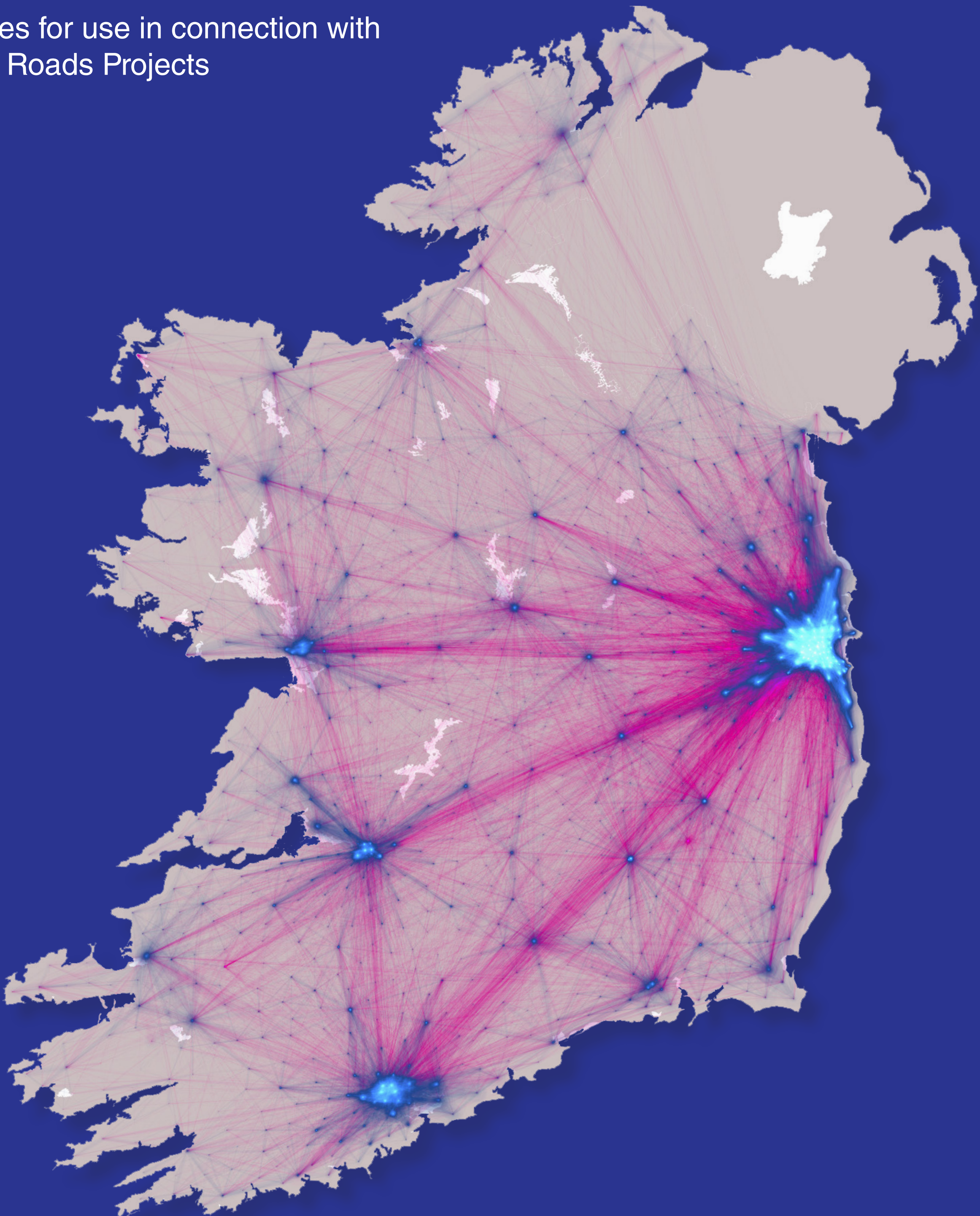
Bonneagar Iompair Éireann
Transport Infrastructure Ireland

Reference Class Forecasting

Guidelines for use in connection with National Roads Projects



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Foreword

The government is seeking to transform the way we both deliver and use our infrastructure so we can extract the maximum possible value from our investment and so bring about real change for people, communities and our economy. In response to updated guidance in the Public Spending Code, Transport Infrastructure Ireland (TII) is transforming its cost forecasting process both through an update to TII's Cost Management Manual (for publication in 2020) and the preparation of this document providing guidance on the use of reference class forecasting in connection with Irish national roads projects.

TII has been involved in the delivery of new national road schemes since the formation of the National Roads Authority in 1994 and thus has a wealth of data available to it from previous Irish national roads projects which is suitable for use in generating specific reference class curves appropriate to Irish national roads projects.

As reference class forecasting, as a concept, evolved from issues with cost estimation identified through behavioural science, it is appropriate that the first section of these guidelines addresses the background to reference class forecasting and provides the context for its use. While it is acknowledged that much of this context is based on international experience and would not truly reflect TII's experience on Irish national roads projects, it was felt that findings from a blend of international experience would provide the reader with an introduction to the concepts underlying reference class forecasting.

Successive national investment plans have acknowledged the need to modernise significant sections of legacy national road network as fundamental building blocks for economic growth, access to services, and social cohesion. To extract value from these investments, better accuracy in forecasting the cost is critical for our decision makers. The processes set out in this document accords with TII's principle of promising what is worth having and delivering what is promised.

I wish to acknowledge the work of TII staff, in particular Richard Bowen, Roads Portfolio Manager, and Anthony Duffy, Head of Project Services, in the preparation of these guidelines and the national roads reference class. I wish also to acknowledge and thank Professor Bent Flyvbjerg and Dr Alexander Budzier of Oxford Global Projects for their guidance and assistance.

Michael Nolan
CEO, Transport Infrastructure Ireland

Section 1
Background to Reference Class Forecasting

1.1. Introduction

1.1.1. Why Reference Class Forecasting?

Reference Class Forecasting is an established method to address the root causes of cost and schedule overrun in projects. These root causes, including optimism bias and strategic misrepresentation, can lead to underestimations of projects' costs, benefits and schedules, which later results in overruns.

1.1.2. Risk in infrastructure projects

Most projects change during the project cycle from idea to reality. Changes may be due to uncertainty regarding, inter alia, the level of ambition, the exact corridor, the technical standards, safety, environment, project interfaces and geotechnical conditions. Prices and quantities of project components are subject to uncertainty and change and the choice of procurement and contracting strategy may lead to changes to the risk profile on the project.

According to ISO 31000, risk is the "effect of uncertainty on objectives" and an effect is a positive or negative deviation from what is expected. More conventionally, risk is regarded as the adverse consequence of change. In terms of risk, most appraisals of projects assume, or purport to assume, that infrastructure projects exist in a world where things go according to plan. In reality, as can be seen from many examples both domestically and internationally, the world of project preparation and implementation is a highly risky one where things happen only with a certain probability and rarely turn out as originally intended.

The "Public Spending Code – A Guide to Evaluating, Planning and Managing Public Investment" published by the Department of Public Expenditure and Reform in December 2019 supports this when it states:

The estimated values of costs, benefits or delivery schedules may not materialise as expected due to uncertainty and risk. The risks of adverse conditions and the potential uncertainty associated with each option should be identified and factored in to the decision making process. Realistic assumptions be made and risk minimisation strategies should be put in place.

1.1.3. Cost overruns in various transport infrastructure projects

Overrun is a problem in private as well as public sector projects and, based on international trends, things are not improving; overruns have stayed high and constant for the 70-year period for which comparable data exist. Geography doesn't seem to matter either; all countries and continents for which data are available suffer from overruns (Flyvbjerg, Holm, & Buhl 2002).

Hence, some degree of risk of cost overrun, schedule delay and benefit shortfall will always exist and it is important to consider this for project appraisal, programming, budget setting and project cost control. Risk is however not unknown and should be duly reflected in the project documentation at any given stage.

Table 1.1 shows, based on international data, the average cost overrun in roads projects (26%), bridges (27%), tunnels (37%) and rail projects (38%). Rails and tunnels, due to their complexity, have the highest cost overrun, but the overrun for roads at 26% is still significant. The frequency of cost overrun in transport projects is reasonably consistent, where 6-7 out 10 projects have experienced cost overrun.

The average schedule overrun in the transport infrastructure projects in Table 1.1 varies between 20% and 40%.

Table 1.1 Overrun data on transport infrastructure projects

	Cost overrun (mean)	Frequency of cost overrun	Schedule overrun (mean)	Frequency of schedule overrun	Sample size (n)
Roads	+26%	76%	+27%	61%	1803
Bridges	+27%	64%	+19%	68%	95
Tunnels	+37%	75%	+21%	56%	75
Rail	+38%*	74%	+39%	63%	496

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$ (p-values based on the difference between road projects and other project types using two-sample Wilcoxon tests)

1.2. Causes and root causes of cost and schedule overruns

1.2.1. Causes of cost and schedule overruns

Frequently, funders, owner-operators and builders of projects tend to explain cost and schedule overruns in major projects as a result of issues such as unforeseen ground conditions, project complexity, scope and design changes, weather, delays in site access and possession and delays in obtaining permits (see Cunningham 2017, for a review of studies of causes of cost and schedule overruns).

No doubt, all of these factors at one time or another contribute to cost overrun and schedule delay, but it may be argued that they are not the real, or root, cause. The root cause of overrun is the fact that project planners can systematically underestimate or even ignore risks during project development and decision making.

The root cause of cost overrun and schedule delay, therefore, is not that unforeseen conditions and adverse events happen to a project. The root cause is found in what a project did or did not do to prepare for unforeseen conditions and adverse events.

As noted earlier, most projects change in scope as they progress from idea into reality. Hence, some degree of cost and schedule risk will always exist. Such risk is however not unknown and should be duly estimated and reflected in the project documentation at any given stage. Hence, cost overruns and schedule delays should be viewed as underestimation of cost and schedule risk.

Only identifying the root causes of what causes projects to underestimate cost and schedule risk allows planners and decision makers to address the issue.

