncertainty*') [note 2] recommends the use of sensitivity testing when there is particular uncertainty around an input parameter (such as changes in values of time or alternative economic forecasts). Presenting uncertainty around forecasts is key - reporting sensitivity testing is a key component of the recommended Uncertainty Log.

3.67 Sensitivity analysis is also a useful technique for addressing uncertainty in VfM assessments. This approach tests the impact of key uncertainties on scheme appraisal, and in turn increases confidence in VfM conclusions drawn.

The Department's Value for Money Framework [note 27] states that the results of sensitivity analysis should be reported and explained. The Framework suggests using ranges around VfM metrics to communicate the analysis. For more details on how best to present uncertainty analysis, please refer to Chapter 4 Presenting Uncertainty and Value for Money of this toolkit.

3.68 **Annex B: Resources for Uncertainty Analysis** provides guidance around variable ranges to be used in sensitivity testing. We suggest using the range of inputs for the Common Analytical Scenarios as a starting point. A databook for the scenarios is published alongside this document, providing full ranges around key input variables such as GDP, employment and population.

3.69 The Value for Money Framework advises sensitivity tests to be "determined on a case-by-case basis in a proportionate manner". This Uncertainty Toolkit places particular emphasis on proportionality in uncertainty analysis (see Section 3.15).

3.70 **Summary of Sensitivity Testing**

Description – Tests used to understand the sensitivity of a model to different parameters, assumptions or differences in key drivers, and how this will impact on the assessment of costs and benefits.

Advantages

- Commonly used and understood;

- Helps narrow in on factors specific to the scheme: key assumptions or important exogenous factors.

Disadvantages

- Standard practice is to run key sensitivities, but thorough testing can be resource intensive;
- Provides no information about the likelihood of different outcomes.
- Only focuses on one dimension of uncertainty in isolation, which risks obscuring additional sources of uncertainty if sensitivities are presented in isolation.

When should this technique be used?

- Refer to Proportionality Framework (see Figure 5 and Table 2)

Monte Carlo and Stochastic Analysis

3.71 This approach can be used to understand the impact of uncertainty in key data that acts as inputs to appraisal, or underlying assumptions. The approach is supported by **HMT's Green Book** [note 6] guidance, with specifics outlined in its Annex 5.

3.72 The approach uses a simulation-based risk modelling technique which produces the expected values of, and confidence intervals around, key outputs and VfM metrics. These outputs are the result of many simulations that model the collective impact of uncertainties. It is therefore only useful for variables with measurable co-variance and probability distributions.

3.73 The process involves replacing single entries for key inputs (such as speed of roll out or expected passenger take-up) with probability distributions of possible values for these inputs. The choice of probabilistic inputs can be based on prior sensitivity testing. It is therefore necessary for these uncertainties to have known (or reasonably estimated) probability distributions. More detail of this is given below. The modelling is then repeated many times randomly, combining different input values selected from the probability distributions specified (which is usually done using a specialised computer program).

3.74 The results are typically presented as a set of probability distributions showing how uncertainties in key inputs might impact on outcomes. Using the probability distribution of results, the likelihood of certain outcomes can be inferred. The simulation method therefore offers an understanding of the range and likelihood of possible outcomes of a scheme.

3.75 Monte Carlo is often conducted along the following steps:

1. Identify any uncertainty around key inputs;

2. Assign a range of potential input values (i.e. a probability distribution) to each input variable deemed to be uncertain:

   - For simplicity and proportionality, a ‘triangular distribution’ is often used although there other may be appropriate (such as normal, log normal, Poisson or negative exponential);

   - A triangular distribution is widely used for risk quantification for continuous random variables. It has only one peak, and is entirely defined by three parameters:

     i) Lower percentile value – typically 10th percentile (i.e. 10% of observed values are below X);
     ii) Modal value (most likely) – represents the central case scenario that is most likely to occur;
     iii) Upper percentile value – typically 90th percentile (i.e. 10% of observed values are above Y);

   - Triangular distributions may be skewed / asymmetric (i.e. not equally distributed about the mean).

3. Use specialist software to run multiple iterations of these key variables (based on the assigned probability distribution) through the model in question, which produces a distribution of outputs.

3.76 A triangular distribution avoids extreme values that can emerge in the tails of a Normal distribution, for example. However, it should be acknowledged that for some parameter inputs, this distribution would be a poor approximation to reality. As outlined above, a range of distributions may be appropriate in transport analysis, including uniform, normal or Poisson distributions.

3.77 Monte Carlo analysis is a more involved analytical technique which may not be proportionate for smaller schemes. The use of simplified (meta) models may enable more permutations to be explored within a given resource constraint for such techniques. Scheme promoters should be confident in their knowledge of the variance-covariance matrix before undertaking Monte Carlo analysis – there should be no missing variables. Whilst under these conditions this approach can be very powerful in understanding a scheme’s range of outcomes, it is highly dependent on the specific assumptions imposed by the analyst (e.g. choice of probability distribution). For this reason, analysts should be transparent regarding the distribution chosen, the rationale behind the decision, and the impact this has had on outcomes.

3.78 Other Stochastic techniques such as autoregressive models can be used to estimate the level of uncertainty around historic growth in a variable. For instance, a large number of evolutionary trajectories for GDP or transport demand itself could be generated. The output of these models is a set of confidence intervals representing the uncertainty around a central forecast. This technique is useful for transport demand forecasting as it is agnostic to the forecast model being used, so reflects both parameter and input uncertainty. This is particularly important for financial forecasting. Scenarios are better suited for investment decisions whereby a plausible range of futures can test scheme robustness to improve decision-making.

3.79 **Summary of Monte Carlo and Stochastic Analysis**

Description – Varies model inputs and parameters statistically, creating a simulated range of results.

Advantages

- If properly and completely specified, provides assessment of likelihood of different outcomes;
- Produces a visual representation of the range of possible outcomes (although this can be achieved with the other approaches).

Disadvantages

- Highly dependent on the accuracy of the distributions and assumptions used;
- Down to practitioners to specify probability distribution assumptions, which implies a lack of objectivity.
- Requires more analytical resource than other methods, and can be computationally expensive.

When should this technique be used?

- When practitioners are confident in their knowledge of variables' variance, co-variance and probability distributions (see Figure 5)

Other Decision-Making Approaches

3.80 There are a variety of analytical approaches and tools for decision-making under deep uncertainty. They seek to find actions that reduce the vulnerability of a policy or strategy to uncertainty in future developments. There are advantages to these approaches but also drawbacks. The benefits are likely to exceed the costs when: the contextual uncertainties are deep; the set of policies has more rather than fewer degrees of freedom; and when the system complexity is such that it is difficult to link policies to outcomes (e.g. some aspects of climate change).

3.81 The techniques aim to prepare and adapt by monitoring how the future evolves and allowing for adaptations over time as knowledge is gained.

3.82 Five approaches are discussed in the open-source book 'Decision Making under Deep Uncertainty' [note 9]:

- **Robust Decision making (RDM)**; a set of concepts, processes and tools that stress test strategies over plausible trajectories and identify robust adaptive strategies.

- **Dynamic Adaptive Planning (DAP)**; focuses on the implementation of an initial plan prior to the resolution of all major uncertainties, which is adapted over time based on new knowledge. DAP specifies the development of a monitoring program with trigger points for responses.

- **Dynamic Adaptive Policy Pathways (DAPP)**; considers the timing of actions. It produces an overview of alternative future routes based on adaption tipping points and focusses on under what conditions a given plan will fail.

- **Info-Gap Decision Theory (IG)**; seeks to optimise the robustness to failure (or opportunity). It starts with an alternative set of actions or strategies and evaluates the actions computationally.

- **Engineering Options Analysis (EOA)**; economic value is assigned to technical feasibility. It consists of a set of procedures for calculating the value of an option (the elements of a system that provide flexibility) and is based on Real Options Analysis.

