Challenges of Dealing with Uncertainty

Bob Prieto

Let me begin by saying that the scope of this subject is well beyond adequate treatment in any one paper. Having done a necessary disclaimer, this paper will take a look at uncertainty as it relates to the economics of investments in community resilience. I have chosen to focus my consideration of how one deals with uncertainty in this area since it presents several characteristics which I find to be of value when considering the subject of uncertainty in dealing with a broader array of programs and projects. These characteristics include:

- The long term nature of both initial investments but also utility and "return on investment"
  - Increasingly we find this consideration of extended timeframes in both large scale public as well as private programs
- The need to meet the long term needs of multiple, interlocking stakeholder groups, with potentially differing views of risk, investment horizons and potential futures
- Consequences of getting it materially wrong.
  - These consequences can include loss of life, economic impacts at scale and even lost generations. In many ways these consequences are growing concerns even in more "traditional" large scale programs we are increasingly undertaking.
- The programmatic nature at scale, dealing with whole communities, broader than even many of today's giga-programs consisting of handfuls of projects
- Complexity, that only allows insights into how to prepare for tomorrow through almost unweighted consideration of scenarios
- The emerging nature of the problem and its likely relationship to many of the future projects we will undertake.

In this paper I will try to provide a framework for the economics of community resilience and touch upon some of the uncertainty factors. Both the framework laid out and the factors highlighted are incomplete but are intended to help advance our understanding of the uncertainties involved and suggest opportunities to address some of our data and knowledge gaps.

I would ask the reader to think of the appropriate analogs in their own project "space". I consider this paper as exploratory in many ways and actively solicit its reader's feedback and thoughts as I will co-chair a panel on this subject shortly and I believe the subject would benefit from broader thoughts and insights than I have laid out here.

Uncertainty and Economics

“Uncertainty, as opposed to mathematical risk, is a pervasive fact of life” (6). Perhaps this is nowhere more true than in the area of economics where despite Keynes’ contributions on the subject an undue predisposition persists that we can have some degree of certainty in projecting the future. In reality we know less about the future than we typically assume and this uncertainty opens the door to multiple potential futures limited only by the way we think about the world. Uncertain futures must not be confused with improbable futures since the relative probabilities of each of these futures is numerically indeterminate and therefore does not allow potential futures to be compared.

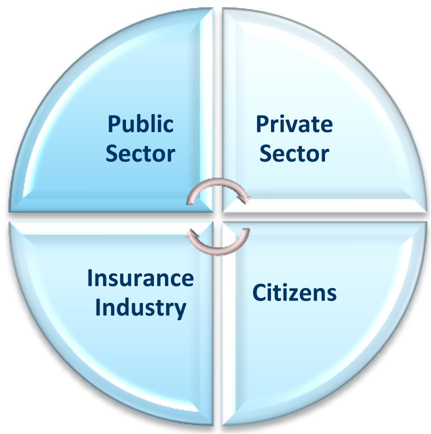
In much of what we do we focus on determining the probability and consequences of the various estimates and events that we believe we may reasonably experience in a project context. Yet at the same time we know that the “tails” of the Monte Carlo analysis we typically use are too thin, underestimating rare events and perhaps failing to consider uncertain futures at all.

Setting the Stage – Community Resilience Defined

Let me begin by stating that we do not have a common definition for resilience but rather many similar, but not the same, definitions. For example, the Community & Regional Resilience Institute (CARRI) defines resilience as the “ability to anticipate risk, limit impact, and bounce back rapidly in the face of turbulent change.” In effect resilience is founded on our ability to identify threats; model these threats to predict risks; and create risk management strategies to counter negative effects. Whether this definition is adequate or not is superseded by a shortcoming found in all definitions of resilience, namely, they lack sufficient specificity to actualize the achievement of resilience. I will return to this point as it is essential for understanding the key uncertainties we must focus our energies on.

