

# Government Finance Review

GOVERNMENT FINANCE OFFICERS ASSOCIATION

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FISCAL SUSTAINABILITY  
The Long View



PROBABILITY MANAGEMENT  
in Financial Planning

BY SAM L. SAVAGE AND SHAYNE KAVANAGH

*“Give me a number,” says the city manager anxiously. “I need to know when the new hotel complex will be shovel ready!” The director of planning, who has just explained that the amount of time needed to obtain each of the required permits is unpredictable, asks, “Would you settle for an average?” “If that’s all you can give me,” she responds. “The developers need to know when to schedule construction.” “Well,” says the planner, “there are ten permits being processed in parallel, and I estimate that each one will take six weeks on average, so that’s my best guess — six weeks.”*

This example exhibits three key concepts about uncertainty that are important to public financial managers:

1. Uncertainties are endemic to planning for the future, whether long term or short term. Public finance activities — estimating project schedules, forecasting tax revenues, and planning reserves to cover natural disasters — are rife with uncertainties.
2. Most people, including city managers, are uncomfortable with uncertainty and prefer to picture the future in terms of average outcomes.
3. This leads to the “flaw of averages,” a set of systematic errors that arises when uncertainties are represented by single numbers, and it explains why so many projects are behind schedule, beyond budget, and below projection.<sup>1</sup> In short, the flaw of averages states that plans based on average assumptions are, on average, wrong.

Exhibit 1 illustrates how the city manager and planner have just run afoul of this ubiquitous problem. The left-hand chart shows all the permits coming in at their average of six weeks. That looks good, right? However, the project can’t start until all of the permits have been obtained. The right-hand chart shows that even if some permits come in at less than six weeks, it only takes one late permit to delay construction. All ten permits are about as likely to come in at six weeks or less as a flipped coin is likely to come up heads ten times in a row,

which means that the estimate the planner provided has only one chance in a thousand of being achieved.

If any permit comes in later than six weeks, construction will be delayed. In the figure on the right, the model, which generates 1,000 sets of “time to issue” scenarios, displays the values that appear on the 77th scenario, which results in a start time of 8.8 weeks.

The discipline of probability management uses proven computer simulation techniques, which have only recently become available to a much wider audience, to eliminate errors caused by using averages (see the “Probability Management” sidebar).<sup>2</sup> This article outlines three simple example problems that apply probability management. The models used are all available for download from the “Models” page at ProbabilityManagement.org. You can download them and try out probability management techniques for yourself while reading this article.

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## 1 THE PROJECT PLANNING PROBLEM

The model is about to inform our city manager and planner that a flaw of averages in scheduling often leads to a flaw of averages in finances. Suppose the developer of the hotel complex has negotiated a deal requiring the city to forgive future tax revenues at the rate of \$100,000 per week for any delay in construction beyond seven weeks.

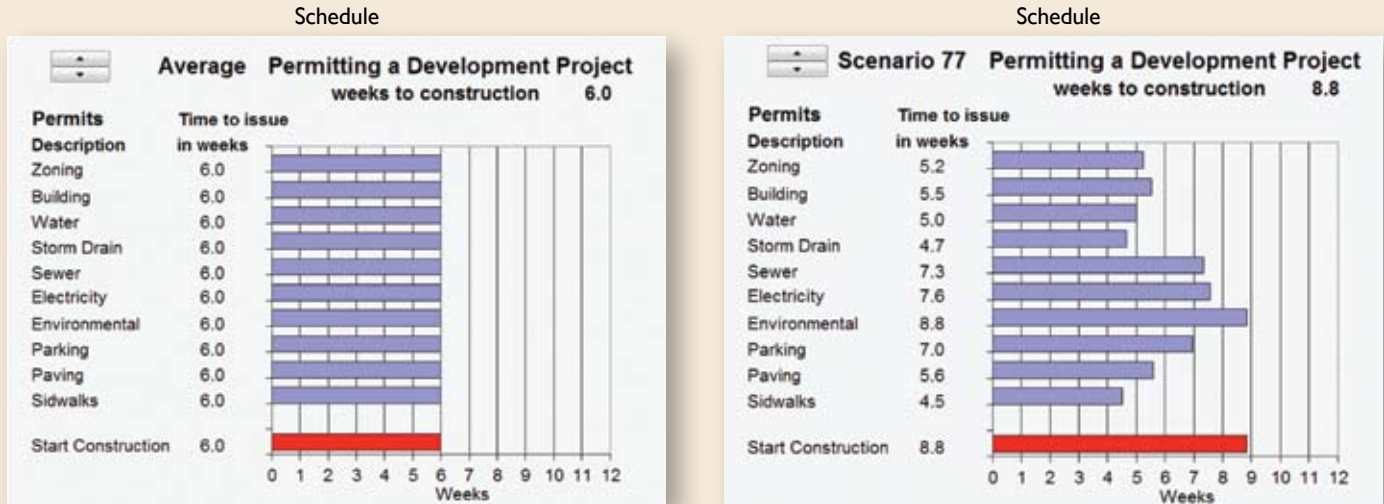
Given the average assumptions, each permit is obtained in exactly six weeks, construction begins in exactly six weeks, and there is no penalty. However, the model that represents the case of the city manager and the planner (the Schedule.xlsx file at ProbabilityManagement.org) calculates average results over 1,000 scenarios, indicating that the expected time to start construction is 7.8 weeks, which means the city will likely face \$86,000 in penalties (see Exhibit 2).