At the most basic level, international experience would show that the root causes of cost overrun and schedule delay may be grouped into three categories, each of which will be considered in turn:

(1) bad luck or error;

(2) optimism bias; and

(3) strategic misrepresentation.

1.2.2. Error

Bad luck, or the unfortunate resolution of one of the major project uncertainties mentioned above, is the explanation typically given for a poor outcome. The problem with such explanations is that they do not hold up in the face of statistical tests.

Explanations that account for overruns in terms of bad luck or error have been able to survive for decades only because data on project performance has generally been of low quality, i.e. data has been disaggregated and inconsistent, because it came from small-N samples that did not allow rigorous statistical analyses. Once higher-quality data was established that could be consistently compared across projects in numbers high enough to establish statistical significance, explanations in terms of bad luck or error collapsed. The very high levels of statistical significance in Table 1.2 show that such explanations simply do not fit the international data for cost overrun.

Table 1.2 Tests of the “error” explanation for roads projects based on International Experience

	Mean	Wilcoxon test, whether the error centers on zero	Frequency of overrun	Binomial test, whether overruns are as frequent as underruns
Cost overrun	26%	$p < 0.001$	76%	$p < 0.001$
Schedule overrun	27%	$p < 0.001$	61%	$p < 0.001$

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First, if underperformance was truly caused by bad luck and error, a relatively unbiased distribution of errors in performance around zero would be expected. In fact, the data shows with very high statistical significance that the distribution does not centre on zero and that the forecasting error is biased towards overrun.

Second, if bad luck or error were main explanations of underperformance, we would expect an improvement in performance over time since, in a professional setting, errors and their sources would be recognised and addressed through the refinement of data and methodologies, much like in weather forecasting or medical science.

Internationally, substantial resources have in fact been spent over several decades on improving data and methods in major project management, including in cost and schedule forecasting. This has led to local improvements such as improvements in cost estimation and forecasting introduced by the National Roads Authority between 2006 and 2010, details of which are included in Section 2 of this document. Still broad international evidence shows that this has not led to overall improved performance in terms of lower cost overruns and delays.

Bad luck or error, therefore, do not appear to explain the data.

1.2.3. Optimism bias

Psychologists tend to explain the underestimation of cost and schedule risks in terms of optimism bias, that is, a cognitive predisposition found with most people to judge future events in a more positive light than is warranted by actual experience. Kahneman and Tversky (1979) found that human judgment is generally optimistic due to overconfidence and insufficient regard to distributional information about outcomes.

Thus people will underestimate the costs, completion times, and risks of planned actions, whereas they will overestimate the benefits of the same actions. Similarly, the cost and time needed to complete a project will be optimistic, i.e. under estimated. Such errors of judgment are shared by experts and laypeople alike, according to Kahneman and Tversky.

From the point of view of behavioural science, the mechanisms of scope changes, complex interfaces, archaeology, geology, bad weather, business cycles, and so forth are not unknown to planners of capital projects, just as it is not unknown to planners that such mechanisms may be mitigated, for instance by Reference Class Forecasting (see below).

However, planners often underestimate these mechanisms and mitigation measures, due to overconfidence bias, the planning fallacy[1], and strategic misrepresentation. In behavioural terms, scope changes and other issues are manifestations of such underestimation on the part of planners, and it is in this sense that bias and underestimation are the root causes of cost overrun. But because scope changes and other issues are more visible than the underlying root causes, they are often mistaken for the cause of cost overrun.

In behavioural terms, the causal chain starts with human bias which leads to underestimation of scope during planning which leads to unaccounted for scope changes during delivery which lead to cost overrun. Scope changes are an intermediate stage in this causal chain through which the root causes manifest themselves.

With behavioural science planners are told, “Your biggest risk is you.” It is not scope changes, complexity, and other issues in themselves that are the main problem; it is how human beings misconceive and underestimate these phenomena, through overconfidence bias, the planning fallacy or strategic misrepresentation. This is a profound and proven insight that behavioural science brings to capital investment planning.

Behavioural science entails a change of perspective. The problem with cost overrun is not error but bias, and as long as efforts are made to try to solve the problem as something it is not (error), the problem will not be solved. Estimates and decisions need to be de-biased, which is fundamentally different from eliminating error (Kahneman et al. 2011, Flyvbjerg 2008, 2013).

Furthermore, the problem is not even cost overrun, it is cost underestimation. Overrun is a consequence of underestimation, with the latter happening upstream from overrun, often years before overruns manifest. Again, if project planners and decision makers try to solve the problem as something it is not (cost and schedule overruns), they will fail. Planners and decision makers need to solve the problem of cost underestimation to solve the problem of cost overrun.

1 | Planning fallacy is a specific form of optimism bias wherein people underestimate the amount of time it will take to complete an upcoming task even though they are fully aware that similar tasks have taken longer in the past.

1.2.4. Strategic Misrepresentation

Economists and political scientists frequently explain underreporting of budget and schedule risks internationally in terms of strategic misrepresentation (Wachs 1989, Flyvbjerg 2005). Based on this theory, when forecasting the outcomes of projects, forecasters and planners deliberately and strategically overestimate benefits and underestimate cost and schedule in order to increase the likelihood that it is their projects, and not the competition's, that gain approval and funding.

Optimism bias and strategic misrepresentation are both deception, but where the latter is deliberate, the former is not. Optimism bias is self-deception.

1.2.5. Summary of the root causes

Research into the track record of past estimates (e.g. Flyvbjerg et al. 2004, Flyvbjerg 2014, 2016) shows that project cost and schedule estimates are systematically and consistently lower than actual outturn cost and actual schedule.

The data shows that conventional, inside-view cost and schedule estimates are biased, i.e. they systematically underestimate cost and schedule risks. The data does not fit the "error" explanation of overrun and raise doubts that better models and better data on their own will improve forecasts.

This leaves optimism bias and strategic misrepresentation as the best explanations of why cost and schedule are underestimated.

As illustrated schematically in Figure 1.1, explanations in terms of optimism bias have their relative merit in situations where political and organisational pressures are absent or low, whereas such explanations hold less power in situations where political and organisational pressures are high.

Conversely, explanations in terms of strategic misrepresentation have their relative merit where political and organisational pressures are high, while they become less relevant when such pressures are not present.

Although the two types of explanation are different, the result is the same: inaccurate forecasts and inflated benefit-cost ratios.

Thus, rather than compete, the two types of explanation complement each other: one is strong where the other is weak, and both explanations are necessary to understand the pervasiveness of inaccuracy and risk in project budgeting and scheduling – and how to curb it.

Figure 1.1 Optimism Bias and Strategic Misrepresentation

1.3. Cures for overrun in transport projects: Reference Class Forecasting Methodology

1.3.1. Introduction

The analysis, above, showed that the causes of cost overrun and schedule delay can be found within the conventional explanations of why overruns occurred such as unforeseen ground conditions, project complexity, bad weather and so forth.

However, as argued above, the root cause of why unforeseen conditions and adverse events turn into overruns can be found in optimism bias or strategic misrepresentation in estimates. These underestimations later turn into overruns.

Project funders, owner/operators, sponsors, project managers i.e. key decision makers in projects, can take the following steps to de-bias their project plans and proposals.

1.3.2. Take an outside view

The conventional "inside view" of project planning and evaluation results in optimistic estimates and plans. Planners and decision makers with an "inside view" focus on the constituents of the specific planned action rather than on the outcomes of similar actions that have already been completed, i.e. an "outside view".

The outside view pools lessons from past projects. In the basic form, the outside view can be taken by comparing the project at hand to comparable past projects with a view to learn from them.

International research has shown that projects are typically weak in applying lessons learned from other projects. Research has shown that this is linked to the perceived uniqueness of projects. When project planners perceive their project to be unique they implicitly exclude the experience and knowledge gained from other projects because these are not relevant to their project. In reality, unique projects are rare. Projects are typically specific to a location and a context, but they are rarely unique when looking at global experience and track record.

Thus, as a first step, decision makers should challenge and evaluate the quality of estimates and plans by taking the outside view of their project.

1.3.3. Probabilistic forecasts of risk

Research has shown that even when project planners take an outside view, they tend to be biased when presenting projects as single point estimates, i.e. when estimates ignore the full distribution of possible outcomes.

The industry standard of quantitative risk assessments has evolved to present estimates as distributions through Monte Carlo simulations. However, the full distributional information of these quantitative risk assessments is not always shared with decision makers. More importantly, Monte Carlo simulations are not a tool that automatically de-biases risk estimates. Monte Carlo simulations based on biased inputs create biased forecasts.

During the front end, when projects are appraised, three key questions are usually considered:

- Is the project economically viable?
- Is the project affordable?
- What project budget and timeline ranges should be set including consideration of appropriate levels of certainty?

The risk appetite of decision makers and hence the total estimate will differ for each of these questions. Sponsors and funders should use probabilistic forecast ranges instead of single point forecasts to capture this reality.

For example, the question of economic viability is relevant to economic appraisals of projects. For this question the mean of the quantitative risk assessment may be the appropriate measure. The mean reflects the expected cost, schedule and benefits of when a project, that is part of a large portfolio of investments, will deliver the outcome intended.

When evaluating project affordability, which is a key concern not only in publicly funded projects, decision makers tend to require a higher degree of certainty, i.e. they have a low risk appetite. To evaluate the affordability, decision makers may consider a downside scenario, i.e. estimates at a high P-level (P80-P90). In some instances, e.g. the UK's High Speed 2 Project, decision makers have asked for a 95% level of certainty of estimates (P95) to evaluate the affordability and judge whether a project could bankrupt private sector partners or negatively impact on the ability to deliver other projects or programmes.

1.3.4. Reference Class Forecasting

Reference class forecasting eliminates biases by taking an outside view and using all the distributional information available.

More accurate estimates, and thus higher-quality project decisions, combine the "outside view" and the use of all the distributional information that is available. This may be considered the single most important piece of advice regarding how to increase accuracy in forecasting through improved methods, according to Kahneman (2011).