3.83 Real Options analysis is another technique that can be employed to determine the value of flexibility. This is similar to Engineering Options Analysis but uncertainty here is better characterised, and can be treated similarly to financial options for the purposes of valuation. Projects that exhibit significant uncertainty e.g. high potential for stranded assets may afford significant value to gaining additional information about the state of the world. The **Green Book** [note 6] contains an example of infrastructure investment that can be phased to provide the real option value. **TAG Unit A4.1** [note 19] provides standardised option and non-use values for bus and rail transport which provide a means of valuing changes to transport availability.

Optimism Bias

3.84 According to the Green Book [note 6], optimism bias is “the demonstrated systematic tendency for appraisers to be over-optimistic about key project parameters, including capital costs, operating costs, project duration and benefits delivery” (paragraph A5.4, page 107). Even in instances where the project is delivered on time, there is still the potential for costs to overrun due to other unforeseen circumstances that planners fail to account for.

3.85 Optimism bias can often arise from taking an ‘inside view’ (i.e. the view held by the project team or other experts closely associated with the scheme), and estimating costs, benefits and duration of activities in a ‘bottom-up’ fashion. Adjustments for optimism bias – termed ‘optimism bias uplifts’ should be based on statistical modelling of past similar projects, using the method known as reference class forecasting (RCF). RCF is a ‘top-down’ estimating approach that deals with optimism bias by taking an ‘outside view’.

3.86 The Green Book [note 6] recommends applying specific adjustments to account for optimism bias when preparing business cases. In line with this, TAG recommends promoters apply explicit optimism bias uplifts to estimated capital and operating costs for appraisal purposes.

3.87 **TAG Unit A1.2** [note 10] provides optimism bias uplifts for capital costs for a range of project types and **TAG Unit A5.3** [note 15] provides guidance on optimism bias uplifts for rail projects. Where these are not applicable for a given project, and in the absence of bespoke RCF evidence, the Green Book [note 6] Annex 5 provides generic rates which may be used.

Conclusion and Key Takeaways

3.88 This chapter has presented a range of techniques which can be used to address and account for uncertainty in transport modelling and appraisal. The key takeaways should be:

- There are several techniques available when addressing uncertainty in transport appraisal. These tools range in analytical involvement, meaning proportionality is a key determinant of assignment. Practitioners should refer to the Proportionality Framework (section 3.5) to help determine which approaches are best suited to their specific scheme. As many of these techniques as is necessary and proportionate should be employed;

- Annex C: Techniques for Understanding Uncertainty summarises the most prominent of the techniques introduced in this chapter, and presents their advantages and disadvantages.

4. Presenting Uncertainty and Value for Money

Introduction

4.1 Promoters should agree the scope of analysis, including relevant analytical scenarios, that are expected to be critical to the decision-maker. Upon completion of the appraisal, it is important to reflect pertinent evidence from these scenarios in an appropriate set of ASTs and in the scheme's VfM assessment.

4.2 After uncertainty analysis has been conducted, it is crucial that the results are appropriately presented and reflected in a scheme's VfM assessment. It is important to remember that all analysis will be subject to a certain degree of uncertainty. This is due, in part, to the fact every model is a simplification of reality. For this reason alone, scheme promoters should not refrain from presenting uncertainty to decision makers.

4.3 Uncertainty might mean that a straightforward conclusion is not realistic; focus should be placed on what the uncertainty analysis *can* tell decision makers. The communication of uncertainty will ensure that the additional analysis is improving the understanding of the risks and uncertainties of a scheme. This will enable more informed decision making.

4.4 Assumptions that have been used to create forecasts should be clearly drawn out and explained. Simplifications of inputs or results can present a false sense of certainty to decision makers and prevent them from fully understanding the analysis. They should be avoided. This chapter presents first how the scenarios critical to the decision maker should be summarised in a set of ASTs, and requirements on how schemes must communicate results from their models for different aspects of uncertainty within a VfM framework. It then sets out a number of visual methods that can be used when presenting uncertainty.

Communicating uncertainty

4.5 It is important for schemes to clearly summarise the results of their uncertainty analysis in a way that is easy to understand but includes the appropriate level of information. Making use of ranges when presenting forecasts should be the norm.

4.6 The main uncertainties, including risks and opportunities to the project, should be presented to the decision maker. This should include as a minimum:

- An uncertainty log with documentation of main assumptions and uncertainties;

- A statement on the quality of the analysis;
- ASTs for the elements of the CAS critical to decision making
- Scenario / sensitivities providing a range of benefit-cost ratios (BCR) and a switching values analysis;
- A value for money category and statement.

Uncertainty Log

4.7 It is important to consider all the sources of uncertainty affecting the analysis and quantify the impact that each has on the overall uncertainty, even if this is approximate or subjective – see Chapter 2 Types of Uncertainty. **TAG Unit M4** [note 2] recommends the practitioner summarise all known assumptions and uncertainties in the modelling and forecasting approach in an uncertainty log. This log will support the consideration of the appropriate tools and techniques for testing and presenting uncertainty in a proportionate way. It is good practice to create links between the uncertainty log and the value for money ranges. This can be achieved by linking the ranges in assumptions to specific scenarios or sensitivities used in the BCRs (see below section 4.7).

Value for Money

4.8 The Department's Value for Money Framework [note 27] provides guidance on a) assessing Value for Money and reporting it in VfM categories and b) producing a VfM statement. In standard cases, where Broad Transport Budget cost outlays exceed revenue or cost savings, the Department uses six VfM categories from very high to very poor. The VfM assessment takes as its starting point the initial and adjusted Benefit Cost Ratio (BCR) generated in the core scenario.

Sensitivities and scenarios

4.9 To better reflect uncertainty in VfM indicators, the impact of sensitivities, and scenarios needs to be communicated to decision makers. This can be done in the Value for Money statement. The range of impacts to benefits and costs (and therefore BCRs) should be presented logically and clearly. If presenting the results for the Common Analytical Scenarios they should be presented alongside the core scenario and include narrative around the impacts on the scheme from that state of the world.

Table 3 Example table summarising impact of scenarios on scheme BCR

Sensitivites	Core	Common Analytical Scenarios						
		High economy	Low economy	Regional	Behavioural Change	Technology	Vehicle-led Decarbonisation	Mode-balanced Decarbonisation
Demand/Supply	1.5	2.1	1.1	2.0	1.2	2.0	1.8	1.4
Cost	1.5	0.8	2.2	-	-	-	-	-
Parameter	1.5	1.6	1.4	-	-	-	-	-
Other	x	x	x	-	-	-	-	-

Switching values

4.10 When conducting sensitivity analysis, switching values can be used to communicate whether any of the sensitivity testing causes a change in the VfM category. The switching values can be split into costs and benefits (as per Table 4). They provide the change in monetary value figures required to switch the category.

Table 4 Example Switching Values to move BCR to different VfM category

Used to inform judgement on the potential for changes in VfM category				
VfM category boundary [note 27]	Cost		Benefit	
	Change	Likelihood	Change	Likelihood
Poor (0-1)	+£10m	Possible	-£15m	Likely
Low (1-1.5)	0	Very Likely	0	Very Likely
Medium (1.5-2)	-£10m	Possible	+£15m	Unlikely
High (2-4)	-£20m	Very Unlikely	+£30m	Very Unlikely

4.11 It is possible to determine the likelihood of these figures being achieved using the scenario and sensitivity analysis results (see Figure 9 for likelihood scale). Taking account of the level of uncertainty, an assessment of the overall likelihood of each given VfM category should be provided.

Table 5 Example table summarising confidence in the VfM category of an illustrative proposal

VfM Category	Poor	Low	Medium	High
Likelihood	Unlikely	Very Likely	Possible	Unlikely

Figure 9 The likelihood scale

4.12 The rationale for the final VfM judgement should be brought together with advice highlighting the caveats with the greatest impact and explain why they matter in the narrative. It is up to the judgement of the analyst to determine the relevant weight to apply in the final judgement (but there should be sufficient evidence to support it).

