From Nobel Prize to Project Management: Getting Risks Right

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ABSTRACT

A major source of risk in project management is inaccurate forecasts of project costs, demand, and other impacts. The paper presents a promising new approach to mitigating such risk based on theories of decision-making under uncertainty, which won the 2002 Nobel Prize in economics. First, the paper documents inaccuracy and risk in project management. Second, it explains inaccuracy in terms of optimism bias and strategic misrepresentation. Third, the theoretical basis is presented for a promising new method called "reference class forecasting," which achieves accuracy by basing forecasts on actual performance in a reference class of comparable projects and thereby bypassing both optimism bias and strategic misrepresentation. Fourth, the paper presents the first instance of practical reference class forecasting, which concerns cost forecasts for large transportation infrastructure projects. Finally, potentials for and barriers to reference class forecasting are assessed.

Keywords: risk management; project forecasting; forecast models

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The American Planning Association Endorses Reference Class Forecasting

In April 2005, based on a study of inaccuracy in demand forecasts for public works projects by Flyvbjerg, Holm, and Buhl (2005), the American Planning Association (APA) officially endorsed a promising new forecasting method called "reference class forecasting" and made the strong recommendation that planners should never rely solely on conventional forecasting techniques when making forecasts:

> APA encourages planners to use reference class forecasting in addition to traditional methods as a way to improve accuracy. The reference class forecasting method is beneficial for non-routine projects... Planners should never rely solely on civil engineering technology as a way to generate project forecasts (American Planning Association, 2005).

Reference class forecasting is based on theories of decision-making under uncertainty that won Princeton psychologist Daniel Kahneman the Nobel prize in economics in 2002 (Kahneman, 1994; Kahneman & Tversky, 1979a; 1979b). Reference class forecasting promises more accuracy in forecasts by taking a so-called "outside view" on prospects being forecasted, while conventional forecasting takes an inside view. The outside view on a given project is based on knowledge about actual performance in a reference class of comparable projects.

Where Flyvbjerg, Holm, and Buhl (2005) briefly outlined the idea of reference class forecasting, this paper presents the first instance of reference class forecasting in practical project management. The emphasis will be on transportation project management, because this is where the first instance of reference class forecasting occurred. It should be mentioned at the outset, however, that comparative research shows that the problems, causes, and cures identified for transportation apply to a wide range of other project types, including concert halls, museums, sports arenas, exhibit and convention centers, urban renewal, power plants, dams, water projects, IT systems, oil and gas extraction projects, aerospace projects, new production plants, and the development of new products and new markets (Altshuler & Luberoff, 2003; Flyvbjerg, 2005; Flyvbjerg, Bruzelius, & Rothengatter, 2003, pp. 18–19; Flyvbjerg, Holm, & Buhl, 2002, p. 286).

Inaccuracy in Forecasts

Forecasts of cost, demand, and other impacts of planned projects have remained constantly and remarkably inaccurate for decades. No improvement in forecasting accuracy seems to have taken place, despite all claims of improved forecasting models, better data, etc. (Flyvbjerg, Bruzelius, & Rothengatter, 2003; Flyvbjerg, Holm, & Buhl, 2002; 2005). For transportation infrastructure projects, inaccuracy in cost forecasts in constant prices is on average 44.7% for rail, 33.8% for bridges and tunnels, and 20.4% for roads (see Table 1).[1] For the 70-year period for which cost data are available, accuracy in cost forecasts has not improved. Average inaccuracy for rail passenger forecasts is –51.4%, with 84% of all rail projects being wrong by more than ±20%. For roads, average inaccuracy in traffic forecasts is 9.5%, with half of all road forecasts being wrong by more than ±20% (see Table 2). For the 30-year period for which demand data are available, accuracy in rail and road traffic forecasts has not improved.

When cost and demand forecasts are combined, for instance in the cost-benefit analyses that are typically used to justify large transportation infrastructure investments, the consequence is inaccuracy to the second degree. Benefit-cost ratios are often wrong, not only by a few percent but by several factors. This is especially the case for rail projects (Flyvbjerg, Bruzelius, & Rothengatter, 2003, pp. 37–41). As a consequence, estimates of viability are often misleading, as are socioeconomic and environmental appraisals, the accuracy of which are all heavily dependent on demand and cost forecasts. These results point to a significant problem in transportation project management: More often than not, the information that managers use to decide whether to invest in new projects is highly inaccurate and biased, making projects highly risky. Comparative studies show that transportation projects are no worse than other project types in this respect (Flyvbjerg, Bruzelius, & Rothengatter, 2003).

Explaining Inaccuracy

Flyvbjerg, Holm, and Buhl (2002; 2004; 2005) and Flyvbjerg and Cowi (2004) tested technical, psychological, and political-economic explanations for inaccuracy in forecasting. Technical explanations are common in the literature, and they explain inaccuracy in terms of unreliable or outdated data and the use of inappropriate forecasting models (Vanston & Vanston, 2004, p. 33). However, when such explanations are put to empirical test, they do not account well for the available data. First, if technical explanations were valid, one would expect the distribution of inaccuracies to be normal or near-normal with an average near zero. Actual distributions of inaccuracies are consistently and significantly non-normal with averages that are significantly different from zero. Thus the problem is bias and not inaccuracy as such. Second, if imperfect data and models were main explanations of inaccuracies, one would expect an improvement in accuracy over time, because in a professional setting errors and their sources would be recognized and addressed, for instance, through referee processes with scholarly journals and similar expert critical reviews. Undoubtedly, substantial resources have been spent over several decades on improving data and forecasting models. Nevertheless, this has had no effect on the accuracy of forecasts, as demonstrated. This indicates that something other than poor data and models is at play in generating inaccurate forecasts, a finding that has been corroborated by interviews with forecasters (Flyvbjerg & Cowi, 2004; Flyvbjerg & Lovallo, in progress; Wachs, 1990).

Psychological and political explanations better account for inaccurate forecasts. Psychological explanations account for inaccuracy 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. Political explanations, on the other hand, explain inaccuracy in terms of strategic misrepresentation. Here, when forecasting the outcomes of projects, forecasters and managers deliberately and strategically overestimate benefits and underestimate costs in order to increase the likelihood that it is their projects, and not the competition's, that gain approval and funding. Strategic misrepresentation can be traced to political and organizational pressures; for instance, competition for scarce funds or

Type of Project	Average Inaccuracy (%)	Standard Deviation	Level of Significance p
Rail	44.7	38.4	<0.001
Bridges and tunnels	33.8	62.4	0.004
Road	20.4	29.9	<0.001

Source: Flyvbjerg database on large-scale infrastructure projects.

Table 1: Inaccuracy in cost forecasts for rail, bridges, tunnels, and roads, respectively (construction costs, constant prices)

	Rail	Road
Average inaccuracy (%)	-51.4 (sd=28.1)	9.5 (sd=44.3)
Percentage of projects with inaccuracies larger than ±20%	84	50
Percentage of projects with inaccuracies larger than ±40%	72	25
Percentage of projects with inaccuracies larger than ±60%	40	13

Source: Flyvbjerg database on large-scale infrastructure projects.

Table 2: Inaccuracy in forecasts of rail passenger and road vehicle traffic

jockeying for position. Optimism bias and strategic misrepresentation both involve deception, but where the latter is intentional—i.e., lying—the first is not. Optimism bias is self-deception. Although the two types of explanation are different, the result is the same: inaccurate forecasts and inflated benefit-cost ratios. However, the cures for optimism bias are different from the cures for strategic misrepresentation, as we will see next.

Explanations of inaccuracy in terms of optimism bias have been developed by Kahneman and Tversky (1979a) and Lovallo and Kahneman (2003). Explanations in terms of strategic misrepresentation have been set forth by Wachs (1989; 1990) and Flyvbjerg, Holm, and Buhl (2002; 2005). As illustrated schematically in Figure 1, explanations in terms of optimism bias have their relative merit in situations where political and organizational pressures are absent or low, whereas such explanations hold less power in situations where political pressures are high. Conversely, explanations in terms of strategic misrepresentation have their relative merit where political and organizational pressures are high, while they become immaterial when such pressures are not present. Thus the two types of explanation complement, rather than compete with one another: one is strong where the other is weak, and both explanations are necessary to understand the phenomenon at hand—the pervasiveness of inaccuracy in forecasting—and how to curb it.

In what follows, we present a forecasting method called "reference class forecasting," which bypasses human bias—including optimism bias and strategic misrepresentation—by cutting directly to outcomes. In experimental research carried out by Daniel Kahneman and others, this method has been demonstrated to be more accurate than conventional forecasting methods (Kahneman, 1994; Kahneman & Tversky, 1979a; 1979b; Lovallo & Kahneman, 2003). First, we explain the theoretical and methodological foundations for reference class forecasting, then we present the first instance of reference class forecasting in project management.