Reference Class Forecasting is a method for systematically taking an outside view on planned actions. Reference class forecasting places particular emphasis on relevant distributional information because such information is most significant to the production of accurate forecasts.

Reference Class Forecasting makes explicit, empirically based adjustments to estimates. In order to be accurate, these adjustments should be based on data from past projects or similar projects elsewhere, and adjusted for the unique characteristics of the project in hand.

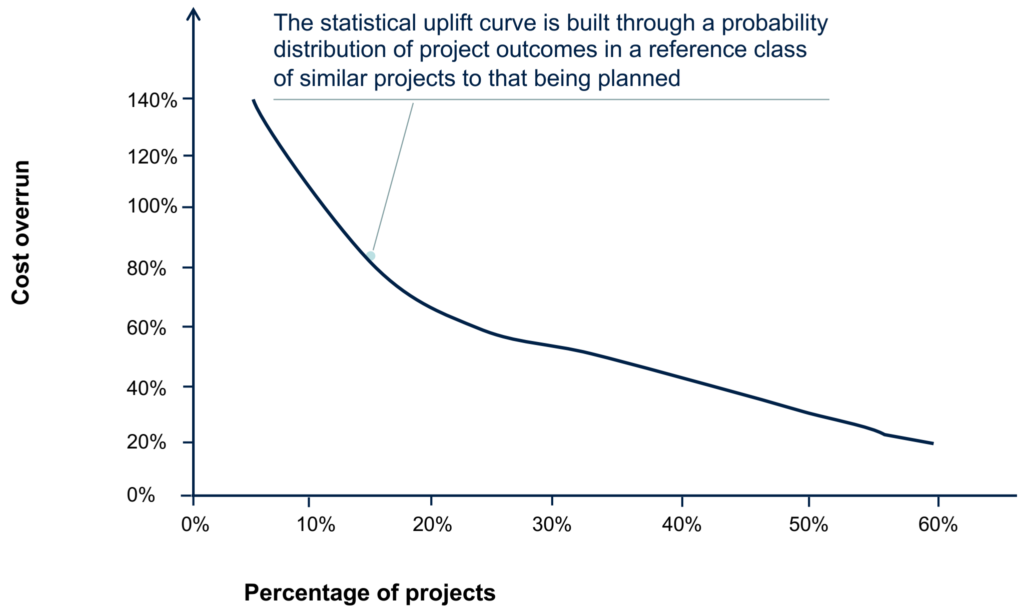
Reference Class Forecasting follows three steps:

1. Identify a sample of past, similar projects – typically a minimum of 20-30 projects is enough to get started, but the more projects the better;
2. Establish the risk of the variable in question based on these projects – e.g. identify the cost overruns of these projects; and
3. Adjust the current estimate – through an uplift or by asking whether the project at hand is more or less risky than projects in the reference class, resulting in an adjusted uplift.

First, a reference class is selected. The key to a reasonable reference class is a broad selection of projects, so that all available information is included, and no potentially informative data are thrown out. In order to establish what is comparable information statistical analysis is used to eliminate the risk of re-introducing optimism into the analysis by excluding valuable data. The availability of good quality data in one place on previous projects is key to both the initial development of the reference class and also to the ongoing updating of the reference class with new data as and when additional projects are completed.

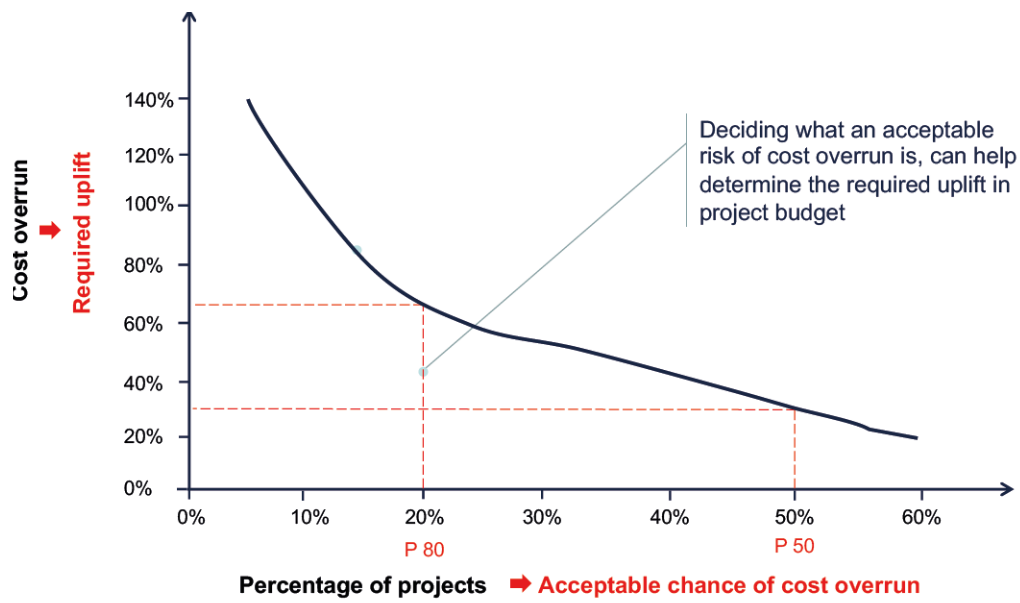
Second, the distribution of the data in question is analysed. For this the cumulative distribution is constructed. In the case of overrun the data are simply sorted from largest to smallest overrun and then the relative share of each data point in the sample is calculated (e.g. if 25 projects are in a reference class each project has 4% share) and summed up so that the distribution ranges from 0%-100% (i.e. the project with the largest overrun project represents 4% the second highest overrun 8% and so on. Figure 1.3 depicts how the cumulative distribution curve of these data is then charted.

Figure 1.2 Cumulative probability distribution of overrun in the reference class (conceptual)



The overrun becomes the uplift necessary to add to bottom-up or inside view estimates to de-bias the inside estimate. For example, if decision makers accept a 50% chance of overrun (i.e. they require a 50% certain estimate or P50) then a certain uplift should be added. Frequently, the P50 is used by portfolio managers, because in this case projects in the portfolio that go over budget will be balanced by projects that go under. If decision makers are more risk averse and only accept a 20% chance of overrun (i.e. they require an 80% certain estimate or P80) then a larger uplift needs to be added. This is frequently the case for individual project cost forecasts where the decision maker's risk appetite is lower and they want to ensure that the anticipated benefits can still be achieved at the higher cost forecast.

Figure 1.3 Establishing the uplifts as a function of the acceptable chance of cost overrun based on the cumulative distribution of cost overrun in the reference class (conceptual)



Because Reference Class Forecasts are based on the actual outcomes of similar past projects, the method estimates not only the known unknowns of a project, i.e. risks identified ex-ante, but also the unknown-unknowns for the project, i.e. risks that have not been identified but may nevertheless impact the project.

It should be noted that the distribution is based on the historical overruns in similar, completed projects. Thus, projects might need to consider whether any adjustments to the uplift are needed. In other words, whether the project at hand is more or less risky than past projects. Any adjustment in the final step ought to be based on hard evidence in order to avoid reintroducing optimism bias back into the estimate.

This approach is consistent with other research and analysis which has identified that Expert Judgement (i.e. judgement from suitably experienced and qualified individuals who may or may not be part of the project development team), Monte Carlo Simulation (QRA) and Reference Class Forecasting all provide elements of comprehensive risk measurement, but the combination of all three approaches will provide a fully comprehensive approach to risk measurement.

As such, while reference class forecasting is an important and useful tool in the preparation of more robust cost estimates, by itself it is not the solution to cost overruns. It is still of the utmost importance that the base cost estimate is as accurate as possible and that a robust process exists for capturing and disseminating lessons learned from completed projects for the benefit of future projects. How all of this is addressed in TII is discussed further in sections 2 and 3 of this document.

Reference Class Forecasting has been used by the UK Department for Transport since 2004 to implement the HMT Green Book. The method has been endorsed by the American Planning Association and is recommended practice in Switzerland, Denmark, The Netherlands, and Australia. Independent research has shown that this method outperforms conventional forecasting and monitoring techniques, such as trend analyses and EVM[2].

2 | RCF used at Sydney Water Corporation on 11 infrastructure projects showed significantly increased likelihood of completing under budget (Napier & Liu 2008); Hybrid method including RCF used at Australian State Road and Traffic Authority on 44 projects showed increased forecast accuracy (Liu, Wehbe & Siscovic 2010); Bridge construction forecast based on Bayesian updating and RCF produced more accurate forecasts (Kim & Reinschmidt 2011); RCF integrated in a Bayesian forecast of healthcare cost in 8 car manufacturing plants produced more accurate forecasts (Bordley 2014); Study of 56 construction projects shows that RCF outperforms conventional techniques, i.e. bottom-up estimation EVM and Monte Carlo simulations (Batselier & Vanhoucke 2016); Application of RCF to Bujagali hydropower dam project increased accuracy of the cost-benefit analysis (Awojobi & Jenkins 2016); Study of 399 political forecasters shows that those trained and using RCF, taking different perspectives, and post-mortem analyses produced more accurate forecasts (Chang, Chen, Mellers & Tetlock 2016); Integrating RCF into EVM on 23 construction projects produces more accurate predictions of schedule performance (Batselier & Vanhoucke 2017)