4.13 Following the VfM assessment, schemes will need to take a view on the level of uncertainty their scheme is facing and the magnitude of its impact. This will ensure decision makers understand the impact of uncertainty analysis and enable them to make more effective decisions.

Decision-making impact

4.14 Effective decision-making about the future depends on anticipating change. The application of uncertainty analysis enables analysts, planners and the decision makers they support to better recognise and confront uncertainty and operate more effectively. Good decisions emerge from processes in which people are explicit about their goals, use the best available evidence to understand the consequences of their actions, carefully consider trade-offs and contemplate the decision from a wide range of views.

4.15 Illustrating the uncertainty to decision makers should result in investment decisions being made which account for risks and uncertainties. Different choices may be made over policy options, namely preference for a scheme that is more robust to changes in demand when it is highly uncertain. Some examples of common frameworks for decision-making are Dynamic Adaptive Planning [note 9] and policy stress testing (as set out in the GO Science Futures Toolkit [note 4]). Uncertainty analysis should provide insights into how to improve the policy or scheme in a circular iteration and re-examination (see Figure 5).

4.16 The AST (see Guidance for the Technical Project Manager) provides a more complete summary of a scheme or option's impacts. Estimates of costs and benefits to transport users and providers from the AMCB table should be included in the AST. As such, it is important to reflect pertinent evidence from all analytical scenarios critical to the decision-maker in an appropriate set of ASTs. TAG Unit A1.1 provides more detailed guidance.

Additional Discretionary Options for Presenting Uncertainty

4.17 Visual aids can be a helpful way to communicate the outputs of uncertainty analysis. There are many techniques available for presenting uncertainty analysis, and some are discussed in this section.

4.18 **Presenting Monte Carlo**

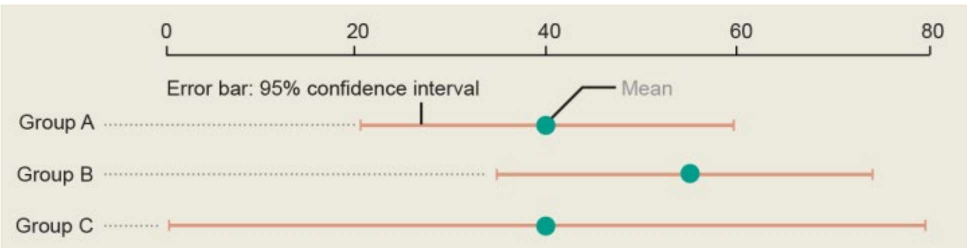
- As highlighted in Chapter 3 Understanding Uncertainty, Monte Carlo simulation produces a visual representation of a range of possible outcomes. The distributional properties of the BCR of a specific proposal can be calculated and visualised in terms of likelihood of outcome. Practitioners can also present the likelihoods assigned to potential value for money categories achieved.

4.19 **Error bars**

- These are a simple way to illustrate a range of uncertainty around an isolated data point (see Figure 10). Error bars can be added to bar, line and scatter graphs to illustrate a range around a central estimate. It is within this range we expect the value to lie, with a given probability. This approach is a widely recognised representation of uncertainty and offers a simple format for expressing the possibility of different values.

- It is possible that the ends of the error bar are incorrectly interpreted as high and low values in observed measurements rather than estimates denoting uncertainty. Describing in prose how the decision maker should interpret the error bar is recommended, and it is important to state what probability the error bars represent.

Figure 10 Illustrative example of error bars [note 28]



4.20 **Box plots**

- These can convey more information about possible outcomes than a range alone: box plots can help the decision maker understand the underlying distribution of possible outcomes in detail.

- Box plots may not be as widely understood or easily interpreted compared to other presentation methods, so careful consideration should be given to whether the additional information will be effective. A labelled example should be used to aid interpretation for non-analyst decision makers.

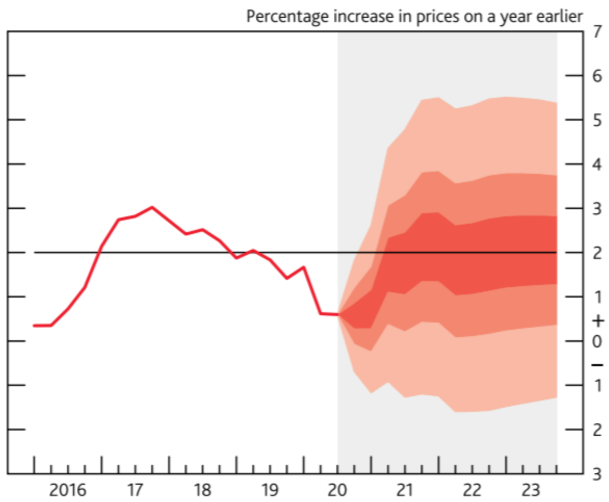
- Please see the Uncertainty Toolkit for Analysts in Government [note 3] for a visual example of Box Plots as a method of communicating uncertainty.

4.21 **Fan charts**

- Fan charts are commonly used as a communication tool for forecast uncertainty. They map possible evolutions of a phenomenon, and are useful for showing how estimates of uncertainty change over time, based on probability distributions.

- Figure 11 illustrates the use of a fan chart in inflation forecasting by the Bank of England, in their November 2020 Monetary Policy Report. Different shades of colour have been used to represent different confidence intervals. As the Bank puts it: "*The fan chart depicts the probability of various outcomes for CPI inflation in the future … If economic circumstances identical to today's were to prevail on 100 occasions, the MPC's best collective judgement is that inflation in any particular quarter would lie within the darkest central band on only 30 of those occasions. The fan chart is constructed so that outturns of inflation are also expected to lie within each pair of the lighter red areas on 30 occasions. In any particular quarter of the forecast period, inflation is therefore expected to lie somewhere within the fans on 90 out of 100 occasions. And on the remaining 10 out of 100 occasions inflation can fall anywhere outside the red area of the fan chart. Over the forecast period, this has been depicted by the light grey background*". [note 29]

Figure 11 Bank of England CPI inflation projection [note 29]

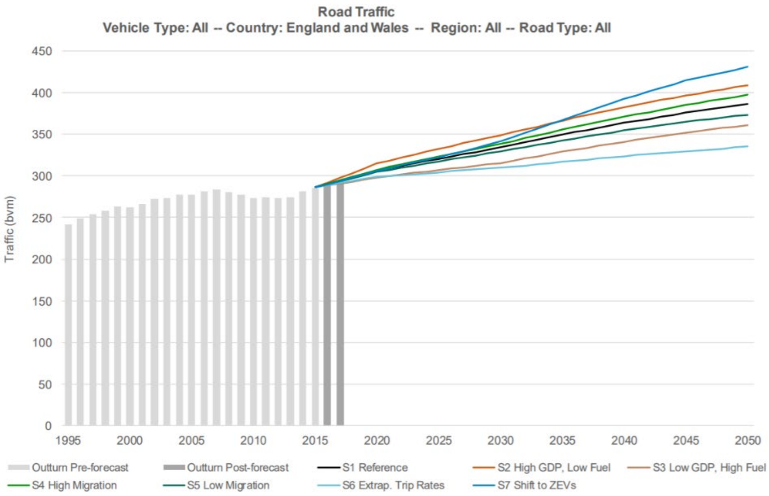


4.22 Multiple line charts

- A series of line charts are particularly well suited to scenario analysis, to show projections associated with each scenario. Each scenario should be presented with equal prominence, relating to the fact each scenario reflects an equally plausible future. Practitioners should avoid suggesting one is more likely than another.

- Figure 12 illustrates the use of a multiple line chart in the Department's Road Traffic Forecasts 2018 report [note 5]. The projected traffic for all vehicle types across seven scenarios is presented. No one scenario is presented as 'central', but a range of uncertainty can be easily observed.