In considering the economics of community resilience it is important to clearly and comprehensively define what we mean by community and ensure our economic views are not limited by political correctness. For purposes of this discussion I will define the “economic community” as encompassing four distinct stakeholder groups (but with overlapping memberships) who will bear the costs, benefits and consequences of appropriate investment or disinvestment in community resilience. These four groups include:

- Public sector
- Private sector
- Citizens
- Insurance industry



Defining a Resilience Outcome

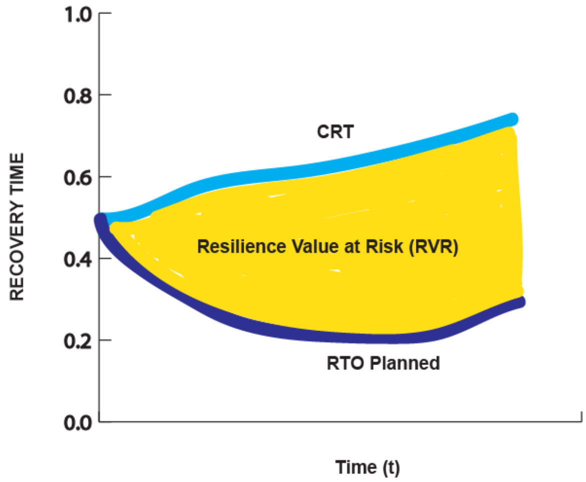
Any consideration of the economics of resilience can only occur if we are able to explicitly define a targeted outcome we desire and score various investments' contributions towards closing the gap between where we are today and where we desire to be at a future point in time. Failure to define clearly the Strategic Business Objectives we are trying to achieve, getting agreement on them, and then continuously communicating them is a principal failure we see in large programs that "under-perform".

In the context of community resilience this leads to the definition of two key concepts with respect to achieving such community based resilience.

The first concept is associated with the desired resilience end state and CARRI's notional objective of "bouncing back rapidly". It goes directly to the concept of recovery time. In a business context we define a "Recovery Time Objective" or RTO as the targeted duration of time, at a specified service level, within which a business process must be restored after a disaster (or disruption) in order to avoid unacceptable consequences associated with a break in business continuity. This definition may be more broadly extended across all four groups comprising the "economic community" previously described.

Each stakeholder group needs to define how long they can comfortably experience capability, business or service interruption. As part of this comprehensive review Current Recovery Time (CRT) can be estimated and compared to the RTO. The gaps should be readily identifiable.

The second concept with respect to achieving community based resilience recognizes that all actions undertaken to address identified gaps will take time to deploy and during this period there is a Resilience Value at Risk (RVR) that is a function of the RTO – CRT gap and the rate at which that gap is closed.



First Order Uncertainties

This brings us now to several first order uncertainties which we risk glossing over as we seek to get more granular in defining uncertainties associated with the economics of community resilience. Principal among them is definition of Recovery Time Objectives by each stakeholder group accompanied by an informed and transparent rationalization of those various RTOs. These RTOs must be defined for several different economic framework elements that must encompass:

- Lifeline capabilities, services and facilities (response, sustaining and protecting)
- Critical enabling capabilities, services and infrastructure (recovery and sustaining lifelines)
- Restoration capabilities and services (long term recovery; economic recovery)