## 2 THE PROBLEM OF FORECASTING UNCERTAIN TAX REVENUES

When forecasting future tax revenues, it is tempting to pick a single number as an educated guess, and then back off a bit just to be safe. What many people don’t realize is that

## Exhibit I: Average versus Reality

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most forecasting techniques provide an explicit measure of the degree of uncertainty for the result. This measure of uncertainty is usually discarded, leading straight back to the flaw of averages.

**Permission to Be Uncertain.** “The problem with committing political suicide,” said Winston Churchill, “is that you live to regret it.” If uncertainty is a problem for city managers, as the above example demonstrated, it is fatal for politicians. Probability management helps by representing uncertainties as auditable, unambiguous data; it is much like recording 1,000 rolls of a die to provide a benchmark.

The City of Colorado Springs, Colorado, is a pioneer in giving politicians permission to be uncertain. The first time the city’s chief finance officer presented the uncertainty generated by a sales tax forecast directly to the city’s elected leaders, Colorado Springs was attempting to build back its reserves after responding to a large wildfire and a severe economic downturn. The city council decided on a revenue forecast that had two-to-one odds of being met or exceeded as the basis

for developing the budget, and as the city’s reserve position has improved, there has been active discussion around the exact odds to use — which is just as it should be. Single numbers mask all trace of uncertainty, but presenting stakeholders with a common view of an uncertain future helps them arrive at a risk attitude that is appropriate for economic and fiscal conditions.

**Useful Intelligence.** Probability management allows trained statisticians to share their expertise as useful data. For example, the Surplus-Deficit.xlsx demonstration model shown in Exhibit 3 is based on the data generated by the Colorado Springs revenue forecast. This model allows the user to experiment with different initial balances and monthly

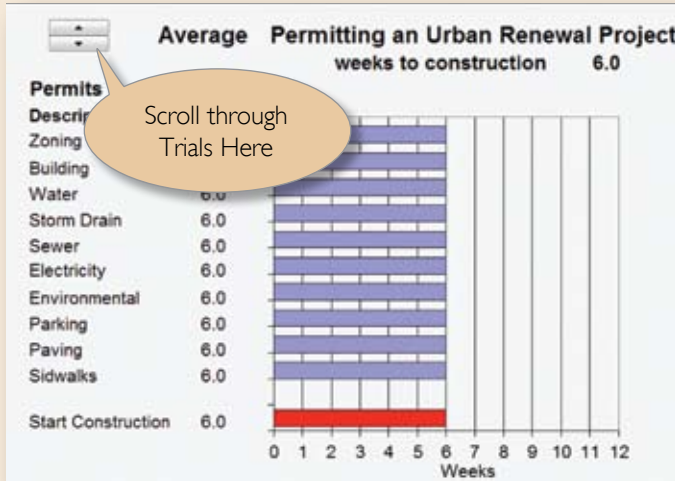
expenditure levels and immediately gauge the likelihood of deficits down the road. The model contains 1,000 simulated revenue scenarios, each of which generates a surplus/deficit graph. Adjusting the percentiles (cells A20 and A21) will display a confidence interval (shown as grey lines on the graph). Experimenting with the grey cells in rows five and seven adjusts the

When forecasting future tax revenues, it is tempting to pick a single number as an educated guess, and then back off a bit just to be safe.