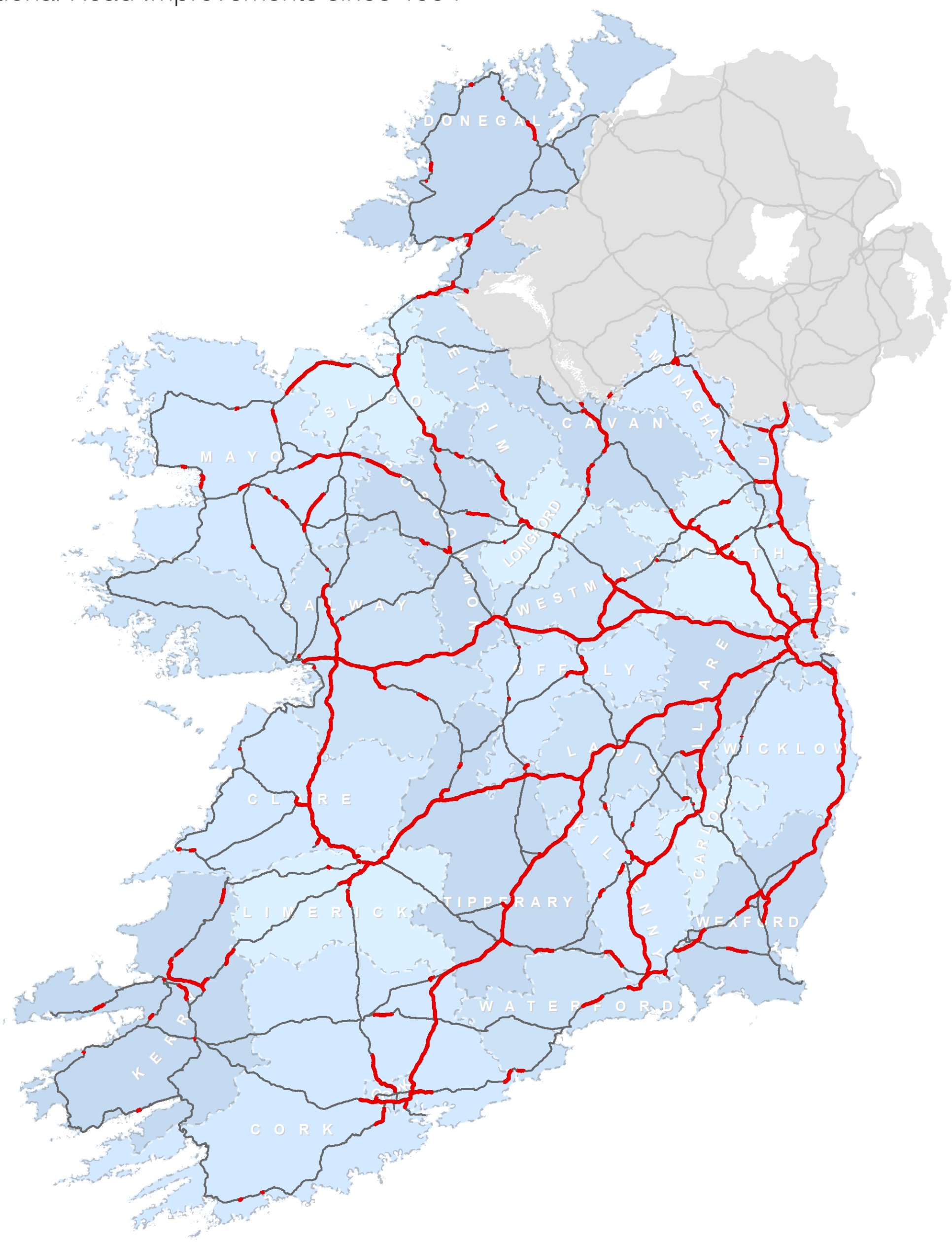
Section 2
Development of National Roads Reference Class

2.1. Introduction

TII has responsibility for both national roads and light rail projects. Due to the nature of light rail projects in Ireland, there are a limited number of these and, thus, not sufficient projects to form a reference class of Irish projects. As such, for light rail / metro projects, TII will rely on international data to augment its own data.

On the other hand, TII has been responsible for the delivery of a significant portfolio of national road improvement schemes since the establishment of the National Roads Authority (the predecessor of TII) in 1994. As part of this work, TII ensured that comprehensive electronic records were kept centrally within TII for each project including forecast and outturn cost, benefit and schedule data. As such, TII is in a position to develop an extensive reference class of national road improvement schemes for use in future cost forecasting.

Figure 2.1 – National Road Improvements since 1994



2.2. Cost Forecasting Processes In TII

In 2006, TII introduced revised cost forecasting processes which broadly remain in use. These processes require each cost forecast to be broken down into seven discrete cost headings as follows:

a. Planning & Design Costs

b. Archaeology Resolution Costs

c. Land Acquisition Costs

d. Advance Works Cost (i.e. works undertaken prior to the award of the main construction contract such as site fencing, site clearance, service diversions, etc.)

e. Main Construction Supervision Cost

f. Main Construction Cost

g. Residual Network Costs (i.e. works undertaken post completion of the main construction works usually involving works to the old national road such as re-signing, rehabilitation, integration with public transport and provision of walking and cycling facilities)

The 2006 processes also identify three key points in cost forecasting for national road schemes as follows:

a. Immediately prior to Planning Application Submission

b. Immediately prior to Tender of Main Construction Contract (if necessary)

c. Immediately prior to Award of Main Construction Contract

At pre planning stage, a well-developed preliminary design has been prepared and it is possible to develop reasonably accurate schedules of main quantities for the main elements of the project and thus it is possible to prepare reasonably accurate cost forecasts. Including allowance for risk (developed using a quantified risk analysis process) and estimates for inflation, this pre planning forecast would be expected to have a confidence level of 50% i.e. a 50% chance of not being exceeded. This forecast is called the Target Cost 1 or TC1.

At pre tender stage, the cost forecast is updated, (where necessary) to reflect any changes to the scheme scope or extent that were imposed by the Planning Authority, any changes that were identified arising from further surveys and investigations, any changes arising from advance works undertaken and any changes identified arising from further design development and refinement done as part of the preparation of the tender documents. At this stage, there is also likely to be more certainty as to the timescale for the delivery of the whole scheme and thus the inflation forecasts can be refined. The risk register and quantified risk analysis is also updated to reflect the removal of any planning stage risks and adjustments to other risks arising from further surveys / investigations and any advance works undertaken. This pre tender forecast is called the Target Cost 2 or TC2 and would normally be expected to have a confidence level of 65%.

At pre award stage, the cost forecast is updated to take account of the developed final tender documents, the preferred tenderer's tender design offering and the preferred tenderer's tender sum, although care is always taken to ensure that the forecast is not influenced by the lowest tenderer's pricing strategy. The risk and inflation allowances for the main construction works are adjusted to incorporate the contract provisions e.g. if it is a fixed price contract, the tender sum would not be adjusted for inflation and inflation on the construction cost may not be included in the forecast. This pre award forecast is called the Target Cost 3 or TC3 and would normally be expected to have a confidence level of 80%.

Section 2
Development of National Roads Reference Class

As can be seen from Table 2.1 below, an analysis of a portfolio of completed national roads projects demonstrates that the cost forecasting processes outlined above are quite robust with the median outturn cost being 8% lower than the forecast for TC1 and 2% lower than the forecast for TC3.

Baseline	Measure	Cost Overrun
TC1	Mean	-6%
TC1	Median	-8%
TC3	Mean	-3%
TC3	Median	-2%

Table 2.1 – Analysis of Portfolio Cost Overruns

2.3. Development of the National Roads Reference Class

As discussed above, TII has access to data from an extensive portfolio of roads projects completed by, and on behalf of, TII over the years 1994 – 2018. These projects vary in size from online single carriageway improvements of less than 1km in length to new, green-field, motorway construction of up to 50km in length. The value of the schemes likewise varies significantly from approximately €1m to over €0.5bn[3]. A total of 124 national road schemes were identified for use in the reference class, however not all of the data fields were available for all schemes. Only 7 of the 124 schemes had TC2 data which proved insufficient to form a robust reference class and accordingly no reference class was prepared for the TC2 cost forecast. Details of the schemes included in the various reference classes are shown in Appendix A.

Cost forecast data for each of the schemes were gathered under each of the seven cost headings for each of TC1, TC2 and TC3. Wherever possible, the cost forecast data were harvested from approved budget sheets. However, in some cases – particularly for older schemes – approved budget sheets were not available, so the data were extracted from cost benefit analysis reports, business cases and tender award approval reports. In a limited number of cases, cost forecasts were used from preliminary design reports, but only when TII were satisfied that these forecasts had been developed with sufficient rigour to be included in the reference class.

Scheme data were also gathered on a number of other factors for each scheme to identify if any of these factors would impact statistically on the portfolio of schemes to such an extent that separate reference classes should be prepared or projects with certain characteristics should be excluded from the reference class. This was performed in part to address the identified perceived reservation relating to the accumulation of a credible, homogeneous and representative reference class of projects.

Some of these factors and the outcome of the analysis are discussed in more detail in the following paragraphs. It should be noted that in order to carry out a rigorous statistical analysis, base cost data only, (i.e. excluding the contingency amounts which were included with the TC1 and TC3 forecasts), were used in the following analyses. As such, the cost overrun percentages in Figures 2.2 – 2.6 inclusive will appear to be higher than the figures in Table 2.1.