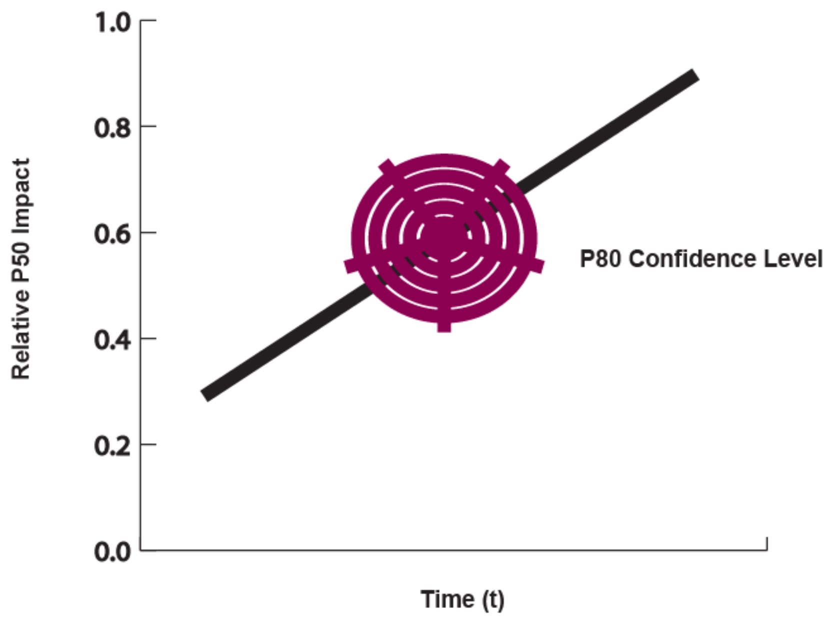
Currently, clear and consistent methodologies for defining economic framework elements comprehensively does not exist; guidance on establishing appropriate RTOs is lacking; and, even more fundamental, we do not understand the current recovery time associated with a given impact scenario.

These uncertainties with respect to RTO and CRT must be addressed if the economics of community resilience is to proceed in a well founded way. An effective review of current recovery times requires:

- A comprehensive understanding of the current condition of key capabilities, services and infrastructure systems and key facilities and their point and rate of degradation
- A mapping of key interdependencies, understanding value chain relationships and second (and higher) order coupling, including that associated with "constraint coupling"

- Insight into the assumptions made with respect to critical enabling capabilities and their impacts on recovery timeframes

Today, data is broadly missing in many of these areas and we see comparable absence of data on interdependencies, value chains and coupling on many of the large scale programs we undertake.



Both Impact and Temporal Uncertainty Must Be Considered

Multiple Futures

An initial word on the future is worthwhile at this point, and I will return to it later in this paper. Simply put, the future is uncertain. In considering the economics of community based resilience it is essential that we consider a full range of potential futures, consciously not filtering out those very rare events which have the potential for greatest impact. The RTOs we establish as well as our assessment of CRT will vary with scenarios considered. For example, we may want our community to have no disruption (RTO = 0 hours) for a snow event of 2" but may be willing to incur a longer disruption for a 12" snow event (RTO = 8 hours). Clearly, more extreme scenarios are of more interest.

It is also important to highlight that some scenarios (climate change) evolve over a longer timeframe than a point source event (tornado; earthquake) and that individual scenarios may have multiple failure modes that develop over time (extreme snow followed by flooding; NATECH event – natural disaster triggers a "technology" failure (Fukushima)). Addressing uncertainties associated with the economics of community resilience for these longer evolving scenarios must focus on the resilience value at risk (RVR) described earlier.

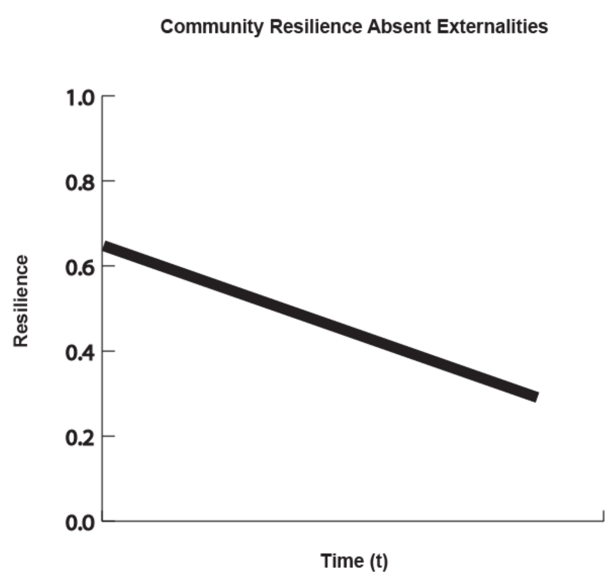
As we evaluate investments in community resilience, in a world of multiple uncertain futures, we must attempt to envelope these potential futures and reflect their uncertainties in terms of impacts and timing. For a singular scenario (climate change) our CRT will grow over time, ignoring any resilience driven investments, but this growth will have an impact uncertainty and timing uncertainty at each future point in time. These temporal uncertainties can be described in terms of time series P50 values related to impact but with variance for impact coupled with temporal variance.