Figure 12 Road Traffic Forecast 2018, vehicle miles forecasts for England & Wales [note 655]



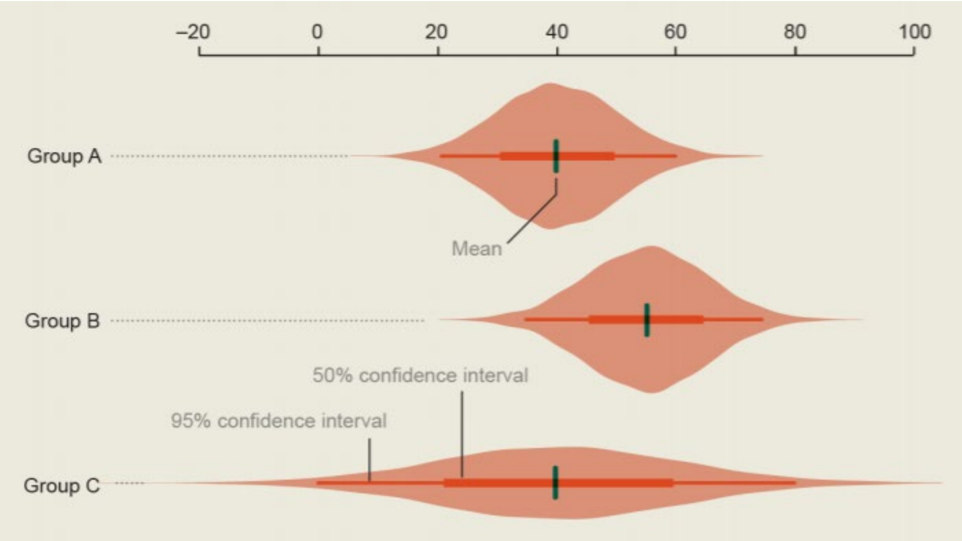
4.23 Violin plots

- These are similar to box plots in presentation, but exhibit the probability density of possible outcomes. A greater width of the plot indicates a higher probability of occurrence, reinforcing an awareness of an underlying distribution (see Figure 13 for an illustrative example).

- An advantage of violin plots is that they help avoid potential interpretation bias that can sometimes occur with other presentation methods (e.g. error bars on a bar chart can be overlooked by decision makers who might be subject to 'within-bar-bias', which occurs when viewers report that values are more likely to lie within the bar of a bar chart despite error bars indicating they could equally lie outside). Displaying probability density using a visual variable generally communicates uncertainty in greater detail than interval methods.

- Scheme promoters should consider the suitability of this type of uncertainty communication – whilst they are often well aligned with intuition (i.e. wider points suggesting greater probability) if decision makers are unfamiliar with violin plots, interpretation is likely to be challenging. It might not be recognised that density reflects probability. The value added from the additional detail on uncertainty should offset the increased potential for audience confusion. For this reason, additional commentary should go alongside the plot to aid interpretation.

Figure 13 Illustrative example of violin plots [note 28]



Conclusion and Key Takeaways

4.24 This chapter has advised on the best approaches to presenting uncertainty analysis in transport modelling and appraisal, and how this should influence communication of value for money. It has also suggested a number of visualisation techniques to accompany uncertainty analysis. The key takeaways are:

- The consistent and effective approach to presentation is an integral part of uncertainty analysis, and will help ensure such analysis feeds through to decision making;
- The following should be produced to communicate uncertainty analysis:
  - An uncertainty log which documents main assumptions and uncertainties;
  - An analytical quality assurance statement;
  - A BCR range from scenario / sensitivity analysis, and switching values;
  - A value for money category and statement;
- There are a number of visualisation techniques available to analysts. Practitioners should use their judgement to determine which approach (if any) is best suited to their particular scheme.

5. Annexes

Annex A: Glossary

5.1 **TAG Unit M4** presents a set of definitions for key terms. In addition to this, the definitions below have been used in this Uncertainty Toolkit:

- **Risk (or aleatory uncertainty)** – events where we do not know the outcome but we can assign it with a probability density function.
- **Exogenous uncertainty –** External inputs outside of the decision maker's control which may influence the system significantly
- **Endogenous uncertainty** – Inputs in which decision makers have influence on the future system outcomes through policy interventions.
- **Demand-side uncertainty** – Uncertainties due to current and future economic, demographic, technological, and behavioural change, policy led demand and proposed developments.
- **Supply-side uncertainty** – Uncertainties associated with the existing and future transport network or the provision of transport services.
- **National uncertainty** – Uncertainties that influence the whole of the country e.g. demographic, technological, behavioural.
- **Local uncertainty** – Uncertainties that are specific to the area in which schemes are being developed e.g. population distribution.
- **Deep uncertainty (or ontological uncertainty)** – situations where experts cannot agree on probabilities and how the system works.
- **Propagation of uncertainty** – when the ultimate forecast involves a series of successive sub-models in which the output of the previous sub-model in the model chain is used as input to the next sub-model, [and] errors in any sub-model may be amplified in subsequent ones.
- **Scenarios** – narratives that describe alternative ways in which the external environment could potentially develop in the future. These narratives should be accompanied by corresponding input data to which transport model results will potentially be sensitive.
- **Visionary Scenarios** – a scenario in which the set of assumptions chosen to frame the potential future reflects a preferred option, as opposed to simply a plausible future. There is often a significant level of endogeneity in the uncertainty considered.

Annex B: Resources for Uncertainty Analysis

Introduction

5.2 This Annex lays out available resources for uncertainty analysis, and aims to reduce the resource burden on scheme promoters by providing a single information point for input assumptions. This should enable consistent, high quality uncertainty analysis to be carried and enable greater consistency in uncertainty analysis.

TEMPro Outputs for the Common Analytical Scenarios

5.3 The Appraisal and Modelling Strategy set out a proposal to publish the Department's Common Analytical Scenarios as TEMPro datasets. Many transport models, particularly for road schemes, take TEMPro growth factors as inputs. By providing scenarios in this way, the resource burden of scenario analysis is reduced.

5.4 The development of a common set of scenarios establishes a more robust and consistent treatment of uncertainty in the appraisal of major schemes. As discussed in Chapter 3 Understanding Uncertainty, scenario analysis has become more prevalent in recent years as a way of testing uncertainty about the future in major schemes. Historically, however, there has been a lack of consistency in the assumptions underpinning scenarios developed by individual scheme promoters. This has made it difficult to compare how different uncertainties may have an impact across schemes. The use of different assumptions in uncertainty testing also makes it difficult to consider the resilience of the DfT portfolio as a whole to future uncertainty.

5.5 Recognising these challenges, DfT has developed a set of seven scenarios designed to test key national-level uncertainties which may have an impact on future travel demand and hence the value for money assessment of new transport investment. The seven scenarios are summarised in Table 6. Publication of the scenarios includes TEMPRo datasets and a Data Book for the scenarios. More detail on the scenario narratives can be found in section 5.11.

5.6 Some of the scenarios will require modification to exogenous inputs into the model (e.g. GDP) whilst others will involve changing model parameters (such as car occupancy and value of time). With the exception of the Technology scenario, all **appraisal** values of time will be held constant across scenarios. **Modelling** values of time should also vary with GDP per capita in the low and high economy scenarios. There are some cases where this may lead to illogical or wrong-signed results, which is most likely where travellers are making acute trade-offs between travel time and cost. In these cases, please contact TASM@dft.gov.uk.