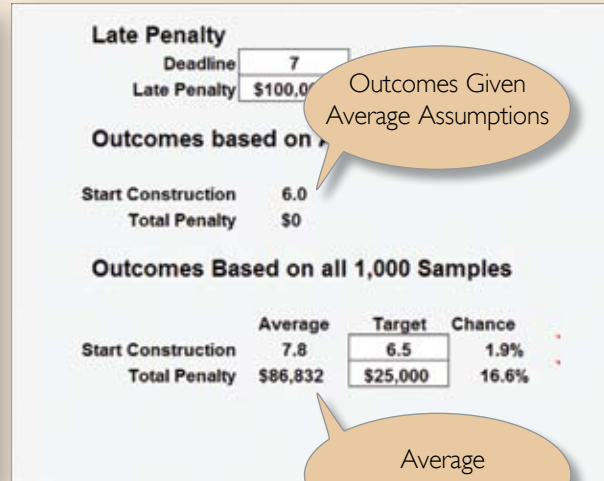
## Exhibit 2. Average Assumptions Do Not Result in Average Outcomes

The model also allows users to specify targets for time-to-construction and penalty, whereupon the worksheet instantly processes 1,000 scenarios to calculate the chances of meeting these goals. For example, under current assumptions there is only a 1.9% chance of being shovel ready in 6.5 weeks or less, and a 16.6% chance of incurring a penalty of \$25,000 or less.