Simple models for temporal variance of longer timeframe events are required to facilitate the handling of these uncertainties. This is a common challenge across all long duration projects and assets and is particularly important in respect to making community resilience investments.

Defining the Economic Model

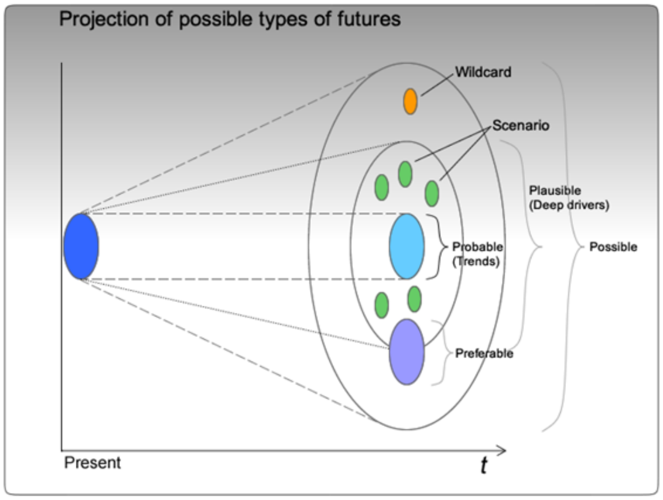
In our evaluation of community resilience we need a baseline economic model that assures we have:

- Captured all economic benefits and costs
- Reflects the value of time and its impact on economic benefits; capital efficiency; and Resilience Value at Risk (RVR)
- Recognizes that community resilience is not a static achievement but rather subject to changing externalities and normal "depreciation" of capabilities and capacities that require mitigating sustaining investments



Community Resilience "Depreciates" Over Time Without Sustaining Investments

- Considers both quantitative uncertainties around key parameters as well as temporal uncertainties with respect to normal financial externalities (inflation rate; financing costs; debt tenor) and principal scenarios considered
- Considered the multiple possible scenarios associated with an uncertain future



This model allows us to:

- better define and enhance this economic framework
- assist key stakeholders in identifying opportunities to support the decision making abilities of communities to plan to mitigate, respond to, and recover from disasters
- enhance understanding of multi-disciplinary perspectives, available methods, best practices, and associated uncertainties.

The economic model described in the next section adopts a life cycle perspective that may be applied to capabilities, services and facilities that I will collectively refer to as community assets

Life Cycle Model for Community Resilience

The life cycle model for community resilience encompasses:

- economic benefits
- asset life cycle costs and investments
- indirect asset costs
- externalities

Life cycle analysis of community resilience provides a valuable option analysis tool, allowing consideration of future investments and their timing and, importantly, prioritization of investments. Risk, especially systemic risks, and uncertainty are fundamental aspects of a sound community resilience model.

Economic Benefits

Economic benefits associated with community resilience investments are largely those associated with the avoided costs associated with:

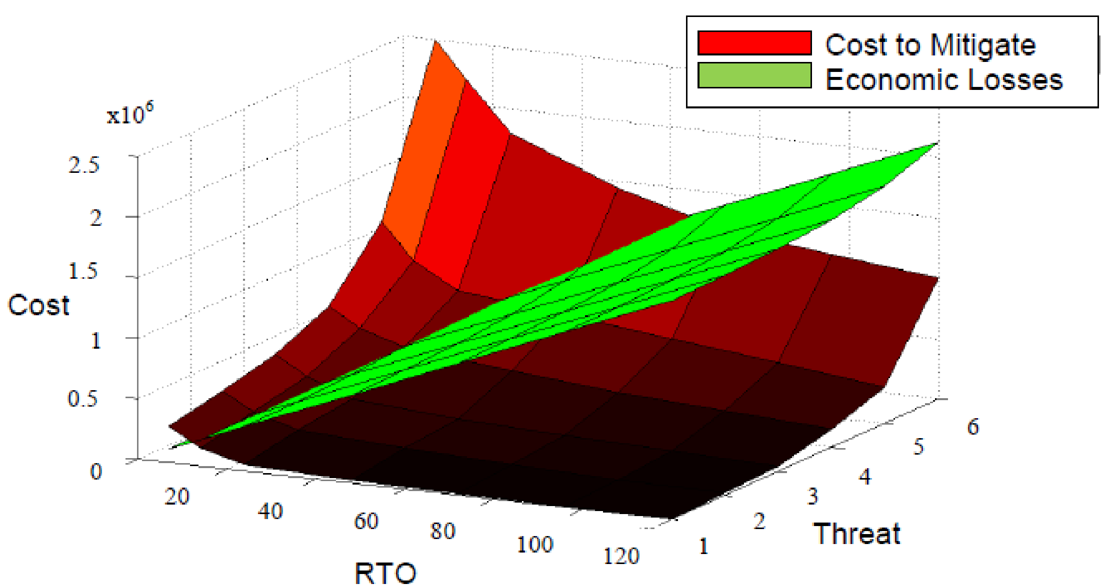
- direct damages from a threat
- economic losses due to business interruption

Many of the design, procurement and construction costs described in the context of proactive resilience investments are incurred post disaster but with elevated uncertainty levels with respect to cost and schedule. This uncertainty is driven by many factors including the fact that the project framework is significantly modified post disaster (3).

In many instances community resilience investments will provide additional economic benefits associated with:

- economic activity generated by undertaking the community resilience investment
- enhanced economic performance as a result of the investment (improved productivity; acceleration of the economic cycle)

The economic benefits derived from avoided costs are a function of the specific threat scenario considered and the level of RTO achieved by the investments. The following figure illustrates the relationship between RTO, threat and costs (the ones which we want to avoid).



As threat magnitude increases, direct damages increase. As RTO increases, economic losses due to business interruption increase. The intersection line between the two planes (cost to mitigate (discussed in the next section) and economic losses) is the economic breakeven line. This line represents the RTO for each threat magnitude that provides mitigated losses equal to the cost to mitigate. Superimposing current recovery time (CRT) allows us to calculate avoided costs.

The principal uncertainties in this community resilience life cycle analysis factor related to economic benefits include:

- avoided (RTO – CRT) economic impact associated with direct damages associated with a particular scenario
    - these impacts may directly impact all four stakeholder groups – public sector; private sector; citizens; insurance industry
    - direct damages include cost of responding to impacts associated with the scenario and cost of replacement of capability in kind
- avoided (RTO – CRT)economic losses due to business interruption
    - these impacts indirectly impact the public sector (tax revenues); private sector not directly impacted through disrupted supply and value chains; citizens (lost wages; lost jobs); insurance industry (business continuity policies)
- current assessment of economic impacts and losses associated with CRT (to enable avoided cost calculation)
- economic activity associated with specific investments made to improve community resilience
    - these will largely involve both marginal direct expenditures but also any economic multipliers associated with such expenditures.
- enhanced economic performance associated with the investments made
- probability of a particular scenario occurring and timing of the scenario
- discount factor considering uncertainty of timing

Asset Life Cycle Costs and Investments

Assets related to community resilience economics encompass capabilities, services and facilities. Life cycle costs (1) associated with investments to meet RTO objectives and reduce economic impacts and losses at a given RTO level consist of the following cost categories:

- planning and permitting
    - the principle costs here are those associated with the cost of time
        - resilience related permitting should be fast tracked
- design
    - design cost and time and confidence in the developed resilience strategies would be enhanced by:
        - transition to performance based standards incorporating resilience