Table 6 Description of Common Analytical Scenarios

Scenario	Narrative: "*This scenario captures a future where…*"	Core features or components
High Economy	… productivity growth returns to its long-term trend, and people become richer than we currently expect. Migration, and population in general, increases above official forecasts.	**GDP** – 10% higher in 2050 relative to core assumptions **Population** - GB total reaches 77.7m by 2050 **Employment** - 12% higher in 2050 relative to core assumptions
Low Economy	… productivity growth fails to return to historic levels and inwards migration is subdued, causing low levels of total population growth.	**GDP** – 31% lower in 2050 relative to core assumptions **Population** - GB total reaches 64.6m by 2050 **Employment** - 7% lower in 2050 relative to core assumptions
Regional	…people leave London, the South East and the East of England in search of more affordable housing. As a result, there is lower employment and population growth in these regions relative to the rest of the country. Areas outside of the South increase their relative level of competitiveness through an increase in productivity.	**Population/ Households/ Employment** – core redistributed, so that regions outside London, the South East and the East of England grow at *at least* the growth rate of the whole country, if not already higher. London, the South East and the East of England are then adjusted downwards, so that the whole country's growth rate is maintained.
Behavioural Change	… people embrace new ways of working, shopping and travelling. Important behavioural trends which have emerged in recent years accelerate, in part because of the Covid-19 pandemic, which include: changes in the travel behaviour of young people; increased flexible working; and increased online shopping.	**Trip Rates** - extrapolation of existing trip rate trends by purpose, meaning overall trips continue to fall, although some purposes do increase **Licence Holding** - reduced rates among younger cohorts throughout forecast period **LGV (Light Goods Vehicles, vans) trips** - increased, reflecting reductions in shopping trips and an increase in deliveries from online shopping.
Technology	.. road travel becomes far more attractive and accessible to road users because of a high take-up of connected autonomous vehicles (CAVs), which enter the fleet in the 2020s and make up to 50% of it by 2047.	**Trip Rates** – elderly trips rates increase after 2031 **Licence Holding** – rates increase after 2031 to over 92% by 2061, reflecting improved accessibility due to availability of CAVs **Electric Vehicles** – high uptake **Value of Time** – perceived time cost of travel falls **Car occupancy** – reduced to account for zero occupancy (empty running) trips.

Vehicle-led Decarbonisation	… there is a high take up of electric and zero-emission vehicles (ZEVs). Tailpipe emissions fall. There is no intervention by government to increase electric vehicle costs, resulting in increasing road traffic.	**Electric Vehicles** – high uptake for both cars and freight, with no adjustment made to current costs **Public transport** – reduced as electric vehicles have a cost advantage
Mode-balanced Decarbonisation	… there is a high take up of electric and zero-emission vehicles (ZEVs). Tailpipe emissions fall. An unspecified intervention leads to electric vehicle costs being equalised with petrol and diesel costs, so that public transport modal share is maintained.	**Electric Vehicles** - high uptake for both cars and freight, with running costs (fuel and non-fuel) equalised to internal combustion engine vehicles **Public transport** - modal share higher than the core. [note 30]

Inputs and Assumptions

5.7 Table 6 outlines high level input assumptions for each of the Common Analytical Scenarios. More detailed assumptions and inputs for modelling can be found in the Common Analytical Scenarios data book [note 31].

5.8 For all other standard inputs and assumptions, we advise practitioners to consult the TAG data book [note 24]. This contains historical and reference information on transport appraisal and modelling values, such as: values of time [note 32]; environmental impacts; social and distributional impacts. More detail on the assumptions and inputs for the core scenario can be found in the NTEM Data report [note 33].

Ranges around Key Variables

5.9 As discussed in Chapter 3 Understanding Uncertainty, sensitivity testing is one of the primary approaches for addressing uncertainty. The range of input assumptions across the seven Common Analytical scenarios are available in the Common Analytical Scenarios data book [note 31]. This should give practitioners a starting point from which to conduct stretching sensitivity analysis around key variables such as GDP, employment and population. The CAS combine variations in multiple key input variables at the same time.

5.10 Centrally providing ranges around forecasts for key variables that practitioners should test their schemes against is a consistent approach which should enable decision makers to compare outcomes across the board.

Scenario Narratives

5.11 This section explains the scenarios in more detail, with narratives that can be used for qualitative analysis and set the scene for quantitative analysis.

5.12 Five of the scenarios (the High and Low Economy, Regional, Behavioural Change and Technology scenarios) require separate TEMPro datasets. The two decarbonisation scenarios use the core scenario TEMPro dataset and are created through adjustments at a later modelling stage (variable demand and assignment modelling).

5.13 For all data series, refer to the CAS Data book [note 31].

High and Low Economy scenarios

5.14 The High and Low Economy scenarios reflect the nature of exogenous economic uncertainty, and are intended to capture how travel demand responds to different GDP, population and employment assumptions. The High Economy scenario captures a future where productivity growth returns to its post-war trend and migration remains near 2016 levels. Conversely, the Low Economy scenario captures a future where productivity growth fails to return to historic levels, and migration falls to lower levels.

5.15 GDP, population, households/dwellings and employment are the key variables that change in these scenarios. All else remains consistent with the core scenario, including values of time [note 32].

5.16 Note that differing assumptions are used in NTEM compared to what can be found in the CAS Data book [note 31], due to the nature of release timings. More detail on the input assumptions to NTEM can be found in the NTEM Data Report, chapter 4.2 [note 33].

5.17 Population assumptions for the High and Low Economy scenarios are derived from the ONS 2018-based National Population Projections [note 34], namely the High and Low population variants, which assume high and low fertility, life expectancy and migration respectively. Note that the ONS released 2020-based projections without variants, so these are the most up-to-date variants available.

5.18 To create the High and Low Economy household projections, the Principal ONS Household projection [note 35] was scaled by the High and Low Population variants. Similarly, to create the High and Low Economy employment projections, the central OBR forecast [note 36] was scaled by the High and Low Population variants. This creates a widening fan for both households and employment, that is consistent with the shape for the High and Low Economy population projections.

5.19 The OBR central GDP forecast, along with the core scenario population projection (0% Future EU Migration Variant) were used to calculate a series of GDP per capita. The High and Low Economy series were then calculated by adding or subtracting 0.5%pts growth, and then scaling the series back up to GDP level using the High and Low Economy population projections.

5.20 The High and Low Economy scenarios consider upper and lower bounds of GDP and population variation in the economy. These translate into moderately stretching forecasts of traffic demand. In the High Economy scenario, traffic, and in particularly road traffic, takes an upward trajectory, which could lead to increased congestion and pressure on the road network. In the Low Economy scenario, road traffic declines, but there is also a marked decline in active mode travel, as a decline in younger cohorts reduces the number of education trips.

5.21 When assessing the High and Low Economy scenarios, key factors for consideration would be how sensitive a scheme is to high or low incomes and/or high or low population growth in the affected area. If the scheme relies on younger cohorts, education trips and active travel, it will likely perform well in the High Economy scenario (where there is increased fertility and hence younger populations) and perform poorly in the Low Economy scenario (where fertility and hence younger populations decline). However, how an individual scheme will perform will vary at the local level, so no immediate assumptions can be made without investigating the precise situation carefully.

Regional scenario

5.22 The Regional scenario captures a world in which regions outside London, the South East and the East of England (henceforth the 'Wider South East') increase their relative level of competitiveness. This may be as people move northward in search of more affordable housing. This leads to regions outside the Wider South East having increased total output relative to the core scenario. This translates to lower employment and population growth in the Wider South East relative to the core scenario.

5.23 Population, households/dwellings and employment are the key variables that change in these scenarios. These are adjusted at the regional level, so that national totals remain the same as in the core scenario. All else, including GDP (which is usually only considered at the national level) remains consistent with the core scenario.

5.24 Note that slightly different assumptions are used in NTEM compared to those found in the CAS Data book [note 31], due to the sequencing of analysis undertaken to develop the CAS. More detail on the input assumptions to NTEM can be found in the NTEM Data Report, chapter 4.3 [note 33].