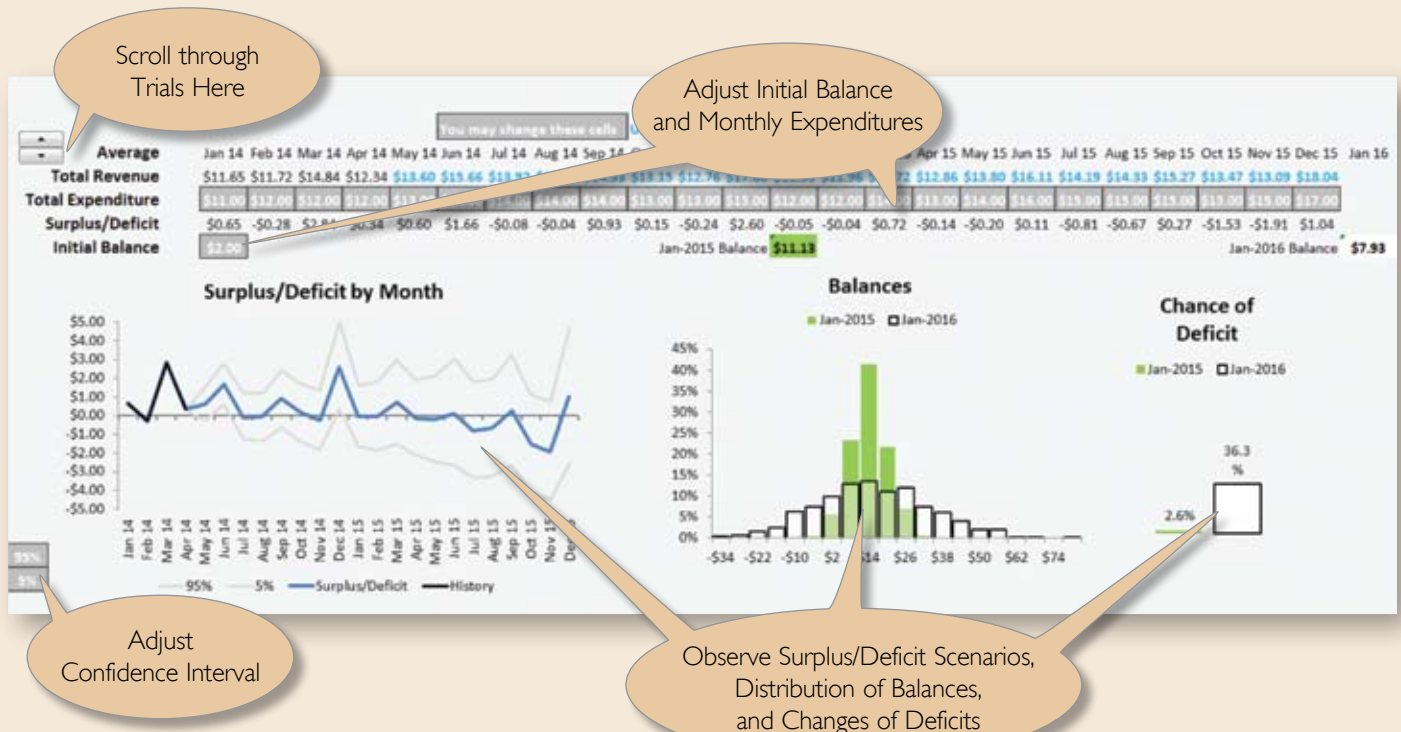
Schedule



Penalty Calculations



## Exhibit 3: Gauging the Likelihood of Future Deficits



initial balance and total expenditure by month, displaying the distribution of balances in both January 2015 and January 2016, as well as the chance of running a deficit on those dates.

**Other Uses of Probability Management for Budgeting.** The authors have discussed a variant of this problem in an earlier publication<sup>3</sup> and another model at [Probabilitymanagement.org](http://Probabilitymanagement.org) called *Shortfall.xlsx*. This model allows the user to see how variability in revenue projections affects different priority “tiers” of spending, where fixed costs such as debt service are the most important, operating costs such as police salaries are second, and special projects such as library expansions are the least important tier. Models like this one, which displays the chances of shortfall for each of these priorities, can stimulate useful discussion about ways to structure spending in the face of uncertain revenues.

The uncertainty in emergency funds is pretty much up to Mother Nature. The acceptable risk of exceeding the reserves on hand, however, is in the eye of the beholder.

### 3 THE PROBLEM OF CALCULATING RESERVES

All municipalities must plan for a rainy day, but in many locations, that “rainy day” also includes fires, floods, or other natural disasters. Through organizations including the U.S. Geological Survey and the National Oceanic and Atmospheric Administration, jurisdictions can obtain distribution severity estimates for different categories of disaster. Allocating financial reserves

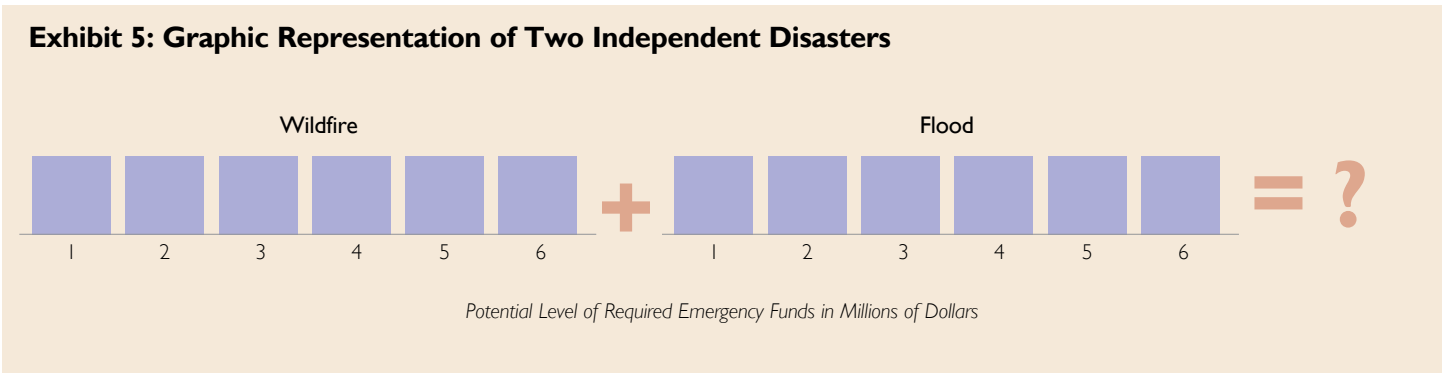
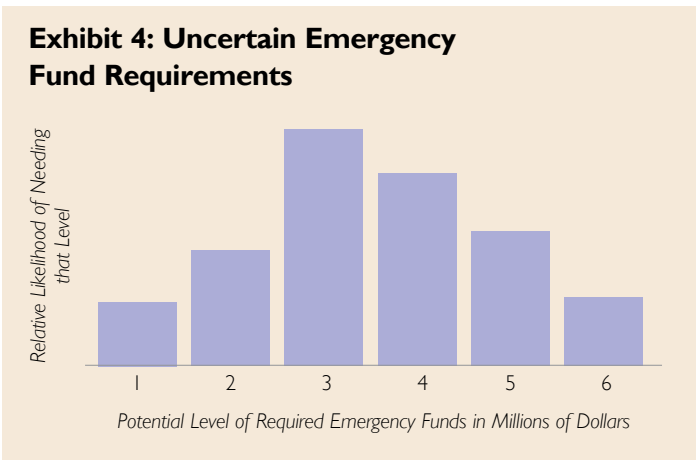
to cover these situations, however, is another question.