        - requires improved methodologies and tools for assessing performance based design adequacy
      - improved guidance and resilience standard on Threat Hazard Identification and Risk Assessment (THIRA)
    - recovery times would be strengthened by expanding the basis of design (BOD) (5) developed to meet owner's project requirements (OPR) to explicitly include:
      - an initial construction basis of design (CBOD)
        - addresses uncertainties in construction cost and time
      - an O&M basis of design that support sustainment of resilience and other performance features through the assets life cycle (O&MBOD)
      - features to facilitate normal and off-normal repair and replacement
- procurement and construction
    - procurement time frames may be impacted by changed regulations with short transition periods or overly prescriptive codes and standards (versus performance based standards)
    - sourcing, degree of standardization and logistical constraints associated with initial asset delivery (or rehabilitation and improvement) need to be considered from a post-event context
    - initial construction uncertainties are associated with:
      - poorly defined and agreed to objectives; weak owner readiness
      - lack of owner – contractor alignment
      - scale (introduces complexity)
        - lack measure of complexity
      - incomplete basis of design – lacks construction, O&M and resilience considerations
      - overly optimistic estimates (optimism bias), often driven by the planning fallacy
        - absence of good estimating data bases
        - lack of reference class forecasting
        - unrealized productivity improvements
          - industry lacks systemic innovation
      - poor scope and change control
      - unnecessary "white space" risks associated with contracting and execution strategy
      - inadequate standardization, fabrication – too much bespoke design
      - impacts of disruption underestimated
    - recovery times would be strengthened if changes to project execution post-event were considered in the initial EPC process
- operations & maintenance
    - Predictive, preventive and routine maintenance
      - Uncertainties and inconsistencies in maintenance levels and expenditure

            - Weak or non-existent industry data in usable form
        - Maintenance backlogs of state of disrepair show we don't have the balance right
    - Repair or replacement of worn or failed assets
        - Function of maintenance program quality
    - Sustaining capital/capital refurbishment of major systems or assets
- end of life
    - inadequate consideration of time and money
    - resilience not a consideration in removal at end of life

Costs associated with rehabilitation, recovery & restoration of assets at the current design and recovery time levels that would have been avoided through the planned investment are not considered as costs in the life cycle analysis but their avoidance is considered as an economic benefit.

Indirect Asset Costs

Indirect asset costs associated with the economics of community resilience fall into the following categories:

- Land use
- Tax regimes
- Financing structures
- Common financial factors

Land use represents a particularly thorny community resilience strategy. In many instances buffer zones and preserves may act to provide added resilience for communities by limiting development in high risk areas or providing relief zones to accommodate flooding or provide buffers against other threats, manmade or natural.

The cost of these land use decisions in support of community resilience will be a function of the land use strategy adopted. The available strategies can be described as:

- **Concurrent availability:** This means the site is available on some basis for use by other facilities. This becomes an important consideration when evaluating community resilience. Concurrent availability may be either:
    - Constrained or limited
    - Unconstrained or unlimited (except with respect to limiting attributes of the site independent of the facility's presence at the site)
- **Concurrent unavailability:** The site is not available for other current use due to the facility's presence at the site.
- **Loss of optionality:** Site use, post facility closure, is limited because of the prior presence of the facility
- **Permanent unavailability:** Use of the site, post closure, is not reasonably possible

Land use uncertainties revolve around time and cost of repurposing existing lands to enhance community resilience. In many instances this will require the use of eminent domain.

Tax regimes represent an opportunity area for encouraging non public sector resilience enhancements similar to what was seen with respect to energy conservation and renewable based tax programs. Uncertainty over liability risks assumed by non public stakeholders who make good intentioned efforts to enhance resilience but which sustain a subsequent failure represents a potential overhang on community resilience efforts.