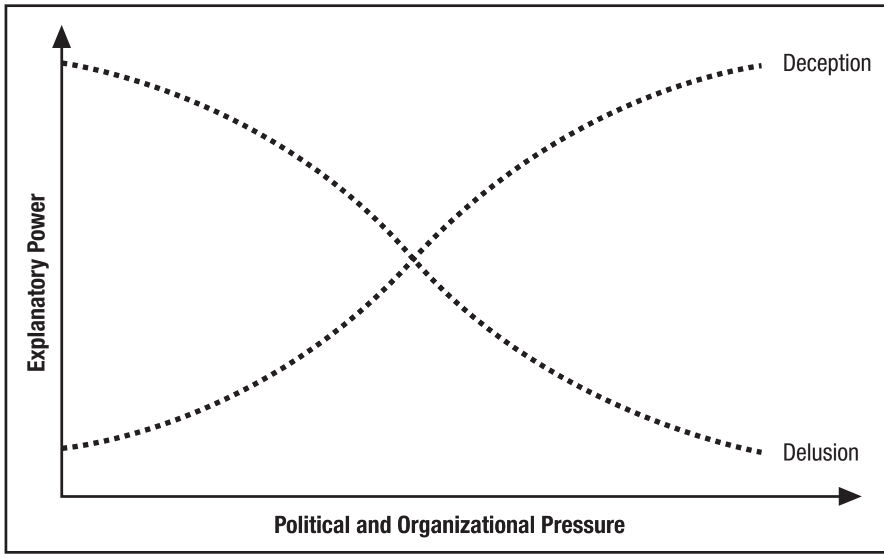


Figure 1: Explanatory power of optimism bias and strategic misrepresentation, respectively, in accounting for forecasting inaccuracy as function of political and organizational pressure

The Planning Fallacy and Reference Class Forecasting

The theoretical and methodological foundations of reference class forecasting were first described by Kahneman and Tversky (1979b) and later by Lovallo and Kahneman (2003). Reference class forecasting was originally developed to compensate for the type of cognitive bias that Kahneman and Tversky found in their work on decision-making under uncertainty, which won Kahneman the 2002 Nobel prize in economics (Kahneman, 1994; Kahneman & Tversky, 1979a). This work showed that errors of judgment are often systematic and predictable rather than random, manifesting bias rather than confusion, and that any corrective prescription should reflect this. They also found that many errors of judgment are shared by experts and laypeople alike. Finally, they found that errors remain compelling even when one is fully aware of their nature. Thus, awareness of a perceptual or cognitive illusion does not by itself produce a more accurate perception of reality, according to Kahneman and Tversky (1979b, p. 314). Awareness may, however, enable one to identify situations in which the normal faith in one's impressions must be suspended and in which judgment should be controlled by a more critical evaluation of the evidence. Reference class forecasting is a method for such critical evaluation. Human judgment, including forecasts, is biased. Reference class forecasting is a method for unbiasing forecasts.

Kahneman and Tversky (1979a; 1979b) found human judgment to be generally optimistic due to overconfidence and insufficient regard to distributional information. Thus, people will underestimate the costs, completion times, and risks of planned actions, whereas they will overestimate the benefits of the same actions. Lovallo and Kahneman (2003, p. 58) call such common behavior the "planning fallacy" and argue that it stems from actors taking an "inside view," focusing on the constituents of the specific planned action rather than on the outcomes of similar already-completed actions. Kahneman and Tversky (1979b) argued that the prevalent tendency to underweigh or ignore distributional information is perhaps the major source of error in forecasting. "The analysts should therefore make every effort to frame the forecasting problem so as to facilitate utilizing all the distributional information that is available," say Kahneman and Tversky (1979b, p. 316). This may be considered the single most important piece of advice regarding how to increase accuracy in forecasting through improved methods. Using such distributional information from other ventures similar to that being forecasted is called taking an "outside view," and it is the cure to the planning fallacy. Reference class forecasting is a method for systematically taking an outside view on planned actions.

More specifically, reference class forecasting for a particular project requires the following three steps:

1. Identification of a relevant reference class of past, similar projects. The class must be broad enough to be statistically meaningful, but narrow enough to be truly comparable with the specific project.
2. Establishing a probability distribution for the selected reference class. This requires access to credible, empirical data for a sufficient number of projects within the reference class to make statistically meaningful conclusions.
3. Comparing the specific project with the reference class distribution, in order to establish the most likely outcome for the specific project.

Thus, reference class forecasting does not try to forecast the specific uncertain events that will affect the particular project, but instead places the project in a statistical distribution of outcomes from the class of reference projects. In statisticians' vernacular, reference class forecasting consists of regressing forecasters' best guesses toward the average of the reference class and expanding their estimate of credible interval toward the corresponding interval for the class (Kahneman & Tversky, 1979b, p. 326).

Daniel Kahneman relates the following story about curriculum planning to illustrate how reference class forecasting works (Lovallo & Kahneman, 2003, p. 61). Some years ago, Kahneman was involved in a project to develop a curriculum for a new subject area for high schools in Israel. The project was carried out by a team of academics and teachers. In time, the team began to discuss how long the project would take to complete. Everyone on the team was asked to write on a slip of paper the number of months needed to finish and report the project. The estimates ranged from 18 to 30 months. One of the team members—a distinguished expert in curriculum development—was then posed a challenge by another team member to recall as many projects similar to theirs as possible, and to think of these projects as they were in a stage comparable to their project. "How long did it take them at that point to reach completion?," the expert was asked. After a while he answered, with some discomfort, that not all the comparable teams he could think of ever did complete their task. About 40% of them eventually gave up. Of those remaining, the expert could not think of any that completed their task in less than seven years, nor of any that took more than 10. The expert was then asked if he had reason to believe that the present team was more skilled in curriculum development than the earlier ones had been. The expert said no, he did not see any relevant factor that distinguished this team favorably from the teams that he had been thinking about. His impression was that the present team was slightly below average in terms of resources and potential. According to Kahneman, the wise decision at this point would probably have been for the team to break up. Instead, the members ignored the pessimistic information and proceeded with the project. They finally completed the project eight years later, and their efforts went largely wasted—the resulting curriculum was rarely used.

In this example, the curriculum expert made two forecasts for the same problem and arrived at very different answers. The first forecast was the inside view; the second was the outside view, or the reference class forecast. The inside view is the one that the expert and the other team members adopted. They made forecasts by focusing tightly on the project at hand, and considering its objective, the resources they brought to it, and the obstacles to its completion. They constructed in their minds scenarios of their coming progress and extrapolated current trends into the future. The resulting forecasts, even the most conservative ones, were overly optimistic. The outside view is the one provoked by the question to the curriculum expert. It completely ignored the details of the project at hand, and it involved no attempt at forecasting the events that would influence the project's future course. Instead, it examined the experiences of a class of similar projects, laid out a rough distribution of outcomes for this reference class, and then positioned the current project in that distribution. The resulting forecast, as it turned out, was much more accurate.

The contrast between inside and outside views has been confirmed by systematic research (Gilovich, Griffin, & Kahneman, 2002). The research shows that when people are asked simple questions requiring them to take an outside view, their forecasts become significantly more accurate. For example, a group of students enrolling at a college were asked to rate their future academic performance relative to their peers in their major. On average, these students expected to perform better than 84% of their peers, which is logically impossible. The forecasts were biased by overconfidence. Another group of incoming students from the same major were asked about their entrance scores and their peers' scores before being asked about their expected performance. This simple diversion into relevant outside-view information, which both groups of subjects were aware of, reduced the second group's average expected performance ratings by 20%. That is still overconfident, but it is much more realistic than the forecast made by the first group (Lovallo & Kahneman, 2003, p. 61).

However, most individuals and organizations are inclined to adopt the inside view in planning new projects. This is the conventional and intuitive approach. The traditional way to think about a complex project is to focus on the project itself and its details, to bring to bear what one knows about it, paying special attention to its unique or unusual features, trying to predict the events that will influence its future. The thought of going out and gathering simple statistics about related projects seldom enters a manager's mind.

This is the case in general, according to Lovallo and Kahneman (2003, pp. 61–62). And it is certainly the case for cost and demand forecasting in transportation infrastructure projects. Of the several-hundred forecasts reviewed in Flyvbjerg, Bruzelius, and Rothengatter (2003) and Flyvbjerg, Holm, and Buhl (2002; 2005), not one was a reference class forecast.[2]

Although understandable, project managers' preference for the inside view over the outside view is unfortunate. When both forecasting methods are applied with equal skill, the outside view is much more likely to produce a realistic estimate. That is because it bypasses cognitive and political biases such as optimism bias and strategic misrepresentation, and cuts directly to outcomes. In the outside view, project managers and forecasters are not required to make scenarios, imagine events, or gauge their own and others' levels of ability and control, so they cannot get all these things wrong. Human bias is bypassed. Surely the outside view, being based on historical precedent, may fail to predict extreme outcomes; that is, those that lie outside all historical precedents. But for most projects, the outside view will produce more accurate results. In contrast, a focus on inside details is the road to inaccuracy.

The comparative advantage of the outside view is most pronounced for non-routine projects, understood as projects that managers and decision-makers in a certain locale or organization have never attempted before—like building new plants or infrastructure, or catering to new types of demand. It is in the planning of such new efforts that the biases toward optimism and strategic misrepresentation are likely to be largest. To be sure, choosing the right reference class of comparative past projects becomes more difficult when managers are forecasting initiatives for which precedents are not easily found; for instance, the introduction of new and unfamiliar technologies. However, most projects are both non-routine locally and use well-known technologies. Such projects are, therefore, particularly likely to benefit from the outside view and reference class forecasting.

First Instance of Reference Class Forecasting in Practice

The first instance of reference class forecasting in practice may be found in Flyvbjerg and Cowi (2004): "Procedures for Dealing with Optimism Bias in Transport Planning."[3] Based on this study in the summer of 2004, the U.K. Department for Transport and HM Treasury decided to employ the method as part of project appraisal for large transportation projects.