#### Combining Uncertainties — the Diversification Effect.

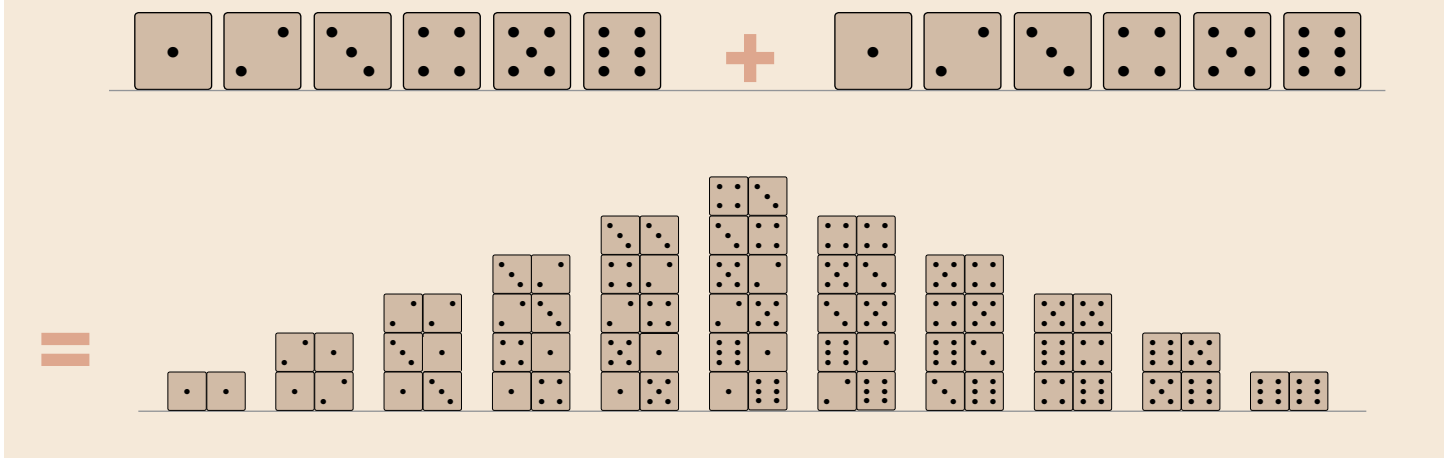
An uncertain quantity such as the level of funds required to meet an emergency can be thought of as a shape, representing the relative likelihood of various outcomes. For example, Exhibit 4 describes a requirement that could be as little as \$1 million or as much as \$6 million, but will most likely fall between \$3 million and \$4 million.

Now consider a municipality that must prepare for two potential independent threats, wildfire and flood. For the purposes of this discussion, each disaster will require \$1 million to \$6 million, with equal likelihood over the planning horizon. Exhibit 5 shows how these two uncertainties could be expressed graphically. Next, we add these two shapes to arrive at the shape of total required emergency funding.