- **Scheme Type**

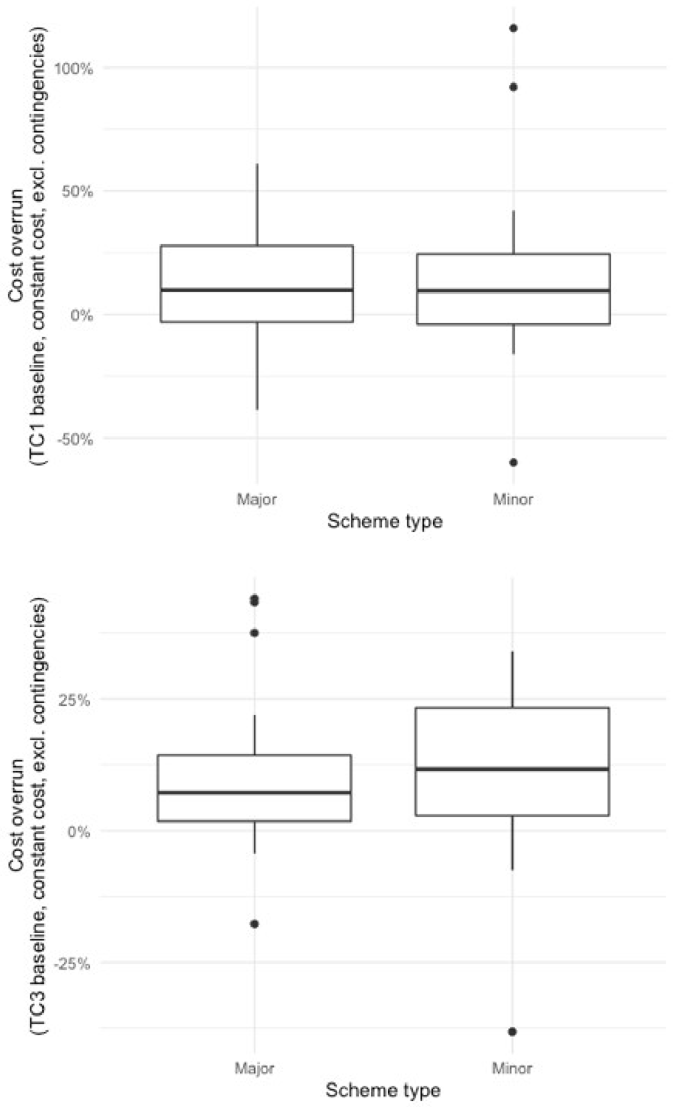
Schemes were divided up between Major Schemes, with value > €20m, and Minor Schemes, with value < €20m. Due to the slightly differing natures of the schemes, with Minor Schemes being smaller, generally involving more work on existing roads (e.g. widening) and having a slightly different supply chain (use of smaller civil engineering contracting firms), there was the potential that the difference in cost overruns between the different scheme types might be sufficient to warrant separate reference classes.

3 | Statistical analysis was done to ensure that the variations in scheme size, type and value did not affect the integrity of the reference class forecasting. This is discussed further later in this document.

Following statistical analysis, it was determined that the difference between cost overruns (excluding contingencies) is not statistically significant between Major and Minor Schemes with p-values of 0.98 for the TC1 baseline and 0.45 for the TC3 baseline both well in excess of the 0.05 p-value cut off point for statistical significance. This is demonstrated in Figure 2.2 below.

Figure 2.2 – Statistical Analysis of Scheme Type

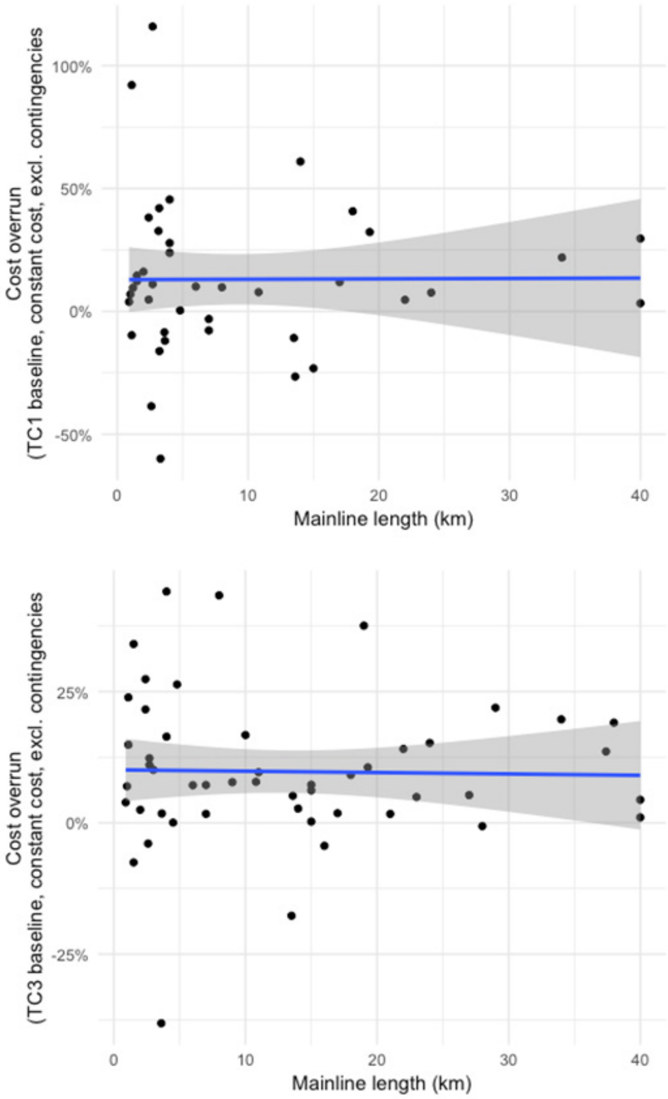
Cost Over Run
(TC1 baseline, constant cost, excl. contingencies



- **Scheme Length**

  As noted previously, the scheme lengths in the proposed reference class varied from less than 1km to 50km. An analysis was carried out into the association between the length of the mainline (in km) and cost overruns (excluding contingencies) in order to determine if there was a need to provide separate reference classes for schemes of different lengths. Following statistical analysis, it was determined that the length of the scheme did not impact on the scale of cost overrun with a p-value of 0.97 for the TC1 baseline and 0.88 for the TC3 baseline both well in excess of the 0.05 p-value cut off point for statistical significance. This is demonstrated in Figure 2.3 below.

Figure 2.3 – Statistical Analysis of Scheme Length



- **Scheme Value**

  An analysis was carried out into the association between the forecast project cost (at both TC1 and TC3) and cost overruns (excluding contingencies) in order to determine if there was a need to provide separate reference classes for schemes of different forecast value. Following statistical analysis, it was determined that the forecast project cost did not impact on the scale of cost overrun with a p-value of 0.88 for the TC1 baseline and 0.60 for the TC3 baseline both well in excess of the 0.05 p-value cut off point for statistical significance.

  This is shown in Figure 2.4 below

- **Date of Scheme Estimate**

  An analysis was undertaken to ascertain if the date at which the scheme forecast was prepared had any statistically significant impact on the level of cost overrun attributable to the scheme. This was important due to changes in TII's cost forecasting processes including the introduction of the Cost Management Manual processes in 2006/2007. Following statistical analysis, it was determined that the date when the forecast cost was prepared did not impact on the scale of cost overrun with a p-value of 0.36 for the TC1 baseline and 0.64 for the TC3 baseline both well in excess of the 0.05 p-value cut off point for statistical significance. This is shown in Figure 2.5 below.

Figure 2.4 – Statistical Analysis of Scheme Value

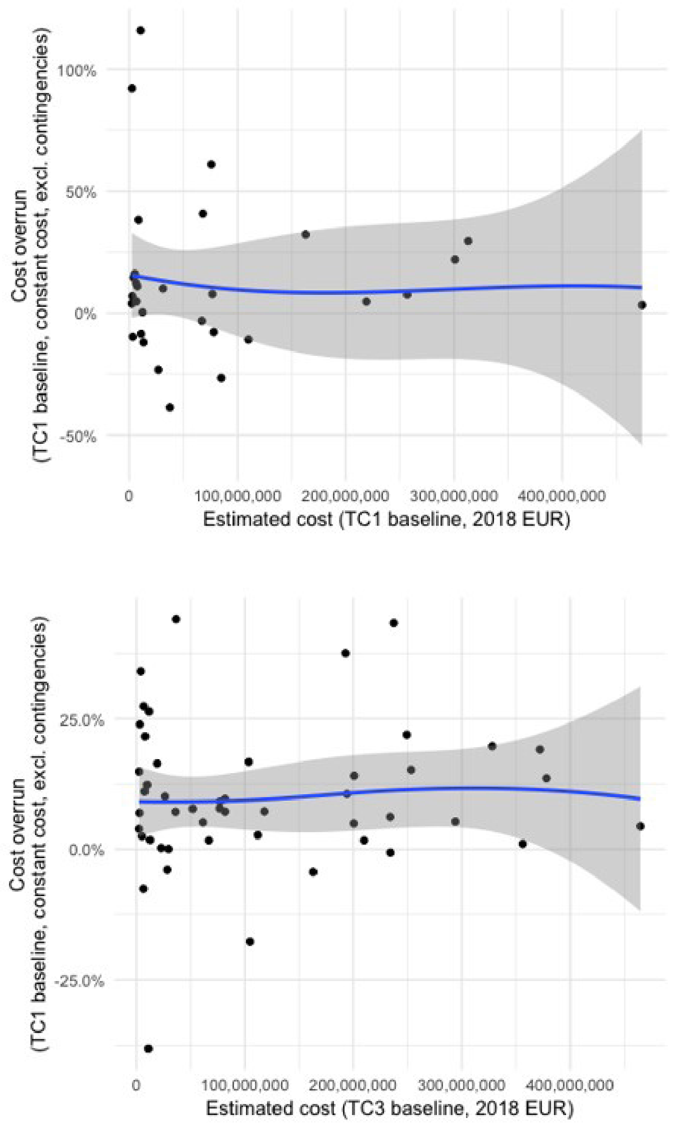
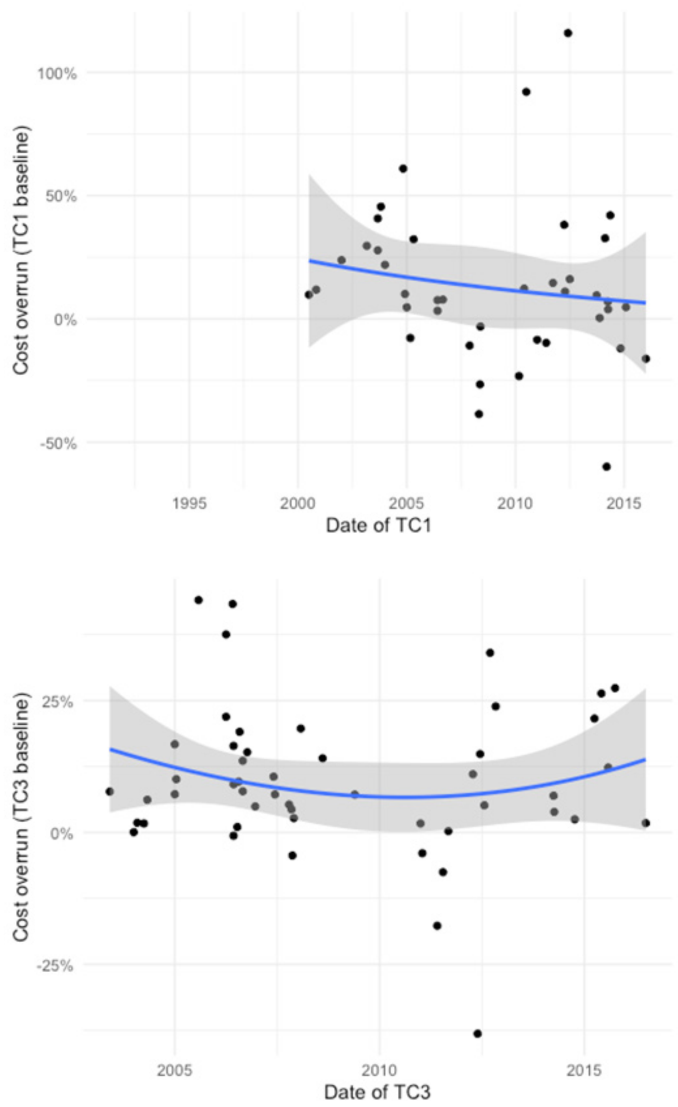