The immediate background to this decision was the revision to *The Green Book* by HM Treasury in 2003 that identified for large public procurement a demonstrated, systematic tendency for project appraisers to be overly optimistic:

"There is a demonstrated, systematic tendency for project appraisers to be overly optimistic. To redress this tendency, appraisers should make explicit, empirically based adjustments to the estimates of a project's costs, benefits, and duration … [I]t is recommended that these adjustments be based on data from past projects or similar projects elsewhere" (HM Treasury, 2003b, p. 1).

Such optimism was seen as an impediment to prudent fiscal planning, for the government as a whole and for individual departments within government. To redress this tendency, HM Treasury recommended that appraisers involved in large public procurement should make explicit, empirically based adjustments to the estimates of a project's costs, benefits, and duration. HM Treasury recommended that these adjustments be based on data from past projects or similar projects elsewhere, and adjusted for the unique characteristics of the project at hand. In the absence of a more specific evidence base, HM Treasury encouraged government departments to collect valid and reliable data to inform future estimates of optimism, and in the meantime to use the best available data. The Treasury let it be understood that in the future the allocation of funds for large public procurement would be dependent on valid adjustments of optimism in order to secure valid estimates of costs, benefits, and duration of large public procurement (HM Treasury, 2003a; 2003b).

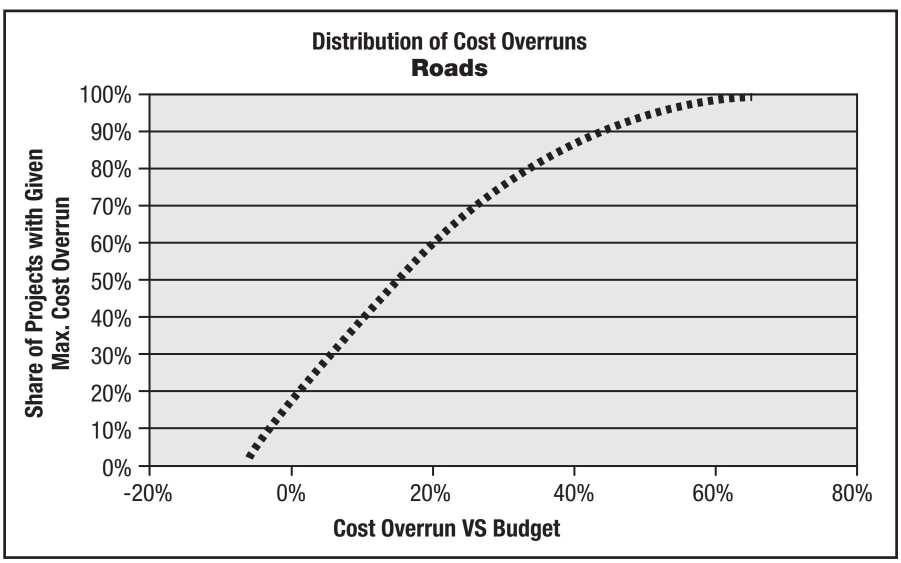
In response to the Treasury's Green Book and its recommendations, the U.K. Department for Transport decided to collect the type of data which the Treasury recommended, and on that basis to develop a methodology for dealing with optimism bias in the planning and management of transportation projects. The Department for Transport appointed Bent Flyvbjerg in association with Cowi to undertake this assignment as regards costing of large transportation procurement. The main aims of the assignment were two; first, to provide empirically based optimism bias uplifts for selected reference classes of transportation infrastructure projects, and, second, to provide guidance on using the established uplifts to produce more realistic forecasts of capital expenditures in individual projects (Flyvbjerg & Cowi, 2004). Uplifts would be established for capital expenditures based on the full business case (time of decision to build).

The types of transportation schemes under the direct and indirect responsibility of the U.K. Department for Transport were divided into a number of distinct categories in which statistical tests, benchmarkings, and other analyses showed that the risk of cost overruns within each category may be treated as statistically similar. For each category, a reference class of projects was then established as the basis for reference class forecasting, as required by step 1 in the three-step procedure for reference class forecasting previously described. The specific categories and the types of project allocated to each category are shown in Table 3.

For each category of projects, a reference class of completed, comparable transportation infrastructure projects was used to establish probability distributions for cost overruns for new projects similar in scope and risks to the projects in the reference class, as required by step 2 in reference class forecasting. For roads, for example, a class of 172 completed and comparable projects was used to establish the

Category	Types of Projects
Roads	Motorway Trunk roads Local roads Bicycle facilities Pedestrian facilities Park and ride Bus lane schemes Guided buses on wheels
Rail	Metro Light rail Guided buses on tracks Conventional rail High speed rail
Fixed links	Bridges Tunnels
Building projects	Stations Terminal buildings
IT projects	IT system development
Standard civil engineering	Included for reference purposes only
Non-standard civil engineering	Included for reference purposes only

Table 3: Categories and types of projects used as basis for reference class forecasting



Source: Flyvbjerg database on large-scale infrastructure projects.

Figure 2: Probability distribution of cost overrun for roads, constant prices (N=172)

probability distribution of cost overruns shown in Figure 2. The share of projects with a given maximum cost overrun is shown in the figure. For instance, 40% of projects have a maximum cost overrun of 10%; 80% of projects a maximum overrun of 32%, etc. For rail, the probability distribution is shown in Figure 3, and for bridges and tunnels in Figure 4. The figures show that the risk of cost overrun is substantial for all three project types, but highest for rail, followed by bridges and tunnels, and with the lowest risk for roads.

Based on the probability distributions described, the required uplifts needed to carry out step 3 in a reference class forecast may be calculated as shown in Figures 5–7. The uplifts refer to cost overrun calculated in constant prices. The lower the acceptable risk for cost overrun, the higher the uplift. For instance, with a willingness to accept a 50% risk for cost overrun in a road project, the required uplift for this project would be 15%. If the Department for Transport were willing to accept only a 10% risk for cost overrun, then the required uplift would be 45%. In comparison, for rail, with a willingness to accept a 50% risk for cost overrun, the required uplift would be 40%. If the Department for Transport were willing to accept only a 10% risk for cost overrun, then the required uplift would be 68% for rail. All three figures share the same basic S-shape, but at different levels, demonstrating that the required uplifts are significantly different for different project categories for a given level of risk of cost overrun. The figures also show that the cost for additional reductions in the risk of cost overrun is different for the three types of projects, with risk reduction becoming increasingly expensive (rising marginal costs) for roads and fixed links below 20% risk, whereas for rail the cost of increased risk reduction rises more slowly, albeit from a high level.

Table 4 presents an overview of applicable optimism bias uplifts for the 50% and 80% percentiles for all the project categories listed in Table 3. The 50% percentile is pertinent to the investor with a large project portfolio, where cost overruns on one project may be offset by cost savings on another. The 80% percentile—corresponding to a risk of cost overrun of 20%—is the level of risk that the U.K. Department for Transport is typically willing to accept for large investments in local transportation infrastructure.

The established uplifts for optimism bias should be applied to estimated budgets at the time of decision to build a project. In the U.K., the approval stage for a large transportation project is equivalent to the time of presenting the business case for the project to the Department for Transport with a view to obtaining the go or no-go for that project.

If, for instance, a group of project managers were preparing the business case for a new motorway, and if they or

Category	Types of Projects	Applicable Optimism Bias Uplifts	
		50% percentile	80% percentile
Roads	Motorway Trunk roads Local roads Bicycle facilities Pedestrian facilities Park and ride Bus lane schemes Guided buses on wheels	15%	32%
Rail	Metro Light rail Guided buses on tracks Conventional rail High speed rail	40%	57%
Fixed links	Bridges Tunnels	23%	55%
Building projects	Stations Terminal buildings	4-51%*	
IT projects	IT system development	10-200%*	
Standard civil engineering	Included for reference purposes only	3-44%*	
Non-standard civil engineering	Included for reference purposes only	6-66%*	

*Based on Mott MacDonald (2002, p. 32) no probability distribution available.

Table 4: Applicable capital expenditure optimism bia uplifts for 50% and 80% percentiles, constant prices

their client had decided that the risk of cost overrun must be less than 20%, then they would use an uplift of 32% on their estimated capital expenditure budget. Thus, if the initially estimated budget were £100 million, then the final budget—taking into account optimism bias at the 80%-level—would be £132 million (£1 = $1.8). If the project managers or their client decided instead that a 50% risk of cost overrun was acceptable, then the uplift would be 15% and the final budget £115 million.

Similarly, if a group of project managers were preparing the business case for a metro rail project, and if they or their client had decided that with 80% certainty they wanted to stay within budget, then they would use an uplift on capital costs of 57%. An initial capital expenditure budget of £300 million would then become a final budget of £504 million. If the project managers or their client required only 50% certainty they would stay within budget, then the final budget would be £420 million.

It follows that the 50% percentile should be used only in instances where investors are willing to take a high degree of risk that cost overrun will occur and/or in situations where investors are funding a large number of projects, and where cost savings (underruns) on one project may be used to cover the costs of overruns on other projects. The upper percentiles (80–90%) should be used when investors want a high degree of certainty that cost overrun will not occur; for instance, in stand-alone projects with no access to additional funds beyond the approved budget. Other percentiles may be employed to reflect other degrees of willingness to accept risk and the associated uplifts as shown in Figures 5–7.