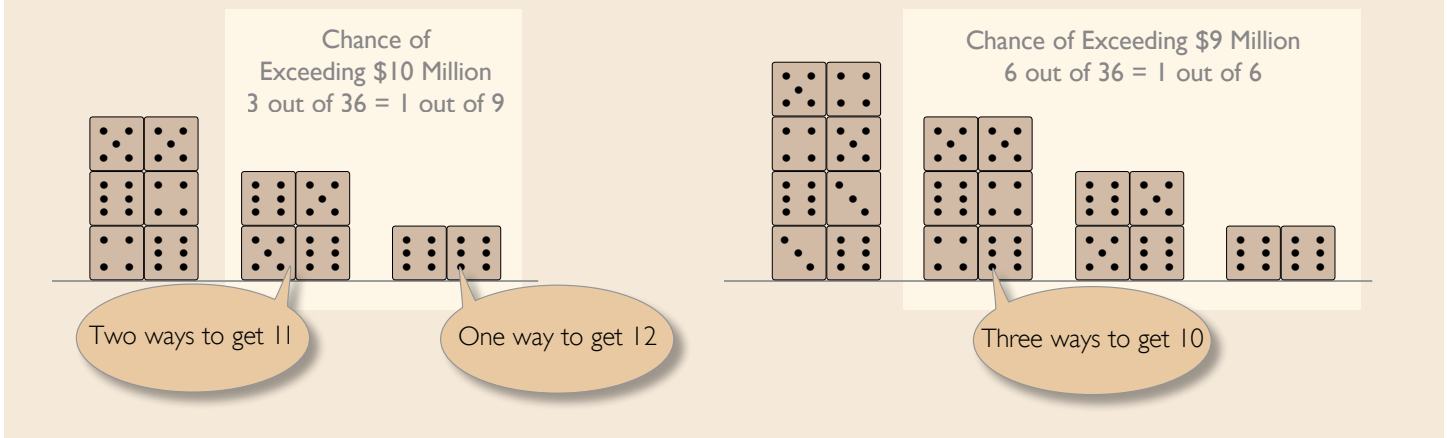
The answer is shown in Exhibit 6. This example is equivalent to adding the numbers on two dice. More combinations result in numbers in the middle (\$7 million) than at either end (\$2 million or \$12 million). This is the well-known effect



## Exhibit 6: The Diversification Effect: The Sum of Two Dice



## Exhibit 7: Determining the Correct Reserve Level



of diversification, which must be taken into account in any reserves calculation. When you roll one die, all results are equally likely, but when you sum two dice, the shape goes up in the middle. Why does this matter?

### Risk Is in the Eye of the Beholder.

The uncertainty in emergency funds is pretty much up to Mother Nature. The acceptable risk of exceeding the reserves on hand, however, is in the eye of the beholder. Can your municipality live with one chance in four of running out of cash? How about

one chance in 20? These are complex and important issues for local governments to debate, but even starting the conversation requires an explicit recognition of uncertainty.

*It is better to be approximately right than precisely wrong. As with horseshoes and hand grenades, once you start modeling uncertainty explicitly, close counts.*

Suppose our imaginary municipality can accept one chance in six that its reserves will be exceeded. By considering each risk independently, the city would set aside \$5 million for wildfire and another \$5 million for flooding, for total reserves of \$10 million. However, by using a single number to represent each contingency, the

municipality has run afoul of another variant of the flaw of averages.

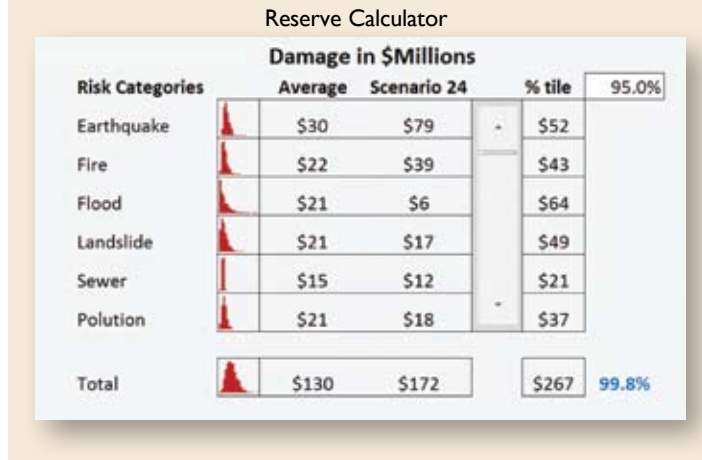
**Risks Don't Add Up.** With one chance in six of exceeding the \$5 million wildfire reserve and one chance in six of exceeding the \$5 million flood reserve, most people would assume one chance in six of exceeding the total reserves of \$10 million — but not so fast. As shown in Exhibit 7, there are only three chances out of 36 (or one in nine) that the total required will be greater than \$10 million. The municipality can actually meet its one-in-six risk limit with only \$9 million in reserves, allowing it to put that extra \$1 million to better use.