Figure 2.5 – Statistical Analysis of Estimate Date



- **Contract Form**

  The reference class of projects were delivered using a number of different conditions of contract and forms of contract as follows:

  - Public Works Contract – Employer Design
  - Public Works Contract – Contractor Design
  - FIDIC – Contractor Design
  - NEC 3 – Option C
  - Institution of Engineers of Ireland 3rd Edition (Employer Design)

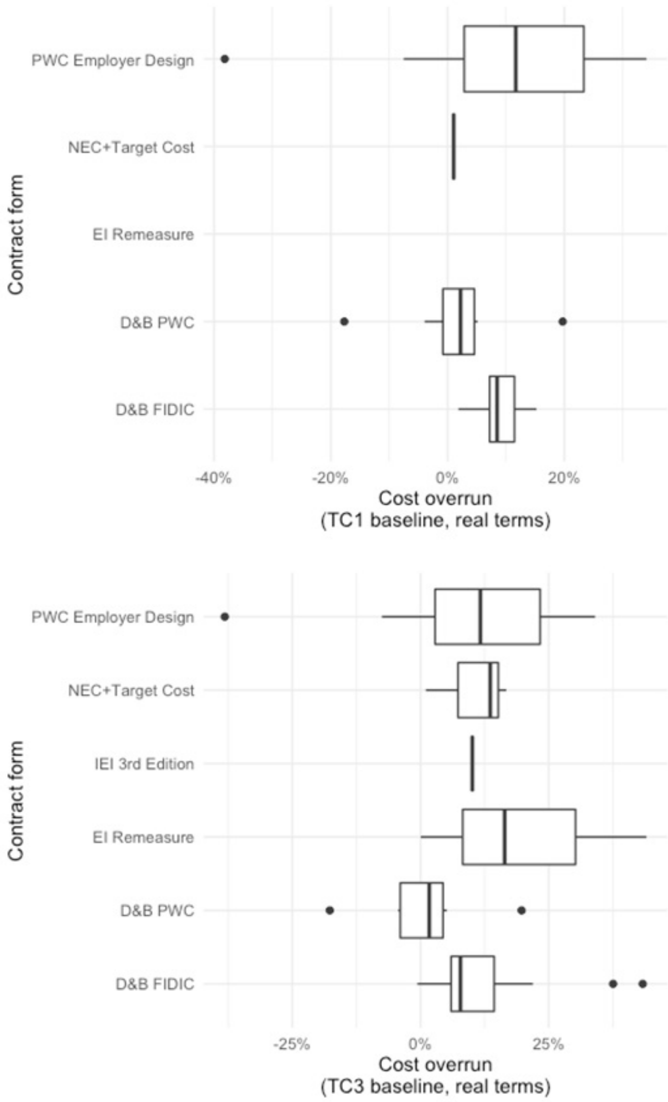
  Table 2.2 below shows how many of each contract type is contained within each reference class.

Table 2.2 – Breakdown of contract types and conditions

Contract Type	Reference Class	
	TC1	TC3
Public Works – Employer Design	19	14
Public Works – Contractor Design	8	9
FIDIC – Contractor Design	9	20
NEC 3 – Option C	1	3
IEI 3rd Edition – Employer Design	3	4

Due to the variety in contract types, an assessment was carried out to identify if the conditions or form of contract has any significant impact on the level of cost overrun experienced. Following statistical analysis on a pairwise basis, it was determined that the conditions of form of contract did not impact on the scale of cost overrun with a p-value of 0.09 or greater for the TC1 baseline and 0.08 or greater for the TC3 baseline both in excess of the 0.05 p-value cut off point for statistical significance. This is shown in Figure 2.6 below.

Figure 2.6 – Statistical Analysis of Contract Forms



Other factors considered and analysed included:

- Scheme Location – divided up between rural and non-rural
- Number of Grade Separated Junctions on the Scheme
- Total Length of Significant Bridges (i.e. greater than 100m in length) on the Scheme
- Ground Conditions
- Scheme Duration

Section 2
Development of National Roads Reference Class

In all cases, it was determined that the association between the above factors and cost overruns was not statistically significant.

As a result of the above analyses, it was clear that all of the projects in the reference class could be used (where the relevant information was available) in the preparation of the reference class curves for national roads.

Having analysed the data available, as can be seen in Appendix A, sufficient data was available to prepare robust reference classes for both the TC1 and TC3 cost forecasts. Summary details of the number and range of projects included in each reference class are shown in Table 2.3. As can be seen, both reference classes contain a broad range of different project types and sizes. As such, it is considered that the reference classes can confidently be used for all national road schemes into the future.

Table 2.3 – Details of the number and range of projects included in each reference class

	Total number of Projects	Of Which		Contains Motorway, Dual & Single Carriageway Schemes	Value Range	
		Major Projects	Minor Projects		High (€m)	Low (€m)
TC1 Reference Class	40	21	19	✓	391	2
TC3 Reference Class	50	36	14	✓	400	2

Section 3

Reference Class Forecasting for National Roads Schemes

3.1. Introduction

Section 1 of this document provides background to the general development and application of reference class forecasting for projects in general. The application of this process to national roads schemes must be considered, taking account of the existing cost forecasting processes within TII.

As noted in Section 2 earlier, extensive work was carried out in gathering data and identifying an appropriate and representative reference class for national roads schemes. This has led to the development of robust reference classes for the TC1 and TC3 cost forecasts which will be dynamic and will be added to and updated as and when further relevant project outturn cost data becomes available.

3.2. Reference Class Curves

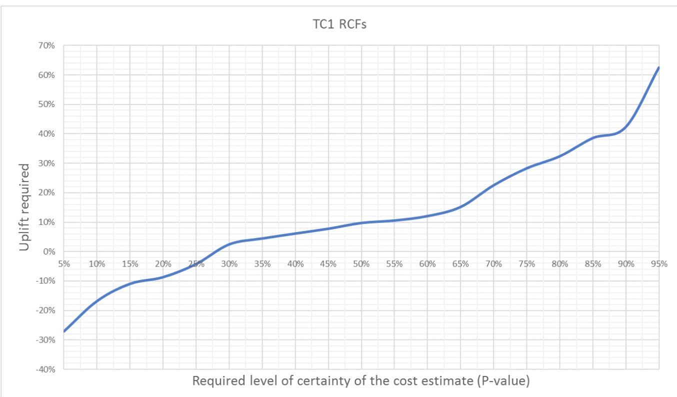
Following the development of the reference classes of projects, further probabilistic analysis (as described in Section 1.3.4 above) was carried out in order to generate useable reference class curves for each of the TC1 and TC3 cost forecasts. These are included in Appendix B and reproduced below:

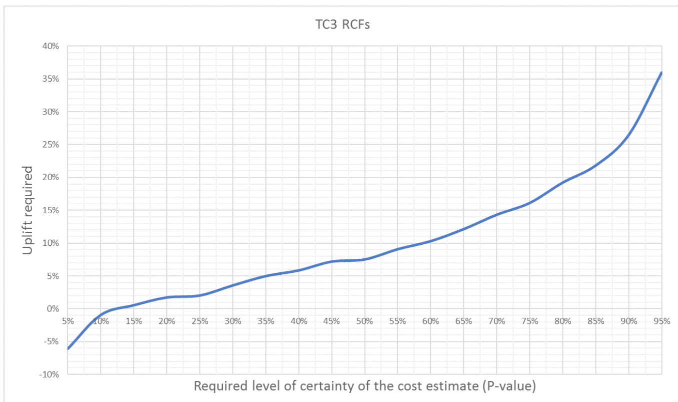
3.3. Incorporating Reference Class Forecasting into TII's Established Cost Management Processes

As noted in Section 1.3.4 above, in order to achieve the most robust cost forecasting, reference class forecasting can only be one of three processes to be applied – the others being Monte Carlo Analysis and Expert Judgement. Both of these processes form part of TII's current processes for cost forecasting and will continue to do so in conjunction with the addition of reference class forecasting. This will be elaborated upon in Section 3.4.

The TII reference classes will be dynamic and will be updated on a regular basis to incorporate data from new completed projects. This will not only ensure that the reference classes remain relevant and robust, but will also provide valuable information on the effectiveness of TII's existing risk management processes and processes for capturing and incorporating lessons learned.