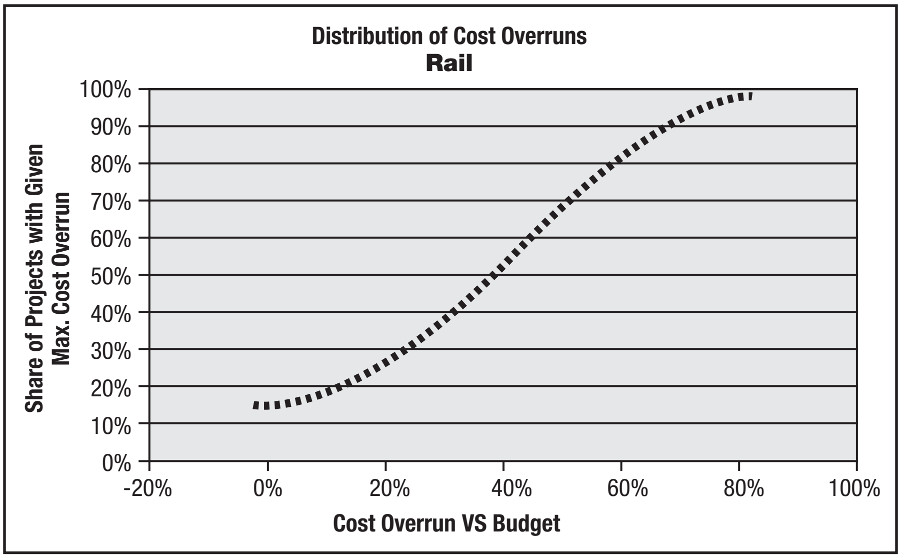
Only if project managers have evidence to substantiate that they would be significantly better at estimating costs for the project at hand than their colleagues were for the projects in the reference class would the managers be justified in using lower uplifts than those previously described. Conversely, if there is evidence that the project managers are worse at estimating costs than their colleagues, then higher uplifts should be used.

The methodology previously described for systematic, practical reference class forecasting for transportation projects was developed in 2003–2004, with publication by the Department of Transport in August 2004. From this date on, local authorities applying for funding for transportation projects with the Department for Transport or with HM Treasury were required to take into account optimism bias by using uplifts as previously described and as laid out in more detail in guidelines from the two ministries.

Forecasting Costs for the Edinburgh Tram

In October 2004, the first instance of practical use of the uplifts was recorded, in the planning of the Edinburgh Tram Line 2. Ove Arup and Partners Scotland (2004) had been appointed by the Scottish Parliament's Edinburgh Tram Bill Committee to provide a review of the Edinburgh Tram Line 2 business case developed on behalf of Transport Initiatives Edinburgh. Transport Initiatives Edinburgh is the project promoter and is a private limited company owned by the City of Edinburgh Council established to deliver major transport projects for the Council. The Scottish Executive is a main funder of the Edinburgh Tram, having made an Executive Grant of £375 million (US$670 million) toward lines 1 and 2, of which Transport Initiatives Edinburgh proposed spending £165 million toward Line 2.

As part of their review, Ove Arup assessed whether the business case for Tram Line 2 had adequately taken into account optimism bias as regards capital costs. The business case had estimated a base cost of £255 million and an additional allowance for contingency and optimism bias of £64 million—or 25%—resulting in total



Source: Flyvbjerg database on large-scale infrastructure projects.

Figure 3: Probability distribution of cost overrun for rail, constant prices (N=46)

capital costs of approximately £320 million. Ove Arup concluded about this overall estimate of capital costs that it seemed to have been rigorously prepared using a database of costs, comparison to other U.K. light rail schemes, and reconciliations with earlier project estimates. Ove Arup found, however, that the following potential additional costs needed to be considered in determining the overall capital costs: £26 million for future expenditure on replacement and renewals and £20 million as a notional allowance for a capital sum to cover risks of future revenue shortfalls, amounting to an increase in total capital costs of 14.4% (Ove Arup and Partners Scotland, 2004, pp. 15–16).

Using the U.K. Department for Transport uplifts for optimism bias previously presented on the base costs, Ove Arup then calculated the 80th percentile value for total capital costs—the value at which the likelihood of staying within budget is 80%—to be £400 million (i.e., £255 million x 1.57). The 50th percentile for total capital costs—the value at which the likelihood of staying within budget is 50%—was £357 million (i.e., £255 million x 1.4). Ove Arup remarked that these estimates of total capital costs were likely to be conservative—that is, low—because the U.K. Department for Transport recommends that its optimism bias uplifts be applied to the budget at the time of decision to build, which typically equates to business case submission. (In addition, Tram Line 2 had not yet even reached the outline business case stage, indicating that risks would be substantially higher at this early stage, as would corresponding uplifts. On that basis, Arup concluded that "it is considered that current optimism bias uplifts [for Tram Line 2] may have been underestimated" [Ove Arup & Partners Scotland, 2004, p. 27].)

Finally, Ove Arup mentioned that the Department for Transport guidance does allow for optimism bias to be adjusted downward if strong evidence of improved risk mitigation can be demonstrated. According to Ove Arup, this may be the case if advanced risk analysis has been applied, but this was not the case for Tram Line 2. Ove Arup therefore concluded that "the justification for reduced Department for Transport optimism bias uplifts would appear to be weak" (Ove Arup & Partners Scotland, 2004, pp. 27–28). Thus, the overall conclusion of Ove Arup was that the promoter's capital cost estimate of approximately £320 million was optimistic. Most likely Tram Line 2 would cost significantly more.

By framing the forecasting problem to allow the use of the empirical distributional information made available by the U.K. Department for Transport, Ove Arup was able to take an outside view on the Edinburgh Tram Line 2 capital cost forecast and thus unbias what appeared to be a biased forecast. As a result, Ove Arup's client, The Scottish Parliament, was provided with a more reliable estimate of what the true costs of Line 2 was likely to be.

Potentials and Barriers for Reference Class Forecasting

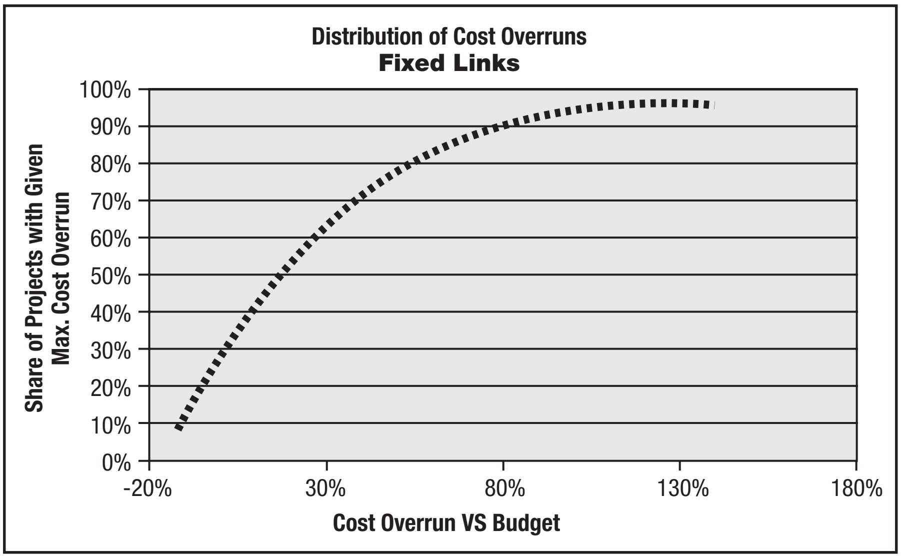
As previously mentioned, two types of explanation best account for forecasting inaccuracy: optimism bias and strategic misrepresentation. Reference class forecasting was originally developed to mitigate optimism bias, but reference class forecasting may help mitigate any type of human bias, including strategic bias, because the method bypasses such bias by cutting directly to empirical outcomes and building forecasts on these. Even so, the potentials for and barriers to reference class forecasting will be different in situations in which (1) optimism bias is the main cause of inaccuracy as compared to situations in which (2) strategic misrepresentation is the reason for inaccuracy. We therefore need to distinguish between these two types of situations when endeavoring to apply reference class forecasting in practice.

In the first type of situation—in which optimism bias is the main cause of inaccuracy—we may assume that managers and forecasters are making honest mistakes and have an interest in improving accuracy. Consider, for example, the students who were asked to estimate their future academic performance relative to their peers. We may reasonably believe that the students did not deliberately misrepresent their estimates, because they had no interest in doing so and were not exposed to pressures that would push them in that direction. The students made honest mistakes, which produced honest, if biased, numbers regarding performance. And, indeed, when students were asked to take into account outside-view information, we saw that the accuracy of their estimates improved substantially. In this type of situation—when forecasters are honestly trying to gauge the future—the potential for using the outside view and reference class forecasting will be good. Forecasters will be welcoming the method and barriers will be low, because no one has reason to be against a methodology that will improve their forecasts.

In the second type of situation—in which strategic misrepresentation is the main cause of inaccuracy—differences between estimated and actual costs and benefits are best explained by political and organizational pressures. Here, managers and forecasters would still need reference class forecasting if accuracy were to be improved, but managers and forecasters may not be interested in this because inaccuracy is deliberate. Biased forecasts serve strategic purposes that dominate the commitment to accuracy and truth. Consider, for example, city managers with responsibility for estimating costs and benefits of urban rail projects. Here, the assumption of innocence regarding outcomes typically cannot be upheld. Cities compete fiercely for approval and for scarce national funds for such projects, and pressures are strong to present projects as favorably as possible; that is, with low costs and high benefits, in order to beat the competition. There is no incentive for the individual city to unbias its forecasts, but quite the opposite. Unless all other cities also unbias, the individual city would lose out in the competition for funds. Project managers are on record confirming that this is a common situation (Flyvbjerg & Cowi, 2004, pp. 36–58; Flyvbjerg & Lovallo, in progress). The result is the same as in the case of optimism: actors promote ventures that are unlikely to perform as promised. But the causes are different, as are possible cures.