5.25 The methodology for redistribution of population, households and employment is as follows.

- If a region outside of the Wider South East has a population growth rate above the average for Great Britain, the region maintains its existing growth rate as in the core scenario.
- If a region outside of the Wider South East has a population growth rate below the average for Great Britain, the region appropriates the average growth rate for Great Britain.
- For regions inside the Wider South East, their population growth rates are adjusted down, in order to maintain the same population growth rate as in the core scenario.

5.26 Using the above methodology, scaling factors are created for each region, based on the population growth rates over time. These scaling factors are then applied to population, households/dwellings and employment.

5.27 The resulting factors indicate that particular regions (for example, regions in the Midlands) are already more competitive than the average for Great Britain, so do not receive an uplift. The regions which see the greatest uplift are Scotland, Wales and the North East of England. In the Wider South East, growth is significantly reduced from the redistribution.

5.28 Note that the Regional scenario maintains totals for Great Britain at the same levels as the core scenario. However, the nature of the redistribution means that modes that are more dominant in the Wider South East (e.g. rail and light-rail) have diminished growth, and that regions that see an uplift have increased travel demand.

5.29 When assessing the Regional scenario, it is important to consider regional, local and distributional impacts. Some areas which do not have adjusted growth from the core scenario may not have changed traffic internally, but if there are trips to and from external regions which do have adjusted growth, these will be impacted.

Behavioural Change scenario

5.30 The Behavioural Change scenario considers a world in which people embrace new ways of working, shopping and travelling, including remote and flexible working and online shopping. Trends which have been observed in the 2010s are accelerated by the Covid-19 pandemic and extrapolated until 2040. The result is substantially lower (or negative) traffic growth over much of the forecast period. This is the only NTEM/TEMPro scenario which explicitly accounts for the expected long-run impact of the Covid-19 pandemic.

5.31 Adjustments are made to license holding and trip rate assumptions, which are embedded in the Behavioural Change TEMPro dataset. Further adjustments are then made to increase LGV trips, in response to increased online shopping. All else remains consistent with the core scenario.

5.32 Younger people have been decreasing their propensity to own a driving license over the past decades. This trend is extrapolated, so that by 2061 the cumulative impact for 21 to 29 year olds is a 21% reduction in license holding. Reductions for people over 45 are relatively small, remaining below a 5% change by 2061. License holding for those aged 70 and over is not affected, as the younger cohorts do not yet filter through to that age group by 2061. For more information on the license holding assumptions in the Behavioural Change scenario, see the NTEM Data Report, chapter 4.4.1 [note 33].

5.33 Trip rates are adjusted down in 2020 and 2021, to account for the inability to travel during the Covid-19 pandemic. In addition, a 10% ‘hysteresis’ or permanent effect on trip rates is used for 2022, implying that 10% of trips never return. From then onwards, trip rate trends from 2011-2016 are extrapolated by purpose. This means for the majority of purposes, there is a decline in trip rates, the starkest being for home-based work, and visiting friends and relatives trips. For some trip purposes (namely home-based holiday/day trips and home-based employer's business trips) there is an upward trend that is extrapolated. The results of the extrapolation can be seen in Table 7 below. From 2041, trip rates are held constant. For more information on the trip rate assumptions in the Behavioural Change scenario, see the NTEM Data Report, chapter 4.4.2 [note 33].

Table 7 Trip rate changes and relative change to core scenario in 2041 for the Behavioural Change scenario

Purpose (Home-based)	Average annual percentage change in trip rates	Ratio of trip rates relative to the core scenario in 2041 (held constant until 2061)
Work	-2.27%	61%
Employer's Business	0.02%	92%
Education	-1.56%	60%
Shopping	-1.77%	70%
Personal Business	-1.14%	59%
Recreation/Social	-0.46%	80%
Visiting friends & relatives	-1.81%	45%
Holiday / Day Trips	0.48%	119%

5.34 Note that the trip rate trend extrapolation uses cross-modal data. Due to the fact that rail (and other public transport modes) have been affected by Covid-19 very differently than road travel, rail scheme promoters should instead use the bespoke Rail Covid-19 scenarios, which consider the impact of the pandemic on rail trips. Please contact TASM@dft.gov.uk for further information.

5.35 Upward adjustments are also made to LGV traffic, in order to account for the increased number of deliveries due to online shopping replacing shopping trips. This is calculated using trends in LGV growth and shopping trips between 2000 and 2019. The result is by 2060, LGV trips are 7% higher than in the core scenario.

5.36 The Behavioural Change scenario is stretching, providing a lower bound (within the set of CAS) for traffic demand in the future. A key consideration when assessing the Behavioural Change scenario is that the significant reduction in traffic is purely derived from extrapolating past trends in trip rates, license holding and LGV trips (accelerated by the Covid-19 pandemic). No adjustment is made to population or GDP. Scheme promoters may wish to consider the effect of a future which contains elements of both the Behavioural Change and Low Economy scenarios e.g. low GDP and population growth, combined with increased online shopping and flexible working.

Technology scenario

5.37 The Technology scenario is, for most schemes, likely to be the most complex to implement out of the Common Analytical Scenarios, requiring changes to both modelling and appraisal assumptions. It captures a future in which travel behaviour is altered by technological progress. In particular, road travel becomes more attractive due to rapid electrification (electric vehicles, EVs) and automation (connected and autonomous vehicles, CAVs) of the fleet.

5.38 In the TEMPro dataset, license holding and trip rates have been adjusted to create a scenario in which the elderly can more easily travel, and where more and more people own a driving license, implying they travel more and can use a CAV. (Note this does not reflect government policy on whether CAVs will require driving license; it is purely an assumption to create the desired outputs from modelling). In addition, vehicle occupancy and values of time are adjusted down, to account for zero-occupancy trips and the fact that drivers would no longer have to focus on the task of driving, and could work or relax, meaning they are more amenable to longer journeys. Finally, mileage splits and fuel efficiencies follow an ambitious deployment of zero emission vehicles, in line with stated ambitions across road transport modes to end the sale of diesel and petrol vehicles for cars, vans, HGVs and buses/coaches. This assumes full electrification of the road fleet by 2050. All other assumptions (e.g. GDP, population) are unchanged from the core scenario.

5.39 Adjustments are made to the relevant data series in accordance with the Centre for Connected Autonomous Vehicles (CCAV) “high automation” scenario, which has a fast take-up of private autonomous vehicles. This can be seen in Table 8. It is worth noting that this is a particularly stretching scenario, assuming 10% of the vehicle fleet is connected and autonomous by 2036. It is a not a prediction of the most likely future, but a ‘what-if’ scenario.

Table 8 Potential “high autonomation” Connected and Autonomous vehicle deployment profile

Year	2025	2036	2041	2047	2052	2058	2070
Percentage of the fleet	0%	10%	25%	50%	75%	90%	99%

5.40 License holding is increased in the Technology scenario to reflect the increased mobility from groups who currently travel less (specifically those without driving licenses). Core scenario license holding by gender, age band and area type is increased by adding a proportion of non-license holders for that area type, age band and gender. The proportional increase is assumed to be approximately the CAV deployment rate. For more information on the license holding assumptions in the Technology scenario, please see the NTEM Data Report, chapter 4.5.1 [note 33].

5.41 For most categories of traveller type, the trip rates for people aged 16 to 74 not in employment and not students (non-employed) are higher than the equivalent trip rate for those aged 75 and over. In these case, trip rates for the 75 and over are adjusted upwards, in proportion to the percentage of CAVs in the fleet, towards that of an equivalent non-employed person. Note that an adjustment was not made to education trips by the elderly, as this was seen as implausible. Note also that an adjustment was not made to a few particular trip rates and personal business trip rates, as the trip rates for the elderly were already above the equivalent non-employed person. For more information on the trip rate assumptions in the Technology scenario, please see the NTEM Data Report, chapter 4.5.2 [note 33].