Figure 3.1 – Reference Class Curves for TC1 and TC3





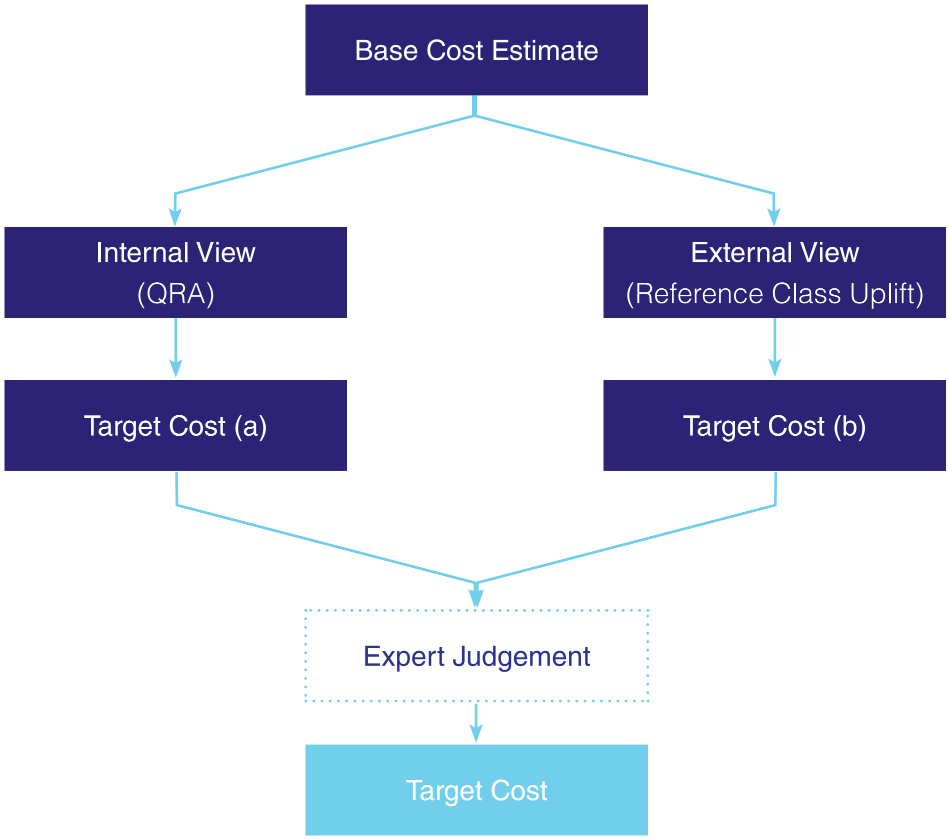
3.4. TII Process for the Use of Reference Class Forecasting

The approach to cost forecasting incorporating reference class forecasting to be used in TII is as follows:

- The uninflated base cost forecast, without contingency, is prepared by the project team in accordance with the guidance given in the TII Cost Management Manual.
- A risk workshop is held on the base cost forecast and a detailed risk register is prepared. This is submitted to TII who carry out the Monte Carlo Analysis (QRA) and identify the appropriate risk allowance for both Target Cost (usually P50) and Total Scheme Budget (usually P80).
- In parallel with this, the equivalent risk allowances are identified from the reference class curves.
- Separate uninflated Target Cost forecasts are prepared using the QRA data and the reference class data.
- The project team and TII hold a structured workshop to use expert judgement to consider both Target Cost figures and record any specific project factors that may exist that would lead to the project being either more or less risky than the reference class. Further details on this process are contained within the TII Cost Management Manual.
- The project team and TII decide, based on the above, on the appropriate Target Cost figure to be used for the project and record the reasons for this decision.
- The final budget sheet is prepared and approved.

This is shown graphically below.

Figure 3.2 – The approach to cost estimation incorporating reference class forecasting to be used in TII



In conclusion, the use of reference class forecasting within TII in conjunction with the existing processes for cost forecasting and ensuring cost effectiveness will enhance TII's overall cost forecasting procedure, thus providing more robust cost forecasts for national road schemes.

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Appendix A

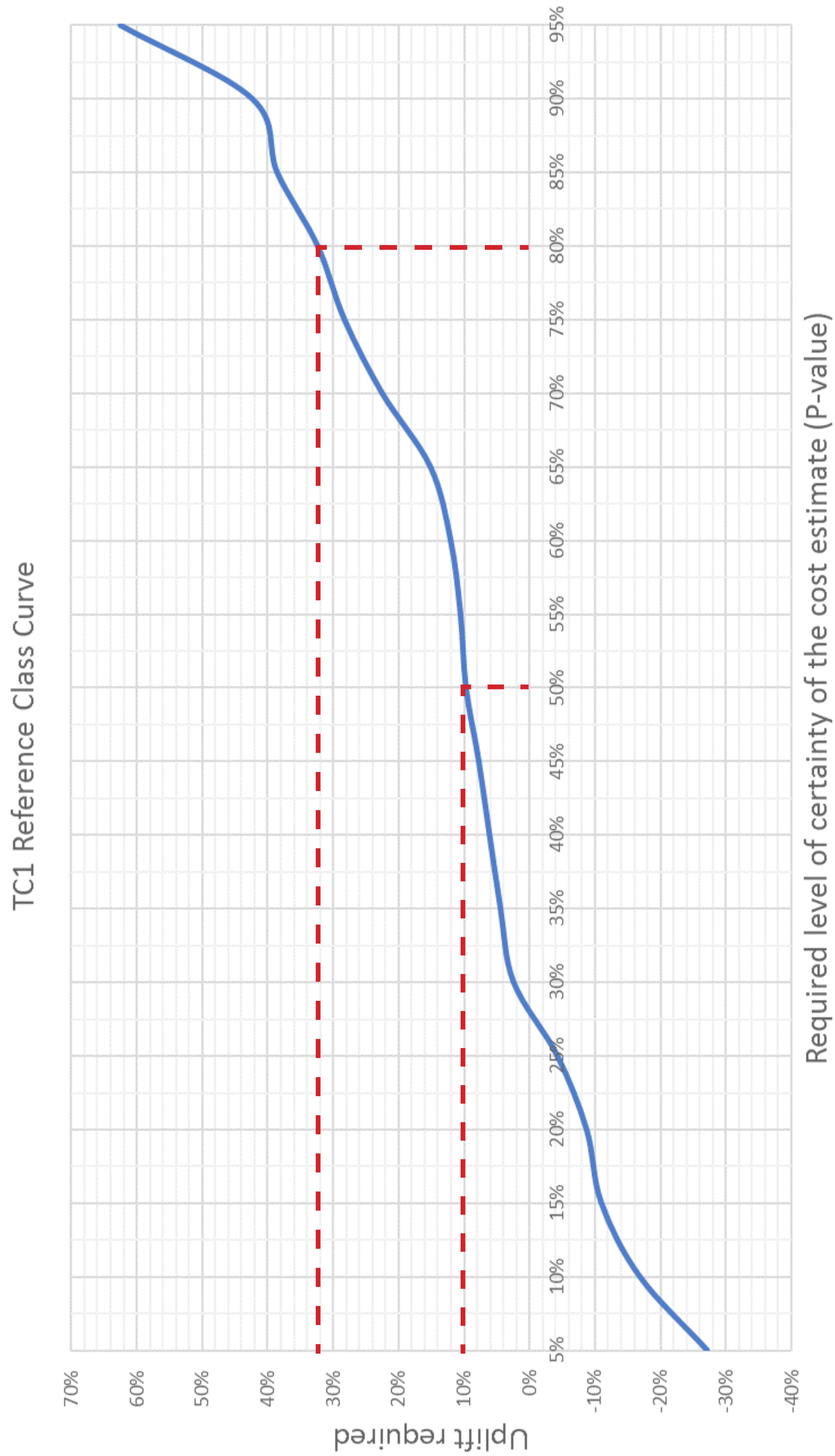
Schemes included in Reference Classes

Scheme Name	Scheme Type	Road Cross Section	Mainline Length (km)	Undiscounted Total Project Cost (€m)	TC1	TC3
M01 N.I. Border/Dundalk	Major	Motorway	10	105		✓
M02 Ashbourne By-Pass/M50 Junction	Major	Motorway	17	170	✓	✓
N02 Carrickmacross Bypass	Major	Single Carriageway	9	51		✓
N02 Castleblaney By-Pass	Major	Single Carriageway	15	100		✓
N02 Monaghan Town By-Pass	Major	Single Carriageway	3	27		✓
N03 Belturbet By-Pass	Major	Dual Carriageway	7	51	✓	✓
M04 McNeads Bridge/Kinnegad	Major	Motorway	5	27		✓
N04 Leixlip/M50 Junction	Major	Dual Carriageway	7	68	✓	✓
N04 Dromod to Roosky	Major	Dual Carriageway	11	65	✓	✓
N05 Ballaghaderreen By-Pass	Major	Single Carriageway	14	51	✓	✓
N05 Charlestown By-Pass	Major	Single Carriageway	18	82	✓	✓
N05 Longford By-Pass	Major	Single Carriageway	3	18	✓	✓
M06 Kilbeggan/Athlone	Major	Motorway	29	247		✓
M06 Kinnegad/Kilbeggan	Major	Motorway	28	217		✓
M06 Athlone/Ballinasloe	Major	Motorway	19	177	✓	✓
N06 Loughrea Bypass	Major	Single Carriageway	4	23	✓	
M07 Castletown/Nenagh	Major	Motorway	34	308	✓	✓
N07 Naas Road Widening	Major	Dual Carriageway	15	232		✓
M07 Nenagh/Limerick	Major	Motorway	38	354		✓
M08 Cullahill to Cashel	Major	Motorway	40	330	✓	✓
M08 Cashel/Mitchelstown	Major	Motorway	37	400		✓
N08 Mitchelstown Relief Road	Major	Single Carriageway	4	26	✓	
M08 Mitchelstown-Fermoy	Major	Motorway	16	119		✓
M09 Carlow By-Pass	Major	Motorway	19	212		✓
M09 Carlow to Knocktopher	Major	Motorway	40	391	✓	✓
M09 Kilcullen to Carlow	Major	Motorway	27	252		✓
M09 Waterford to Knocktopher	Major	Motorway	24	224	✓	✓
M11 Arklow/Gorey By-Pass	Major	Motorway	23	190		✓
N15 Ballyshannon/Bundoran By-Pass	Major	Single Carriageway	11	84		✓
M18 Gort - Crusheen	Major	Motorway	22	186	✓	✓
N18 Ennis By-Pass	Major	Dual Carriageway	21	200		✓
N21 Castleisland By-Pass	Major	Single Carriageway	6	32	✓	✓
N21 Castleisland/Abbeyfeale	Major	Single Carriageway	8	34	✓	
N22 Gortatlea/Farranfore	Major	Single Carriageway	4	20	✓	
N22 Tralee By-Pass	Major	Single Carriageway	14	73	✓	✓