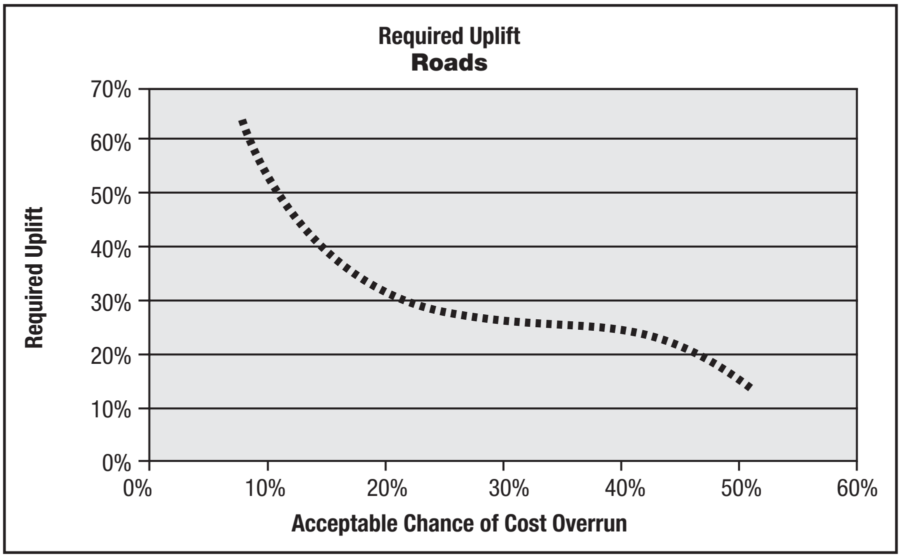
In this type of situation, the potential for reference class forecasting is low—the demand for accuracy is simply not there—and barriers are high. In order to lower barriers, and thus create room for reference class forecasting, measures of accountability must be implemented that would reward accurate forecasts and punish inaccurate ones. Forecasters and promoters should be made to carry the full risks of their forecasts. Their work should be reviewed by independent bodies such as national auditors or independent analysts, and such bodies would need reference class forecasting to do their work. Projects with inflated benefit-cost ratios should be stopped or placed on hold. Professional and even criminal penalties should be considered for people who consistently produce misleading forecasts. The higher the stakes, and the higher the level of political and organizational pressures, the more pronounced will be the need for such measures of accountability. Flyvbjerg, Bruzelius, and Rothengatter (2003) and Flyvbjerg, Holm, and Buhl (2005) further detailed the design of such measures and how they may be implemented in practical project management.

The existence of strategic misrepresentation does not exclude the simultaneous existence of optimism bias, and vice versa. In fact, it is realistic to



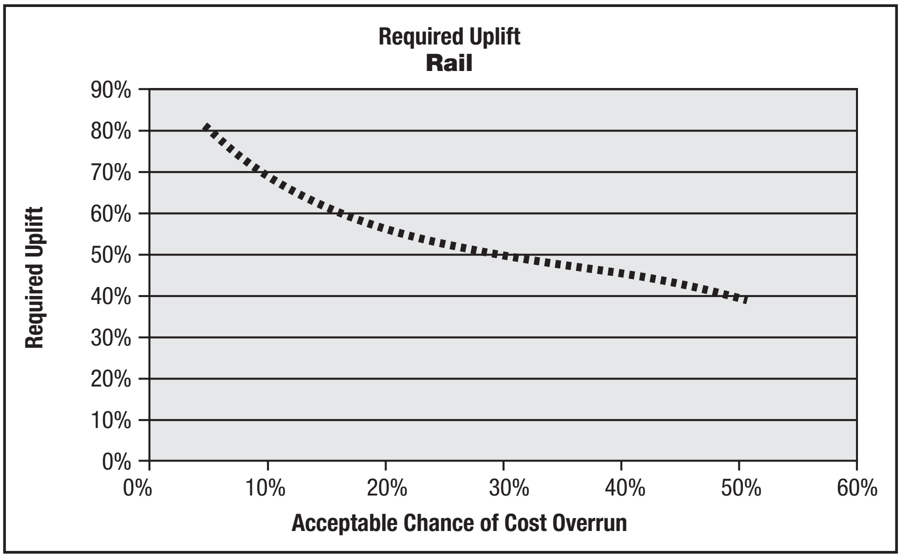
Source: Flyvbjerg database on large-scale infrastructure projects.

Figure 4: Probability distribution of cost overrun for fixed links, constant prices (N=34)



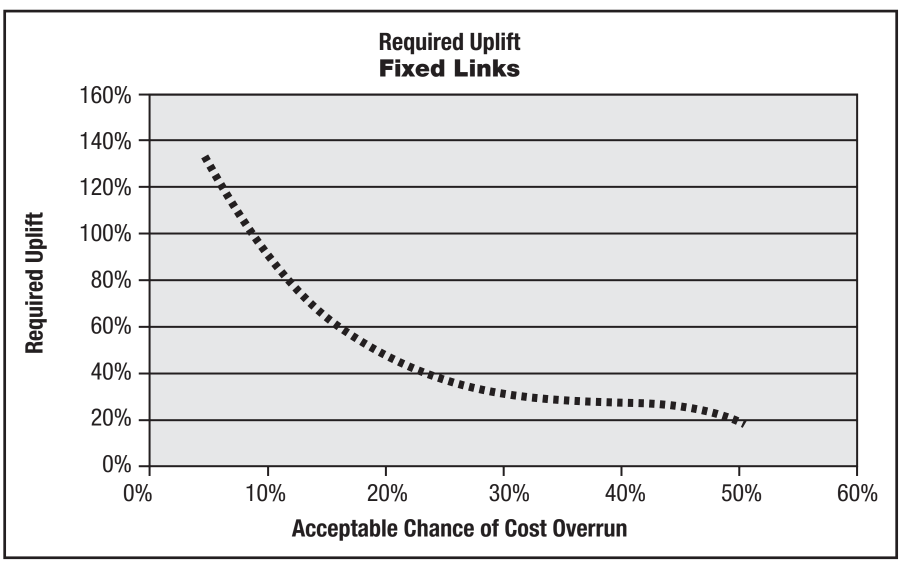
Source: Flyvbjerg database on large-scale infrastructure projects.

Figure 5: Required uplift for roads as function of the maximum acceptable level of risk for cost overrun, constant prices (N=172)



Source: Flyvbjerg database on large-scale infrastructure projects.

Figure 6: Required uplift for rail as function of the maximum acceptable level of risk for cost overrun, constant prices (N=46)



Source: Flyvbjerg database on large-scale infrastructure projects.

Figure 7: Required uplift for fixed links as function of the maximum acceptable level of risk for cost overrun, constant prices (N=34)

expect such co-existence in forecasting in large and complex projects and organizations. This again underscores the point that improved forecasting methods—here, reference class forecasting—and measures of accountability must go hand in hand if the attempt to arrive at more accurate forecasts is to be effective.

Finally, it could be argued that in some cases the use of reference class forecasting may result in such large reserves set aside for a project that this would in itself lead to risks of inefficiencies and overspending. Reserves will be spent simply because they are there, as the saying goes in the construction business. For instance, it is important to recognize that, for the previously mentioned examples, the introduction of reference class forecasting and optimism-bias uplifts would establish total budget reservations (including uplifts) which for some projects would be more than adequate. This may in itself create an incentive which works against firm cost control if the total budget reservation is perceived as being available to the project and its contractors. This makes it important to combine the introduction of reference class forecasting and optimism bias uplifts with tight contracts, and maintained incentives for promoters to undertake good quantified risk assessment and exercise prudent cost control during project implementation. How this may be done is described in Flyvbjerg and Cowi (2004).

Notes

[1] Inaccuracy is measured in percent as (actual outcome/forecast outcome -1) x 100. The base year of a forecast for a project is the time of decision to build that project. An inaccuracy of 0 indicates perfect accuracy. Cost is measured as construction costs. Demand is measured as number of vehicles for roads and number of passengers for rail.

[2] The closest thing to an outside view in large infrastructure forecasting is Gordon and Wilson's (1984) use of regression analysis on an international cross section of light-rail projects to forecast patronage in a number of light-rail schemes in North America.

[3] The fact that this is, indeed, the first instance of practical reference class forecasting has been confirmed with Daniel Kahneman and Dan Lovallo, who also knows of no other instances of practical reference class forecasting. Personal communications with Daniel Kahneman and Dan Lovallo, author's archives.

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PREFACE

Welcome to Version 3.2 of the *PMI Lexicon of Project Management Terms*. The *Lexicon* was first published in 2012, and was heralded as PMI's newest tool for project, program, and portfolio managers, providing access to approximately 150 clear and concise definitions for frequently used terms. In the years since its introduction, it has grown to include 200+ definitions and PMI standard development committees are chartered to use the *PMI Lexicon* definitions without modification.

The *PMI Lexicon of Project Management Terms* contains foundational terms used within professional project, program, and portfolio management. This tool should be used by lexicographers and standards teams as a reference source and not as a glossary of every possible project, program, or portfolio management related term that would normally be defined in the glossary of a typical PMI global standard.