The City of San Clemente, California, provides an example of accounting for real world contingencies. The city is beginning to apply probability management to its emergency reserves. As an early step, staff analyzed 100 years of storm data and used it to develop a probabilistic description of damage to the pier jutting out from the city's famous beach. The basic approach is demonstrated in Exhibit 8 (the Reserves.xlsx file). This conceptual model demonstrates the problem of estimating reserves for a given time horizon. Once the uncertainties are described statistically, probability management makes it easy to add them up.

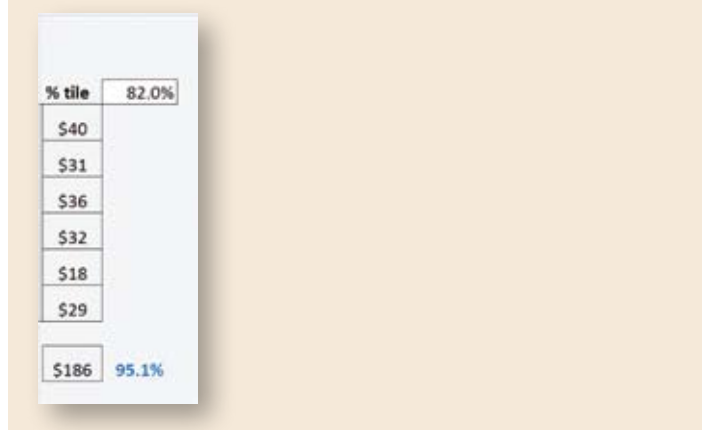
The model has six categories of disaster, along with a graph of their distribution of damage over the given time horizon. (Damage scenarios are stored as data in the library tab of the workbook.) A column in the model displays the average damage in millions of dollars for each category, with the total across all categories at the bottom, and any one of 1,000 individual scenarios can be selected with a slide bar. In Exhibit 8, the column of percentiles is set at 95 percent; that is, one would expect the damage in any category to fall below the number in the percentile column 95 percent of the time. Put another way, there is only a 5 percent chance of exceeding this number.

Suppose the city decided that its reserves should be maintained to cover 95 percent of all cases. Adding up the reserves by category, we see that the city will be overfunded due to the diversification effect, like the dice example. In fact, Exhibit 8 shows that adding the 95th percentiles of each category totals \$267 million, which is actually the 99.8th percentile of total risk. Reducing the percentile at the top of the chart until the

### Exhibit 8: Estimating Reserves for a Given Time Horizon



### Exhibit 9: Finding the Appropriate Reserve Level



percentile of the total is 95 percent shows that we only need to be 82 percent confident for each risk category to achieve a 95 percent confidence overall, resulting in total reserves of \$186 million, a reduction of \$81 million. (See Exhibit 9.)

**Independence and Restrictions.** The overall benefit of the diversification effect is affected by both the independence of the contingencies being covered and the degree to which funds may be moved between categories. That is, if a flood is likely to cause a mud slide, or if money in one emergency fund may not be used to cover a different emergency, then the required reserves may need to be increased. While such interrelationships are beyond the scope of the illustrative models shown in this article, when present, they should be accounted for in probabilistic terms.



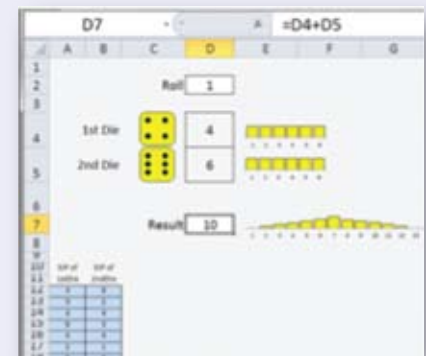
## Probability Management

ProbabilityManagement.org is a non-profit that promotes the communication and calculation of uncertainties.