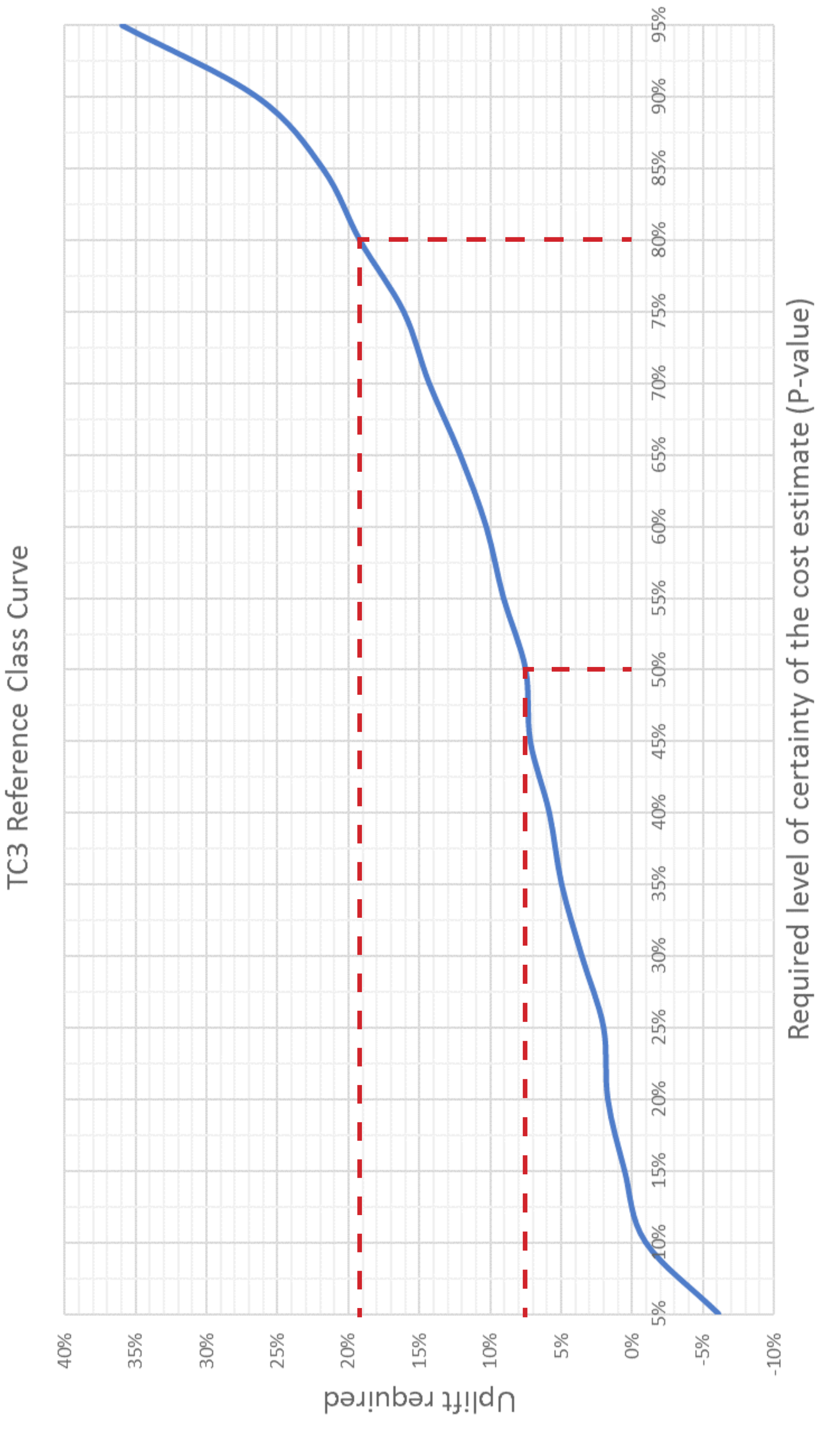
Appendix A
Schemes included in Reference Classes

Scheme Name	Scheme Type	Road Cross Section	Mainline Length (km)	Undiscounted Total Project Cost (€m)	TC1	TC3
M50 Upgrade Phase 1	Major	Motorway	8	326		✓
N52 Carrick Bridge to Clonfad	Major	Single Carriageway	15	18	✓	✓
N52 Mullingar/Belvedere	Major	Single Carriageway	4	18		✓
N52 Tullamore By-Pass	Major	Single Carriageway	14	98	✓	✓
N77 Kilkenny Ring Road	Major	Single Carriageway	4	38		✓
N02 Monaghan to Emyvale Improvement Phase 3	Minor	Single Carriageway	3	6	✓	
N02 Monaghan to Emyvale Improvement Phase 2 & 4	Minor	Single Carriageway	4	5	✓	✓
N04 Ardloy Bend Realignment	Minor	Single Carriageway	1	3	✓	✓
N15 Blackburn Bridge Realignment Scheme	Minor	Single Carriageway	2	8	✓	✓
N16 Realignment at Cornacloy Phase 1	Minor	Single Carriageway	1	4	✓	✓
N16 Realignment at Cornacloy Phase 2	Minor	Single Carriageway	1	6	✓	
N17 Carrownurlaur Realignment Scheme	Minor	Single Carriageway	2	4	✓	✓
N17 Carrownurlar to Ballindine	Minor	Single Carriageway	2	7	✓	✓
N51 Junction Ballyboy	Minor	Single Carriageway	1	2	✓	✓
N52 Cloghan to Billistown Ph 1	Minor	Single Carriageway	4	11	✓	✓
N52 Rathconnell to Macetown Realignment	Minor	Single Carriageway	2	5	✓	✓
N53 Barrownstown to Hackballs Cross	Minor	Single Carriageway	1	3	✓	
N55 Corduff to South of Killydoon - Section A	Minor	Single Carriageway	3	10	✓	
N55 Dundavan Mullaghoran Realignment Scheme	Minor	Single Carriageway	3	8	✓	✓
N61 Rathallen/Treanagry Realignment Scheme	Minor	Single Carriageway	3	9	✓	✓
N63 Abbeyknockmoy to Annagh	Minor	Single Carriageway	3	10	✓	
N76 Callan Road Realignment (Tennypark)	Minor	Single Carriageway	3	10	✓	
N77 Ballynaslee Realignment	Minor	Single Carriageway	2	5	✓	✓
N84 Luimnagh Realignment Scheme	Minor	Single Carriageway	5	11	✓	✓

Appendix B
Reference Class Curves for National Roads



Appendix B
Reference Class Curves for National Roads



Appendix C
Worked Examples

Worked Example No 1

Preparation of TC1 Cost Forecast

Step 1: Prepare Base Cost forecasts under 7 cost headings.

Cost Heading	Forecast (€m)
Main Contract Construction	13.75
Main Contract Supervision	1.32
Advance Works	0.50
Archaeology	0.80
Residual Network	0.14
Land	4.10
Planning & Design	1.82
Total	22.43

Step 2: Carry out Quantified Risk Analysis and Add Risk Amounts to Base Cost to form uninflated Target Cost (a).

Cost Heading	Forecast (€m)	QRA Risk
Main Contract Construction	13.75	1.22
Main Contract Supervision	1.32	0.02
Advance Works	0.50	0.05
Archaeology	0.80	0.08
Residual Network	0.14	0.00
Land	4.10	0.41
Planning & Design	1.82	0.10
Total	22.43	1.88

Target Cost (a) = 22.43 + 1.88 = €24.31m

Step 3: Apply appropriate Reference Class Uplift to form uninflated Target Cost (b).

TC1 Reference Class Curve – P50 uplift = 10%

Target Cost (b) = 22.43 x 1.10 = €24.67m

Step 4: Apply Expert Judgement to Target Costs (a) and (b).

In this worked example the reference class uplift is higher than the QRA risk allowance. There is no evidence that the scheme is less risky than the reference class, therefore the appropriate cost forecast is Target Cost (b).

To prepare the Total Scheme Budget in this case, use the P80 value from the TC1 Reference Class chart and apply to the base cost forecast.

Worked Example No 2

Preparation of TC3 Cost Forecast

Step 1: Prepare Base Cost forecasts under 7 cost headings.

Cost Heading	Forecast (€m)
Main Contract Construction	26.30
Main Contract Supervision	3.00
Advance Works	0.90
Archaeology	1.19
Residual Network	1.50
Land	10.21
Planning & Design	4.94
Total	48.04

Step 2: Carry out Quantified Risk Analysis and Add Risk Amounts to Base Cost to form uninflated Target Cost (a).

Cost Heading	Forecast (€m)	QRA Risk
Main Contract Construction	26.30	7.00
Main Contract Supervision	3.00	3.00
Advance Works	0.90	0.36
Archaeology	1.19	1.00
Residual Network	1.50	0.00
Land	10.21	0.10
Planning & Design	4.94	0.00
Total	48.04	11.46

Target Cost (a) = 48.04 + 11.46 = €59.50m

Step 3: Apply appropriate Reference Class Uplift to form uninflated Target Cost (b).

TC3 Reference Class Curve – P50 uplift = 7.5%

Target Cost (b) = 48.04 x 1.075 = €51.64m

Step 4: Apply Expert Judgement to Target Costs (a) and (b).

In this worked example the scheme contains two significant bridges and sections of extremely poor ground. It could be considered that this scheme is, for these reasons, more risky than the reference class and that the Target Cost (a) is the appropriate cost forecast.

To prepare the Total Scheme Budget in this case, use the P80 value from the QRA and apply to the base cost forecast.

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