Since January 2016, the Lexicon committee has been chartered to maintain the *Lexicon*, address change requests from the public, and work with standard development committees to ensure that glossaries and definitions within the content of the standards are aligned with the PMI *Lexicon* and with one another. Members of the 2017 Lexicon Committee are:

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Etienne Cornu, PhD, PMP, PMI-RMP (Committee Vice Chair)

Dianne E. Allen, PMP, M. Eng., P. Eng.

Debra A. Hunter, PMP

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Acceptance Criteria. A set of conditions that are met before deliverables are accepted. See also *deliverable* and *requirement.*

Activity. A distinct, scheduled portion of work performed during the course of a project.

Activity Code. An alphanumeric value assigned to each activity that enables classifying, sorting, and filtering. See also *activity identifier* and *activity label.*

Activity Identifier. A unique alphanumeric value assigned to an activity and used to differentiate that activity from other activities. See also *activity code* and *activity label.*

Activity Label. A phrase that names and describes an activity. See also *activity code* and *activity identifier.*

Actual Cost (AC). The realized cost incurred for the work performed on an activity during a specific time period. See also *budget at completion (BAC), earned value (EV), estimate at completion (EAC), estimate to complete (ETC),* and *planned value (PV).*

Analogous Estimating. A technique for estimating the duration or cost of an activity or a project using historical data from a similar activity or project. See also *bottom-up estimating, parametric estimating, program evaluation and review technique (PERT),* and *three-point estimating.*

Apportioned Effort. An activity where effort is allotted proportionately across certain discrete efforts and not divisible into discrete efforts. [Note: Apportioned effort is one of three earned value management (EVM) types of activities used to measure work performance]. See also *discrete effort* and *level of effort.*

Assumption. A factor in the planning process considered to be true, real, or certain, without proof or demonstration.

Backward Pass. A critical path method technique for calculating the late start and late finish dates by working backward through the schedule model from the project end date. See also *forward pass.*

Baseline. The approved version of a work product that can be changed using formal change control procedures and is used as the basis for comparison to actual results. See also *cost baseline, performance measurement baseline, schedule baseline,* and *scope baseline.*

Bottom-Up Estimating. A method of estimating project duration or cost by aggregating the estimates of the lower-level components of the work breakdown structure (WBS). See also *analogous estimating, parametric estimating, program evaluation and review technique (PERT),* and *three-point estimating.*

Budget at Completion (BAC). The sum of all budgets established for the work to be performed. See also *actual cost (AC), earned value (EV), estimate at completion (EAC), estimate to complete (ETC),* and *planned value (PV).*

Change Control. A process whereby modifications to documents, deliverables, or baselines associated with the project are identified, documented, approved, or rejected. See also *change control board* and *change control system.*

Change Control Board. A formally chartered group responsible for reviewing, evaluating, approving, delaying, or rejecting changes to the project, and for recording and communicating such decisions. See also *change control* and *change control system.*

Change Control System. A set of procedures that describes how modifications to the project deliverables and documentation are managed and controlled. See also *change control* and *change control board.*

Change Request. A formal proposal to modify a document, deliverable, or baseline.

Code of Accounts. A numbering system used to uniquely identify each component of the work breakdown structure.

Communications Management Plan. A component of the project, program, or portfolio management plan that describes how, when, and by whom information will be administered and disseminated. See also *project management plan.*

Configuration Management System. A collection of procedures used to track project artifacts and monitor and control changes to these artifacts.

Constraint. A factor that limits the options for managing a project, program, portfolio, or process.

Contingency Plan. A document describing actions that the project team can take if predetermined trigger conditions occur.

Contingency Reserve. Time or money allocated in the schedule or cost baseline for known risks with active response strategies. See also *management reserve* and *project budget.*

Control Account. A management control point where scope, budget, actual cost, and schedule are integrated and compared to earned value for performance measurement.

Corrective Action. An intentional activity that realigns the performance of the project work with the project management plan. See also *preventive action.*

Cost Baseline. The approved version of work package cost estimates and contingency reserve that can be changed using formal change control procedures and is used as the basis for comparison to actual results. See also *baseline, performance measurement baseline, schedule baseline,* and *scope baseline.*

Cost Management Plan. A component of a project or program management plan that describes how costs will be planned, structured, and controlled. See also *project management plan.*

Cost Performance Index (CPI). A measure of the cost efficiency of budgeted resources expressed as the ratio of earned value to actual cost. See also *schedule performance index (SPI).*

Cost Variance (CV). The amount of budget deficit or surplus at a given point in time, expressed as the difference between the earned value and the actual cost. See also *schedule variance (SV).*

Crashing. A schedule compression technique used to shorten the schedule duration for the least incremental cost by adding resources. See also *fast tracking* and *schedule compression.*

Critical Chain Method. A schedule method that allows the project team to place buffers on any project schedule path to account for limited resources and project uncertainties.

Critical Path. The sequence of activities that represents the longest path through a project, which determines the shortest possible duration. See also *critical path activity* and *critical path method.*

Critical Path Activity. Any activity on the critical path in a project schedule. See also *critical path* and *critical path method.*

Critical Path Method. A method used to estimate the minimum project duration and determine the amount of scheduling flexibility on the logical network paths within the schedule model**.** See also *critical path* and *critical path activity.*

Data Date. A point in time when the status of the project is recorded.

Decision Tree Analysis. A diagramming and calculation technique for evaluating the implications of a chain of multiple options in the presence of uncertainty.

Decomposition. A technique used for dividing and subdividing the project scope and project deliverables into smaller, more manageable parts.

Defect Repair. An intentional activity to modify a nonconforming product or product component.

Deliverable. Any unique and verifiable product, result, or capability to perform a service that is produced to complete a process, phase, or project.

Discrete Effort. An activity that can be planned and measured and that yields a specific output. [Note: Discrete effort is one of three earned value management (EVM) types of activities used to measure work performance.] See also *apportioned effort* and *level of effort.*

Duration. The total number of work periods required to complete an activity or work breakdown structure component, expressed in hours, days, or weeks. See also *effort.*

Early Finish Date. In the critical path method, the earliest possible point in time when the uncompleted portions of a schedule activity can finish based on the schedule network logic, the data date, and any schedule constraints. See also *early start date, late start date, late finish date,* and *schedule network analysis.*

Early Start Date. In the critical path method, the earliest possible point in time when the uncompleted portions of a schedule activity can start based on the schedule network logic, the data date, and any schedule constraints. See also *early finish date, late finish date, late start date,* and *schedule network analysis.*

Earned Value (EV). The measure of work performed expressed in terms of the budget authorized for that work. See also *actual cost (AC), budget at completion, estimate at completion (EAC), estimate to complete (ETC),* and *planned value (PV).*

Earned Value Management. A methodology that combines scope, schedule, and resource measurements to assess project performance and progress.

Effort. The number of labor units required to complete a schedule activity or work breakdown structure component, often expressed in hours, days, or weeks. See also *duration.*

Enterprise Environmental Factors. Conditions, not under the immediate control of the team, that influence, constrain, or direct the project, program, or portfolio.

Estimate at Completion (EAC). The expected total cost of completing all work expressed as the sum of the actual cost to date and the estimate to complete. See also *actual cost (AC), budget at completion (BAC), earned value (EV), estimate to complete (ETC)* and *planned value (PV).*

Estimate to Complete (ETC). The expected cost to finish all the remaining project work. See also *actual cost (AC), budget at completion (BAC), earned value (EV), estimate at completion (EAC),* and *planned value (PV).*

Fast Tracking. A schedule compression technique in which activities or phases normally done in sequence are performed in parallel for at least a portion of their duration. See also *crashing* and *schedule compression.*

Finish-to-Finish. A logical relationship in which a successor activity cannot finish until a predecessor activity has finished. See also *finish-to-start, start-to-finish, start-to-start,* and *logical relationship.*

Finish-to-Start. A logical relationship in which a successor activity cannot start until a predecessor activity has finished. See also *finish-to-finish, start-to-finish, start-to-start,* and *logical relationship.*

Fixed Formula Method. A method of estimating earned value in which a specified percentage of the budget value of a work package is assigned to the start milestone and the remaining percentage is assigned when the work package is complete. See also *weighted milestone method.*

Forward Pass. A critical path method technique for calculating the early start and early finish dates by working forward through the schedule model from the project start date or a given point in time. See also *backward pass.*

Free Float. The amount of time that a schedule activity can be delayed without delaying the early start date of any successor or violating a schedule constraint. See also *total float, critical path, near-critical activity,* and *near-critical path.*

Functional Organization. An organizational structure in which staff is grouped by areas of specialization and the project manager has limited authority to assign work and apply resources. See also *matrix organization* and *projectized organization.*

Gantt Chart. A bar chart of schedule information where activities are listed on the vertical axis, dates are shown on the horizontal axis, and activity durations are shown as horizontal bars placed according to start and finish dates.

Lag. The amount of time whereby a successor activity will be delayed with respect to a predecessor activity. See also *lead.*

Late Finish Date. In the critical path method, the latest possible point in time when the uncompleted portions of a schedule activity can finish based on the schedule network logic, the project completion date, and any schedule constraints. See also *early finish date, early start date, late start date,* and *schedule network analysis.*

Late Start Date. In the critical path method, the latest possible point in time when the uncompleted portions of a schedule activity can start based on the schedule network logic, the project completion date, and any schedule constraints. See also *early finish date, late finish date, early start date,* and *schedule network analysis.*

Lead. The amount of time whereby a successor activity can be advanced with respect to a predecessor activity. See also *lag.*

Lessons Learned. The knowledge gained during a project which shows how project events were addressed or should be addressed in the future for the purpose of improving future performance.