The discipline of probability management was formalized in 2006.<sup>1</sup> As described by Daniel Ralph, Professor, and Director of the Centre for Risk Studies, at Cambridge University: “The discipline of probability management provides a transformation of proven risk modeling techniques into simple business steps. Its open standard advances the field by representing uncertainties as unambiguous data, which may be shared across platforms.”

This is accomplished by storing potential outcomes in data arrays called SIPs. For example, the SIP of a die would consist of a column of integers randomly chosen between 1 and 6. Calculations using SIPs are referred to as SIPmath, which forms the basis of the three models supplied with this article. SIPmath can be performed in almost any computer environment, including a commonly used spreadsheet format with the native data table function. The technique is now being applied by several large corporations and has even been used successfully in a pilot program to teach the concept of risk/return tradeoffs to middle school students.<sup>2</sup>

The basic idea behind SIPmath is easy to explain; the hard part is getting anyone to understand it. A worksheet on the Models page of ProbabilityManagement.org simulates calculations based on 10,000 rolls of a pair of dice. The model allows you to sum or multiply the numbers on the two dice, or perform virtually any other calculation, and instantly observe the shape of the potential outcomes.



### Notes

1. Sam Savage, Stefan Scholtes, and Daniel Zweidler, “Probability Management,” *OR/MS Today*, February 2006, Volume 33.
2. Investment contest at Horace Mann School in Beverly Hills; see <http://youtu.be/vR0BFjFEvCM>.

## COMMON QUESTIONS AND CONCERNS ABOUT PROBABILITY MANAGEMENT

The first question is: Where do the data come from to provide inputs into a probability management model? All forecasting methods generate some estimate of uncertainty in their results. For example, a record of comparisons between the forecast and what actually occurred is a good basis for estimating future accuracy. Historical data are also a rich source of information on the degree of uncertainty that a government’s finances are subject to — recall San Clemente’s use of historical data on pier repairs to estimate the range of future likely damages. One of the primary benefits of probability management is that decision makers do not need to be statistical experts themselves, but can use the analysis of others as data in interactive risk models.

An uncertain quantity such as the level of funds required to meet an emergency can be thought of as a shape, representing the relative likelihood of various outcomes.

Another common, related concern involves the level of precision needed in the data to build a useful model; people worry that imprecise data may lead to inaccurate modeling. The good news is that it is better to be approximately right than precisely wrong. As with horseshoes and hand grenades, once you start modeling uncertainty explicitly, close counts. For example, consider what you do before you climb on a ladder — most people give it a good shake to find out if it is stable. The distribution of forces when you shake a ladder,

however, is quite different from the distribution of forces when you climb on it. Will you stop shaking ladders now that you have learned that you have been using inaccurate data?

## CONCLUSIONS

The basic principles of probability management have been proven in stand-alone risk management systems

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for decades. It is only recently, however, that they could be applied in a native spreadsheet with no additional software. And the transition from single numbers to probability management is not as great as the transition from calculators to spreadsheets; however, it does typically require at least a three-person team: a forecaster who has solid undergraduate statistical training to estimate the uncertainties, a financial planner to build a plan around those uncertainties, and a leader, such as a finance director, chief finance officer, or chief executive officer, who can take the lead in engaging other decision makers in probabilistic thinking. The results should be a model that does not give the right answer so much as spark the right questions about the chances of meeting targets and what level of risk the government is willing to take on. The GFOA is currently performing pilot projects on using probability management with the City of San Clemente and the City of Colorado Springs and will report the results of these projects in future *Government Finance Review* articles. ■

### Notes

1. Sam L. Savage, *The Flaw of Averages: Why We Underestimate Risk in the Face of Uncertainty*, (Hoboken, N.J.: John Wiley & Sons, 2009).
2. Sam L. Savage, “Distribution Processing and the Arithmetic of Uncertainty,” *Analytics Magazine*, November/December. (Available at <http://viewer.zmags.com/publication/90fcc6b#/90fcc6b/29>.)
3. Sam L. Savage and Shayne Kavanagh, “The Sequestetron,” *Analytics Magazine*, November/December 2013. (Available at <http://viewer.zmags.com/publication/24bf7927#/24bf7927/52>.)

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