5.42 In addition to the adjustments to license holding and trip rates in the TEMPro dataset, the Technology scenario also assumes lower values of time and vehicle occupancy compared to the core scenario. The lower value of time reflects the fact that drivers of CAVs can work or relax whilst driving, and so may be more amenable to longer journeys. The reduced vehicle occupancy assumptions reflects a scenario of private CAVs, where individuals have their own CAV, which can often drive with no passengers (including no driver). The profiles are created in line with the percentage of CAVs in the fleet and are available in the CAS Data book [note 31].

5.43 In the Technology scenario, a high and fast up-take of electric vehicles is also considered. The mileage splits and fuel efficiencies in the scenario are derived from a High Zero Emission Vehicle Deployment scenario, which assumes full electrification of the fleet by 2050. Data series are available in the CAS Data book [note 31].

5.44 Due to the fact that values of time, vehicle occupancy, mileage splits and fuel efficiencies are adjusted in modelling, the Technology scenario requires separate Economics file inputs into the TUBA software. Due to current limitations of the software, we advise that scheme promoters wanting to appraise the Technology scenario run the software twice: once with the Technology Economics file and once with the High Electric Vehicle Economics file. (The Technology Economics file includes adjusted value of time growth, adjusted vehicle occupancy, and adjusted mileage splits and fuel efficiencies. The High Electric Vehicle Economics file includes only the adjusted mileage splits and fuel efficiencies.) Then car transport economic efficiency benefits can be taken from the Technology Economics file run and all other benefits can be taken from the High Electric Vehicle Economics file run. If this is not possible, the value of time change can be left out and TUBA can be run once with the High Electric Vehicle Economics file. In this case, it should be clearly stated that the resulting transport economic efficiency benefits will be over-estimates.

5.45 When considering the Technology scenario, scheme promoters should consider increased mobility and increased road traffic. The increase in road traffic may increase pressure on the road network, although road users may be more willing to live with congestion if they are in a CAV. The scenario also considers fast electrification of the fleet, so although the road network may be more congested, the vehicles may emit far less in terms of carbon emissions.

Vehicle-led and Mode-balanced Decarbonisation scenarios

5.46 The two Decarbonisation scenarios explore a high and fast up-take of electric vehicles, in line with a High Zero Emission Vehicle Deployment scenario, with varying electric vehicle costs. In the Vehicle-led Decarbonisation scenario, no intervention is made to increase electric vehicle costs to align with current petrol and diesel costs. As cars are cheaper to run, transport users switch to electric vehicles, away from not only petrol and diesel but also other modes (including public transport). This leads to increased road traffic on the network. The Mode-balanced Decarbonisation scenario considers an alternative future, where, either through an unspecified intervention and/or market forces, electric vehicle costs are equalised to those of petrol and diesel cars. As a result, the modal share of public transport is higher than in the core.

5.47 The Decarbonisation scenarios use mileage splits and fuel efficiencies which are in line with stated ambitions across road transport modes to end the sale of diesel and petrol vehicles for cars, vans, HGVs and buses/coaches. As such, tailpipe (but not whole-life) carbon emissions from road traffic are almost completely eliminated by 2050. In addition, the Mode-balanced scenario equalises costs of electric vehicles with petrol and diesel. All other variables are held unchanged from the core scenario.

5.48 Note that no adjustments are made in the NTEM, meaning that both Decarbonisation scenarios use the core scenario TEMPro dataset.

5.49 In both the Core and the Vehicle-led Decarbonisation scenario, the relative cost competitiveness of electric vehicles leads to transport users shifting away from other modes towards electric vehicles. However, the effect is weaker in the Core as there is a slower uptake of electric vehicles. In the Mode-balanced Decarbonisation scenario, as all electric vehicle costs are equalised, including those that would be cheaper in the core, there is reduced road traffic compared to the Core and a slight shift towards public transport.

5.50 Due to the different mileage split and fuel efficiency assumptions, both scenarios require adjustments to the TUBA Economics file. For the Vehicle-led Decarbonisation scenario, the High Electric Vehicle Economics file can be used for all benefits. For the Mode-balanced Decarbonisation, two runs are needed, one with the Mode-balanced Decarbonisation Economics file and one with the High Electric Vehicle Economics file. (The Mode-balanced Decarbonisation Economics file accounts for the cost equalisation between electric vehicles and petrol and diesel cars, whereas the High Electric Vehicle Economics file accounts for the reduced carbon emissions from road traffic in the scenario.) Car, LGV & HGV greenhouse gas benefits should be taken from the High Electric Vehicle Economics file run, and all other benefits should come from the Mode-balanced Decarbonisation Economics file run.

5.51 When considering the two Decarbonisation scenarios, scheme promoters should juxtapose a future in which there is increased, but decarbonised road traffic, with a future in which there is decreased, but decarbonised road traffic. How road and public transport schemes will perform across the two scenarios will differ.

Using the scenarios in Qualitative ways

5.52 Examples of impacts that can be considered are provided below in Table 9. When it is not proportionate to conduct quantitative analysis (see Proportionate Scenario Analysis section 3.15), a qualitative discussion of the scenarios can be used. This has been discussed in section 3.19.

Table 9 Potential impacts for qualitative analysis of the Common Analytical Scenarios

Impact	Qualitative description of scheme in the scenarios
Revenue	All scenarios will have revenue impacts.
Mode switching	Technology and Decarbonisation scenarios experience mode switching behaviour. Could the intervention make mode switching more likely?
Spatial, Land use, distributional	Are regional movements in population and employment likely in your scheme? Does it fit with levelling up policy objectives?
Congestion	Will specific scenarios come up against congestion constraints or will certain scenarios relieve congestion issues?
Emissions	Is the intervention likely to push society towards a vehicle-led or mode-balanced decarbonisation future?

Using the scenarios in Quantitative ways

5.53 Quantitative analysis of the Common Analytical Scenarios can range from using the data series in the CAS Data book [note 31] to full model runs. Scheme promoters should use the CAS Data book [note 31] and the Scenario narratives in section 5.11 as a guide to which variables change in each scenario.

Appraisal Guidance for the scenarios

5.54 The appraisal of the scenarios should be treated similarly to the core scenario and high/low scenarios defined in TAG Unit M4. However, in the case of the Technology, Vehicle-led and Mode-balanced scenarios, TUBA files should be used in line with the description in the Scenario Narratives (see section 5.11) and Table 10.

Table 10 TUBA File Application for Technology and Decarbonisation scenarios

Scenario Name	Detail	Component Run 1	Component Run 2
Technology	**Economics File:**	'Technology' [1]	'High EV' [2]
	Changes vs 'Core'	VTTS benefit growth factors; Car occupancy; EV fleet share (high), fuel efficiencies as per vehicle led decarbonisation CAS	EV fleet share (high), fuel efficiencies as per vehicle led decarbonisation CAS
	Applied to:	Car transport economic efficiency benefits	All other benefits
Mode Balanced Decarbonisation	**Economics File:**	'Mode Balanced Decarbonisation' [3]	'High EV' [2]
	Changes vs 'Core'	EV fleet share (zero), fuel efficiencies for cars, LGVs and HGVs as per vehicle led decarbonisation CAS	EV fleet share (high), fuel efficiencies as per vehicle led decarbonisation CAS
	Applied to:	All benefits except Car, LGV & HGV Greenhouse Gas	Car, LGV & HGV Greenhouse Gas benefits
Vehicle-led Decarbonisation	**Economics File:**	'High EV' [2]	N/A (No second run required)
	Changes vs 'Core'	EV fleet share (high), fuel efficiencies as per vehicle led decarbonisation CAS	N/A
	Applied to:	All	N/A

Annex C: Techniques for Understanding Uncertainty

5.55 This annex summarises the main techniques discussed in Chapter 3 and highlights the advantages and disadvantages for each. It also signposts practitioners to the most appropriate time to use each.