Level of Effort. An activity that does not produce definitive end products and is measured by the passage of time. [Note: Level of effort is one of three earned value management (EVM) types of activities used to measure work performance.] See also *apportioned effort* and *discrete effort.*

Logical Relationship. A dependency between two activities or between an activity and a milestone. See also *finish-to-finish, finish-to-start, start-to-finish,* and *start-to-start.*

Management Reserve. Time or money that management sets aside in addition to the schedule or cost baseline and releases for unforeseen work that is within the scope of the project. See also *contingency reserve* and *project budget.*

Matrix Organization. An organizational structure in which the project manager shares authority with the functional manager temporarily to assign work and apply resources. See also *functional organization* and *projectized organization.*

Milestone. A significant point or event in a project, program, or portfolio.

Milestone Schedule. A type of schedule that presents milestones with planned dates.

Most Likely Duration. An estimate of the most probable activity duration that takes into account all of the known variables that could affect performance. See also *optimistic duration,* and *pessimistic duration.*

Near-Critical Activity. An activity with a total float that is deemed to be low based on expert judgment. See also *critical path, free float, near-critical path,* and *total float.*

Near-Critical Path. A sequence of activities with low float which, if exhausted, becomes a critical path sequence for the project. See also *critical path, free float, near-critical activity,* and *total float.*

Network Logic. All activity dependencies in a project schedule network diagram. See also *early finish date, early start date, late finish date, late start date,* and *network path.*

Network Path. A sequence of activities connected by logical relationships in a project schedule network diagram. See also *early finish date, early start date, late finish date, late start date,* and *network logic.*

Node. A point at which dependency lines connect on a schedule network diagram. See also *precedence diagramming method (PDM)* and *project schedule network diagram.*

Opportunity. A risk that would have a positive effect on one or more project objectives. See also *issue, risk,* and *threat.*

Optimistic Duration. An estimate of the shortest activity duration that takes into account all of the known variables that could affect performance. See also *most likely duration* and *pessimistic duration.*

Organizational Breakdown Structure. A hierarchical representation of the project organization, which illustrates the relationship between project activities and the organizational units that will perform those activities. See also *resource breakdown structure, risk breakdown structure,* and *work breakdown structure (WBS).*

Organizational Enabler. A structural, cultural, technological, or human-resource practice that the performing organization can use to achieve strategic objectives. See also *organizational project management.*

Organizational Process Assets. Plans, processes, policies, procedures, and knowledge bases specific to and used by the performing organization.

Organizational Project Management. A framework in which portfolio, program, and project management are integrated with organizational enablers in order to achieve strategic objectives. See also *organizational enabler.*

Organizational Project Management Maturity. The level of an organization's ability to deliver the desired strategic outcomes in a predictable, controllable, and reliable manner.

Parametric Estimating. An estimating technique in which an algorithm is used to calculate cost or duration based on historical data and project parameters. See also *analogous estimating, bottom-up estimating, program evaluation and review technique (PERT),* and *three-point estimating.*

Path Convergence. A relationship in which a schedule activity has more than one predecessor. See also *path divergence, predecessor activity,* and *successor activity.*

Path Divergence. A relationship in which a schedule activity has more than one successor. See also *path convergence, predecessor activity,* and *successor activity.*

Percent Complete. An estimate expressed as a percent of the amount of work that has been completed on an activity or a work breakdown structure component.

Performance Measurement Baseline. Integrated scope, schedule, and cost baselines used for comparison to manage, measure, and control project execution. See also *baseline, cost baseline, schedule baseline,* and *scope baseline.*

Performing Organization. An enterprise whose personnel are the most directly involved in doing the work of the project or program.

Pessimistic Duration. An estimate of the longest activity duration that takes into account all of the known variables that could affect performance. See also *most likely duration,* and *optimistic duration.*

Phase Gate. A review at the end of a phase in which a decision is made to continue to the next phase, to continue with modification, or to end a project or program. See also *project phase.*

Planned Value (PV). The authorized budget assigned to scheduled work. See also *actual cost (AC), budget at completion (BAC), earned value (EV), estimate at completion (EAC),* and *estimate to complete (ETC).*

Portfolio. Projects, programs, subsidiary portfolios, and operations managed as a group to achieve strategic objectives. See also *program* and *project.*

Portfolio Balancing. The process of optimizing the mix of portfolio components to further the strategic objectives of the organization.

Portfolio Charter. A document issued by a sponsor that authorizes and specifies the portfolio structure and links the portfolio to the organization's strategic objectives. See also *program charter* and *project charter.*

Portfolio Management. The centralized management of one or more portfolios to achieve strategic objectives. See also *program management* and *project management.*

Portfolio Management Plan. A document that specifies how a portfolio will be organized, monitored, and controlled. See also *program management plan* and *project management plan.*

Portfolio Manager. The person or group assigned by the performing organization to establish, balance, monitor, and control portfolio components in order to achieve strategic business objectives. See also *program manager* and *project manager.*

Precedence Diagramming Method. A technique used for constructing a schedule model in which activities are represented by nodes and are graphically linked by one or more logical relationships to show the sequence in which the activities are to be performed. See also *node* and *project schedule network diagram.*

Predecessor Activity. An activity that logically comes before a dependent activity in a schedule. See also *successor activity* and *summary activity.*

Preventive Action. An intentional activity that ensures the future performance of the project work is aligned with the project management plan. See also *corrective action.*

Probability and Impact Matrix. A grid for mapping the probability of occurrence of each risk and its impact on project objectives if that risk occurs. See also *risk.*

Procurement Management Plan. A component of the project or program management plan that describes how a team will acquire goods and services from outside of the performing organization. See also *project management plan.*

Product Life Cycle. The series of phases that represent the evolution of a product, from concept through delivery, growth, maturity, and to retirement. See also *project life cycle.*

Program. Related projects, subsidiary programs, and program activities managed in a coordinated manner to obtain benefits not available from managing them individually.

Related projects, subsidiary programs, and program activities managed in a coordinated manner to obtain benefits not available from managing them individually.

Program Charter. A document issued by a sponsor that authorizes the program management team to use organizational resources to execute the program and links the program to the organization's strategic objectives. See also *portfolio charter* and *project charter.*

Program Evaluation and Review Technique (PERT). A technique used to estimate project duration through a weighted average of optimistic, pessimistic, and most likely activity durations when there is uncertainty with the individual activity estimates. See also *analogous estimating, bottom-up estimating, parametric estimating,* and *three-point estimating.*

Program Management. The application of knowledge, skills, and principles to a program to achieve the program objectives and to obtain benefits and control not available by managing program components individually. See also *portfolio management* and *project management.*

Program Management Office. A management structure that standardizes the program-related governance processes and facilitates the sharing of resources, methodologies, tools, and techniques. See also *project management office.*

Program Management Plan. A document that integrates the program's subsidiary plans and establishes the management controls and overall plan for integrating and managing the program's individual components. See also *portfolio management plan* and *project management plan.*

Program Manager. The person authorized by the performing organization to lead the team or teams responsible for achieving program objectives. See also *portfolio manager* and *project manager.*

Progressive Elaboration. The iterative process of increasing the level of detail in a project management plan as greater amounts of information and more accurate estimates become available.

Project. A temporary endeavor undertaken to create a unique product, service, or result. See also *portfolio* and *program.*

Project Budget. The sum of work package cost estimates, contingency reserve, and management reserve. See also *contingency reserve* and *management reserve.*

Project Calendar A calendar that identifies working days and shifts that are available for scheduled activities.

Project Charter. A document issued by the project initiator or sponsor that formally authorizes the existence of a project and provides the project manager with the authority to apply organizational resources to project activities. See also *portfolio charter* and *program charter.*

Projectized Organization. An organizational structure in which the project manager has full authority to assign work and apply resources. See also *functional organization* and *matrix organization.*

Project Life Cycle. The series of phases that a project passes through from its start to its completion. See also *product life cycle.*

Project Management. The application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. See also *portfolio management* and *program management.*

Project Management Office. A management structure that standardizes the project-related governance processes and facilitates the sharing of resources, methodologies, tools, and techniques. See also *program management office.*

Project Management Plan. The document that describes how the project will be executed, monitored and controlled, and closed. See also *portfolio management plan, program management plan, communications management plan, cost management plan, resource management plan, procurement management plan, quality management plan, requirements management plan, risk management plan, schedule management plan, scope management plan, staffing management plan,* and *stakeholder engagement plan.*

Project Manager. The person assigned by the performing organization to lead the team that is responsible for achieving the project objectives. See also *portfolio manager* and *program manager.*

Project Phase. A collection of logically related project activities that culminates in the completion of one or more deliverables. See also *phase gate.*

Project Schedule. An output of a schedule model that presents linked activities with planned dates, durations, milestones, and resources.

Project Schedule Network Diagram. A graphical representation of the logical relationships among the project schedule activities. See also *node* and *precedence diagramming method (PDM).*

Project Scope. The work performed to deliver a product, service, or result with the specified features and functions.

Project Scope Statement. The description of the project scope, major deliverables, assumptions, and constraints.

Quality Management Plan. A component of the project or program management plan that describes how an organization's policies, procedures, and guidelines will be implemented to achieve the quality objectives. See also *project management plan.*

Requirements Management Plan. A component of the project or program management plan that describes how requirements will be analyzed, documented, and managed. See also *project management plan.*

Requirements Traceability Matrix. A grid that links product requirements from their origin to the deliverables that satisfy them.

Residual Risk. The risk that remains after risk responses have been implemented. See also *secondary risk.*

Resource Breakdown Structure. A hierarchical representation of resources by category and type. See also *organizational breakdown structure, risk breakdown structure,* and *work breakdown structure (WBS).*

Resource Calendar. A calendar that identifies the working days and shifts upon which each specific resource is available.

Resource Leveling. A resource optimization technique in which adjustments are made to the project schedule to optimize the allocation of resources and which may affect critical path. See also *resource smoothing* and *resource optimization technique.*

Resource Management Plan. A component of the project management plan that describes how project resources are acquired, allocated, monitored, and controlled. See also *project management plan* and *staffing management plan.*

Resource Optimization Technique. A technique in which activity start and finish dates are adjusted to balance demand for resources with the available supply. See also *resource leveling* and *resource smoothing.*

Resource Smoothing. A resource optimization technique in which free and total float are used without affecting the critical path. See also *resource leveling* and *resource optimization technique.*

Responsibility Assignment Matrix. A grid that shows the project resources assigned to each work package.

Risk. An uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives. See also *issue, opportunity,* and *threat.*

Risk Acceptance. A risk response strategy whereby the project team decides to acknowledge the risk and not take any action unless the risk occurs. See also *risk avoidance, risk enhancement, risk exploiting, risk mitigation, risk sharing,* and *risk transference*.

Risk Appetite. The degree of uncertainty an organization or individual is willing to accept in anticipation of a reward. See also *risk threshold* and *risk tolerance.*

Risk Avoidance. A risk response strategy whereby the project team acts to eliminate the threat or protect the project from its impact. See also *risk acceptance, risk enhancement, risk exploiting, risk mitigation, risk sharing,* and *risk transference*.

Risk Breakdown Structure. A hierarchical representation of potential sources of risk. See also *organizational breakdown structure, resource breakdown structure,* and *work breakdown structure (WBS).*

Risk Category. A group of potential causes of risk.

Risk Enhancement. A risk response strategy whereby the project team acts to increase the probability of occurrence or impact of an opportunity. See also *risk acceptance, risk avoidance, risk exploiting, risk mitigation, risk sharing,* and *risk transference.*

Risk Exploiting. A risk response strategy whereby the project team acts to ensure that an opportunity occurs. See also *risk acceptance, risk avoidance, risk enhancement, risk mitigation, risk sharing,* and *risk transference.*

Risk Exposure. An aggregate measure of the potential impact of all risks at any given point in time in a project, program, or portfolio.

Risk Management Plan. A component of the project, program, or portfolio management plan that describes how risk management activities will be structured and performed. See also *project management plan.*

Risk Mitigation. A risk response strategy whereby the project team acts to decrease the probability of occurrence or impact of a threat. See also *risk acceptance, risk avoidance, risk enhancement, risk exploiting, risk sharing,* and *risk transference.*

Risk Owner. The person responsible for monitoring the risk and for selecting and implementing an appropriate risk response strategy.

Risk Register. A repository in which outputs of risk management processes are recorded.

Risk Sharing. A risk response strategy whereby the project team allocates ownership of an opportunity to a third party who is best able to capture the benefit of that opportunity. See also *risk acceptance, risk avoidance, risk enhancement, risk exploiting, risk mitigation,* and *risk transference*.

Risk Threshold. The measure of acceptable variation around an objective that reflects the risk appetite of the organization and stakeholders. See also *risk appetite* and *risk tolerance.*

Risk Tolerance. [deprecated] The degree of uncertainty that an organization or individual is willing to withstand. See also *risk appetite* and *risk threshold.*

Risk Transference. A risk response strategy whereby the project team shifts the impact of a threat to a third party, together with ownership of the response. See also *risk acceptance, risk avoidance, risk enhancement, risk exploiting, risk mitigation,* and *risk sharing.*

Rolling Wave Planning. An iterative planning technique in which the work to be accomplished in the near term is planned in detail, while the work in the future is planned at a higher level.

Schedule Baseline. The approved version of a schedule model that can be changed using formal change control procedures and is used as the basis for comparison to actual results. See also *baseline, cost baseline, performance measurement baseline,* and *scope baseline.*

Schedule Compression. A technique used to shorten the schedule duration without reducing the project scope. See also *crashing* and *fast tracking.*

Schedule Management Plan. A component of the project or program management plan that establishes the criteria and the activities for developing, monitoring, and controlling the schedule. See also *project management plan.*

Schedule Model. A representation of the plan for executing the project's activities, including durations, dependencies, and other planning information, used to produce a project schedule along with other scheduling artifacts. See also *schedule model analysis.*

Schedule Model Analysis. A process used to investigate or analyze the output of the schedule model in order to optimize the schedule. See also *schedule model.*

Schedule Network Analysis. A technique to identify early and late start dates, as well as early and late finish dates, for the uncompleted portions of project activities. See also *early finish date, early start date, late finish date,* and *late start date.*

Schedule Performance Index (SPI). A measure of schedule efficiency expressed as the ratio of earned value to planned value. See also *cost performance index (CPI).*

Schedule Variance (SV). A measure of schedule performance expressed as the difference between the earned value and the planned value. See also *cost variance (CV).*

Scope Baseline. The approved version of a scope statement, work breakdown structure (WBS), and its associated WBS dictionary that can be changed using formal change control procedures and is used as the basis for comparison to actual results. See also *baseline, cost baseline, performance measurement baseline,* and *schedule baseline.*

Scope Creep. The uncontrolled expansion to product or project scope without adjustments to time, cost, and resources.

Scope Management Plan. A component of the project or program management plan that describes how the scope will be defined, developed, monitored, controlled, and validated. See also *project management plan.*

S-Curve Analysis. A technique used to indicate performance trends by using a graph that displays cumulative costs over a specific time period.

Secondary Risk. A risk that arises as a direct result of implementing a risk response. See also *residual risk.*

Sponsor. An individual or a group that provides resources and support for the project, program, or portfolio, and is accountable for enabling success. See also *stakeholder.*

Staffing Management Plan. A component of the resource management plan that describes when and how team members will be acquired and how long they will be needed. See also *resource management plan.*

Stakeholder. An individual, group, or organization that may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project, program, or portfolio. See also *sponsor.*

Stakeholder Engagement Plan. A component of the project or program management plan that identifies the strategies and actions required to promote productive involvement of stakeholders in project or program decision making and execution. See also *project management plan.*

Start-to-Finish. A logical relationship in which a successor activity cannot finish until a predecessor activity has started. See also *finish-to-finish, finish-to-start, start-to-start,* and *logical relationship.*

Start-to-Start. A logical relationship in which a successor activity cannot start until a predecessor activity has started. See also *finish-to-finish, finish-to-start, start-to-finish,* and *logical relationship.*

Successor Activity. A dependent activity that logically comes after another activity in a schedule. See also *predecessor activity* and *summary activity.*

Summary Activity. A group of related schedule activities aggregated and displayed as a single activity. See also *predecessor activity* and *successor activity.*

Threat. A risk that would have a negative effect on one or more project objectives. See also *issue, opportunity,* and *risk.*

Three-Point Estimating. A technique used to estimate cost or duration by applying an average or weighted average of optimistic, pessimistic, and most likely estimates when there is uncertainty with the individual activity estimates. See also *analogous estimating, bottom-up estimating, parametric estimating,* and *program evaluation and review technique (PERT).*

To-Complete Performance Index (TCPI). A measure of the cost performance that is achieved with the remaining resources in order to meet a specified management goal, expressed as the ratio of the cost to finish the outstanding work to the remaining budget. See also *actual cost (AC), budget at completion (BAC), earned value (EV),* and *estimate at completion (EAC).*

Total Float. The amount of time that a schedule activity can be delayed or extended from its early start date without delaying the project finish date or violating a schedule constraint. See also *free float, critical path, near-critical activity,* and *near-critical path.*

Trigger Condition. An event or situation that indicates that a risk is about to occur.

Variance Analysis. A technique for determining the cause and degree of difference between the baseline and actual performance. See also *cost variance (CV), schedule variance (SV),* and *variance at completion.*

Variance at Completion (VAC). A projection of the amount of budget deficit or surplus, expressed as the difference between the budget at completion and the estimate at completion. See also *budget at completion (BAC), cost variance (CV), estimate at completion (EAC),* and *variance analysis.*

WBS Dictionary. A document that provides detailed deliverable, activity, and scheduling information about each component in the work breakdown structure. See also *work breakdown structure (WBS).*

Weighted Milestone Method. A method of estimating earned value in which the budget value of a work package is divided into measurable segments, each ending with a milestone that is assigned a weighted budget value. See also *fixed formula method.*

What-If Scenario Analysis. The process of evaluating scenarios in order to predict their effect on project objectives.

Workaround. An immediate and temporary response to an issue for which a prior response had not been planned or was not effective. See also *risk mitigation.*

Work Breakdown Structure (WBS). A hierarchical decomposition of the total scope of work to be carried out by the project team to accomplish the project objectives and create the required deliverables**.** See also *organizational breakdown structure, resource breakdown structure, risk breakdown structure,* and *WBS dictionary.*

Work Package. The work defined at the lowest level of the work breakdown structure for which cost and duration are estimated and managed.