Table 11 Summary of technical approaches to addressing uncertainty

	Judgement Based Approach
Description	*A subjective estimate of the overall uncertainty using expert elicitation techniques.*
Advantages	*Requires little to no data;* *Based on real-world performance, so avoids optimism/ pessimism bias;* *Do not need to mathematically combine uncertainties.*
Disadvantages	*Highly subjective;* *Requires expertise to reasonably grasp the range of possible outcomes.*
When should this technique be used?	*When quantitative uncertainty analysis is unfeasible due to time, resource or data constraints.*
	Scenarios
Description	*Narratives that describe alternative ways in which the external environment could potentially develop in the future. These narratives should be accompanied by corresponding input data to which transport model's results will be potentially sensitive.*
Advantages	*Can be consistently applied across many schemes;* *Gives 'real-world', narrative-rich explanations to the range of possible outcomes, which can increase buy-in from decision makers;* *Enables the inclusion of low-probability, high-impact events, without needing to define their probability.*
Disadvantages	*The choice of scenarios can be subjective, and may not cover the full range of plausible future outcomes;* *Provides no information about the likelihood of each scenario occurring;* *Scenarios will not be evenly distributed around the most likely outcome, risking optimism / pessimism bias*
When should this technique be used?	*Refer to Proportionality Framework (*Figure 5 and Table 2).
	Sensitivity Testing

Description	*Tests used to understand the sensitivity of a model to different parameters, assumptions or differences in key drivers, and how this will impact on the assessment of costs and benefits.*
Advantages	*Commonly used and understood;* *Helps narrow in on factors specific to the scheme: key assumptions or important exogenous factors.*
Disadvantages	*Standard practice is to run key sensitivities, but thorough testing can be resource intensive;* *Provides no information about the likelihood of different outcomes.*
When should this technique be used?	*Refer to Proportionality Framework (*Figure 5 and Table 2).
	Monte Carlo Analysis
Description	*Varies model inputs and parameters statistically, creating a simulated range of results.*
Advantages	*If properly and completely specified, provides assessment of likelihood of different outcomes;* *Produces a visual representation of the range of possible outcomes (although this can be achieved with the other approaches).*
Disadvantages	*Highly dependent on the accuracy of the distributions used;* *Down to practitioners to specify probability distribution assumption, implying a lack of objectivity.* *Requires more analytical resource than other methods, and can be computationally expensive.*
When should this technique be used?	*When practitioners are confident in their knowledge of variables' variance, co-variance and probability distributions.*
	Other Decision-Making Approaches
Description	*Analytical approaches and tools for decision-making under deep uncertainty. These seek to find actions that reduce the vulnerability of a policy or strategy to uncertainty in future developments. Examples include Dynamic Adaptive Planning and Robust Decision Making.*
Advantages	*Use of signposts and triggers can protect scheme promoters and decision makers against 'deep uncertainty';*
Disadvantages	*A planning and monitoring approach is likely to be cost and resource intensive;*
When should this technique be used?	*When: the contextual uncertainties are deep; the set of policies has more rather than fewer degrees of freedom; and when the system complexity is such that it is difficult to link policies to outcomes (e.g. some aspects of climate change).*

Annex D: Notes

1. See Transport Analysis Guidance (TAG): https://www.gov.uk/guidance/transport-analysis-guidance-tag

2. See DfT TAG Unit M4 Forecasting and uncertainty: https://www.gov.uk/government/publications/tag-unit-m4-forecasting-and-uncertainty

3. See the Cross Whitehall Uncertainty Toolkit: https://analystsuncertaintytoolkit.github.io/UncertaintyWeb/index.html

4. See the Government Office for Science Futures Toolkit: https://www.gov.uk/government/publications/futures-toolkit-for-policy-makers-and-analysts

5. See DfT's Road Traffic Forecasts: https://www.gov.uk/government/publications/road-traffic-forecasts-2018

6. See the Green Book: https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

7. See the Aqua Book: https://www.gov.uk/government/publications/the-aqua-book-guidance-on-producing-quality-analysis-for-government

8. Michael Miller and Eckhard Szimba, Karlsruhe Institute of Technology, How To Reflect The Issue Of Risk In Transport Infrastructure Appraisal: Synthesis Of Methods And Best Practice, July 2013

9. Vincent A.W. Marchau, Warren E. Walker, Pieter J.T.M. Bloemen, Steven W. Popper, Decision making under Deep Uncertainty (2019)

10. See DfT TAG Unit A1.2 Scheme Costs: https://www.gov.uk/government/publications/webtag-tag-unit-a1-2-scheme-costs-july-2017

11. Walker, W. E. (2000). Policy analysis: A systematic approach to supporting policymaking in the public sector. Journal of Multicriteria Decision Analysis, 9(1–3), 11–27.

12. See DfT TAG Unit M1.1 Principles of Modelling and Forecasting: https://www.gov.uk/government/publications/webtag-tag-unit-m1-1-principles-of-modelling-and-forecasting

13. See DfT TAG Unit A2.2 Induced Investment: https://www.gov.uk/government/publications/tag-unit-a2-2-induced-investment

14. See DfT TAG Unit A3 Environmental Impact Appraisal: https://www.gov.uk/government/publications/tag-unit-a3-environmental-impact-appraisal

15. See DfT TAG Unit A5.3 Rail Appraisal: https://www.gov.uk/government/publications/webtag-tag-unit-a5-3-rail-appraisal-may-2018

16. See DfT TAG Unit A1.1 Cost-Benefit Analysis: https://www.gov.uk/government/publications/webtag-tag-unit-a1-1-cost-benefit-analysis-may-2018

17. See DfT TAG Unit A1.3 User and Provider Impacts: https://www.gov.uk/government/publications/webtag-tag-unit-a1-3-user-and-provider-impacts-march-2017

18. See DfT TAG Unit A2.1 Wider Economic Impacts: https://www.gov.uk/government/publications/tag-unit-a2-1-wider-economic-impacts

19. See DfT TAG Unit A4.1 Social Impact Appraisal: https://www.gov.uk/government/publications/tag-unit-a4-1-social-impact-appraisal

20. Richard Batley, ITS Leeds, Uncertainty Stocktake – Scoping Phase, 2018

21. See, for example Wheat & Batley (2015) Quantifying and decomposing the uncertainty in appraisal value of travel time savings. http://dx.doi.org/10.1016/j.tranpol.2015.06.010

22. Cabinet Office Business Impact Levels

23. See DfT Transport Business Case Guidance https://www.gov.uk/government/publications/transport-business-case

24. See DfT TAG Data book https://www.gov.uk/government/publications/tag-data-book

25. Kees Van Der Heijden, Technological Forecasting and Social Change, *Scenarios and Forecasting: Two Perspectives*, September 2000

26. See DfT TAG Unit M2.1 Variable Demand Modelling: https://www.gov.uk/government/publications/tag-unit-m2-1-variable-demand-modelling

27. The DfT value for money framework https://www.gov.uk/government/publications/dft-value-for-money-framework

28. Jessica Hullman, Scientific American, How to Get Better at Embracing Unknowns: Interpreting uncertainty through data visualisations, September 2019

29. Bank of England, Monetary Policy Report, November 2020

30. Please note, this is an expected output of modelling this CAS, rather than a target or input assumption.

31. See DfT Common Analytical Scenarios Data book https://www.gov.uk/guidance/transport-analysis-guidance-tag#tag-data-book

32. Note, as discussed above, modelling values of time vary in the Low and High Economy scenarios.

33. See DfT NTEM Data Report, visit https://www.gov.uk/ and search for National Trip End Model version 8

34. See ONS Variant Population Projections https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/methodologies/nationalpopulationprojectionsvariantprojections2018based

35. See ONS 2018-based Households Projection https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/householdprojectionsforengland/2018based

36. See Office for Budget Responsibility's March 2022 Economic and Fiscal Outlook https://obr.uk/efo/economic-and-fiscal-outlook-march-2022/