Financing structures will be key to meeting the level of investments required to address a rapidly deteriorating infrastructure base (reducing resilience and increasing CRT) and improve community resilience. A range of financing tools and structures are available, ranging from pure public sector expenditure through public-private partnerships (PPP) to pure private investments in business continuity. Key uncertainties in financing structures for long lived assets include:

- Tax policy or other community resilience incentives
  - Regulatory taxes on negative resilience
  - Subsidies for positive resilience investments
- Available loan facilities (Transportation Infrastructure Finance and Innovation Act (TIFIA) like instruments) and tenors
- Refinancing risks
- Liability limitations on resilience based risk assumption and mitigation
- Catastrophic insurance coverage and costs

Common financial factors whose uncertainties can significantly impact the economics of community resilience modeling and investment include:

- Planning horizon
- Discount rate as a function of time
- Inflation/deflation
- Uninsured portion of events of scale
- Assumption migration associated with longer investment time frames
- Changed risk premiums over time
- Changed materialization of long term evolving risks (climate change)
- Changed assessment of probability and severity of severe impact threats (increased frequency of terrorist events; non linear growth of severity with coastal urbanization)

Externalities

The economics of resilience is susceptible to uncertainty created by a wide range of externalities. These include:

- **Financial factors**, beyond those typically considered such as hyperinflation and depression
- **Environmental factors**, especially those with significant global climate change trajectories
- **Social factors**, such as changed user behavior and changes in the subject community with respect to the community resilience features adopted
- **Correlated risks**, such as those associated with:
  - Scale and complexity
    - Scale and complexity move you into a new risk regime where "Black Swans" are more likely
    - Scaling drives non-linear and non-correlated growth in risks
    - Complexity masks existing risk or creates new ones
  - Dynamic risk modeling
  - Disruptive economic factors, including war, social strife and changed energy or water security and economics
  - Political and social action
  - Litigation

Modeling Risk and Uncertainty in Life Cycle Analysis of Community Resilience Investments

Risk and uncertainty are inherent characteristics of the delivery, operation and maintenance of asset including those associated with improving community based resilience. There are risks and uncertainties around likely future economic benefits and their timing. Comprehensive life cycle analysis of resilience investments must address both risk and uncertainty, particularly in the comparison of significantly different timing, phasing, operating periods and financing structures.

Risk is used to describe those factors where probabilities can be estimated. Uncertainty describes those factors where probabilities cannot be estimated.

Table 1 shows some of the risks and uncertainties that must be considered utilizing a statistical approach such as Monte Carlo analysis. Selection of confidence levels must be appropriate for the intended use of the analysis and is discussed further in the next section.

Table 1 **Risks and Uncertainties to be Considered**
□ Quantitative/estimate uncertainties (quantity, unit price, and productivity)
□ Duration uncertainties
□ Sequencing or timing uncertainties
□ Resilience (RTO) factor
□ Current Recovery Time (CRT)
□ Changing scenario probabilities and severities
□ Discount rate considering uncertainty of timing
□ Complexity
□ Land use
□ Inflation/deflation rate (over time; by cost category – general, labor, labor social and benefit costs, energy, water, and feedstock)
□ Refinancing timing
□ Refinancing cost of capital
□ Tax regime
□ Tax rates (over time)
□ Planning horizons
□ Assumption migration over extended timeframes
□ Changed risk premium over time
□ Resilience coverage rate (associated with resilience ramp up rate)
□ Economic benefit levels over time
□ Maintenance level
□ Asset availability and lifetime
□ Terminal value (if any)
□ Confidence level selection and calculation

LCA is equal to the summation across all:

- Time periods beginning with the initial time periods (t = 1) in the resilience asset life cycle, planning and permitting, and extending through the full life cycle to end of life (t = P)

This summation is undertaken for all economic benefit (EB) and cost (C) elements, where:

- Economic Benefit (EB) and Cost (C) have been segregated to ensure each is comprehensively covered. Economic benefits, may be treated as negative or avoided costs in the general form for determining LCA.
- Each Economic Benefit (EB) and Cost (C) element is individually characterized such that for:

  - EB_n, where the various Economic Benefit elements may be written as EB1, EB2, EB3 …, the characterization of each economic benefit element may differ with respect to each of the properties listed below.
  - Similarly, Cn, where the various cost elements may be written as C1, C2, C3 …, the characterization of each cost element may differ with respect to each of the properties.
- Properties associated with each Economic Benefit (EB) and Cost (C) element are characterized, as shown in the general form of LCA, as including:
  - An associated level of uncertainty, σ, described by a standard deviation or minimum and maximum
  - A probability distribution function, PDF, related to σ and described by a distribution type (normal, triangular, lognormal, etc.)
  - An Economic Benefit (EB) or Cost (C) value in the time period, t, which represents $EB_{Base\ Period}$ or $C_{Base\ Period}$ multiplied by the cumulative Escalation Factor (EF) as of time period t
  - With associated discount factor, q, that allows for consideration of multiple funding sources (public sector, private sector, citizens, insurance) with different discount factors
- Properties associated with each Economic Benefit (EB) and Cost (C) element are further characterized, in an extended form, to include:
  - Linkage to common drivers (or coupling constraints), D, of the general form D# such as D1, D2, D3… that may influence the behavior of multiple Economic Benefit (EB) and Cost (C) elements in a correlated way. Drivers may be a function of time and will vary by Scenario. Drivers could then be written as D#(t, $Scenario_N$). Example of a common driver impacting many revenue and cost elements could be energy cost, rate of climate change or increase in flooding levels.
  - Linkage to defined constraints (Limit) that may vary over time and be influenced by the value of one or more common Drivers, D, as well as the Scenario being considered. Limits would take the general form of Limit#(t, D, $Scenario_N$). An example of a constraint might be limits imposed by regulations such as those related to zoning, building codes or greenhouse gas emissions.
  - Scenario, where sets of Drivers and Constraints maybe associated with a given asset narrative associated with the Base Case for determination of the asset's LCA. LCA optimization can then be subsequently stress tested against alternative scenarios, outside the range of Drivers, Constraints and Uncertainties otherwise considered. This stress testing will help determine the resilience of the asset program's performance. Scenarios may be enumerated in the general form:
    - $Scenario_N$, where N is the scenario enumeration number
    - Variations around a given scenario for the purposes of stress (S) testing would be of the form $Scenario_N^{S1}$, $Scenario_N^{S2}$, $Scenario_N^{S3}$…

- Finally, in a program context (community resilience vs asset resilience) multiple configurations (Config) may be considered, all of which meet the program's strategic business objectives but with different LCA characteristics. Configurations may be enumerated in the general form:
  - $Config_x$, where x is the configuration enumeration number
  - Variations around a given configuration would be of the form $Config_x^1$, $Config_x^2$, $Config_x^3$

Combining the above considerations, we arrive at the following for determining an LCA value for a combination of scenarios, configurations, drivers, constraints and uncertainties for a given set of base assumptions. Optimization would have us perform a Monte Carlo analysis to determine the LCA value with the desired confidence level.

$$\mathbf{LCA}_{\mathbf{NPV(Confidence)}} =$$

$$\sum_{t=1}^{P} \left[\left(\sum_{n=1}^{All} C(n(\sigma, PDF), t, q, Scenario_N, Config_x, D\#(t, Scenario_N), Limit\#(t, D, Scenario_N)) *q \right) - \left(\sum_{n=1}^{All} EB(n(\sigma, PDF), t, q, Scenario_N, Config_x, D\#(t, Scenario_N), Limit\#(t, D, Scenario_N)) *q \right) \right]$$

Confidence Levels

The selection of confidence levels for both the various input parameters into economic evaluations related to community resilience and the accompanying confidence level in and economic analysis performed to drive resilience related investments is an important and often overlooked area.

Each of the various input parameters carries with it a different confidence level and distribution which is best highlighted by example:

- A particular asset investment has a CAPEX value of X based on a P50 confidence level associated with Monte Carlo simulations run in consideration of a range of normal estimation uncertainty and project execution event risks. This same asset has a CAPEX value of 1.3X at a P80 confidence level.

- Frequency of rainfalls exceeding X inches in a given year is assumed to grow over time based on a long range climatic model considering global climate change. At a P20 confidence level, the frequency of such events is expected to hit a threshold level of T in 20 years. At a P80 confidence level the T threshold would not be reached until year 50.

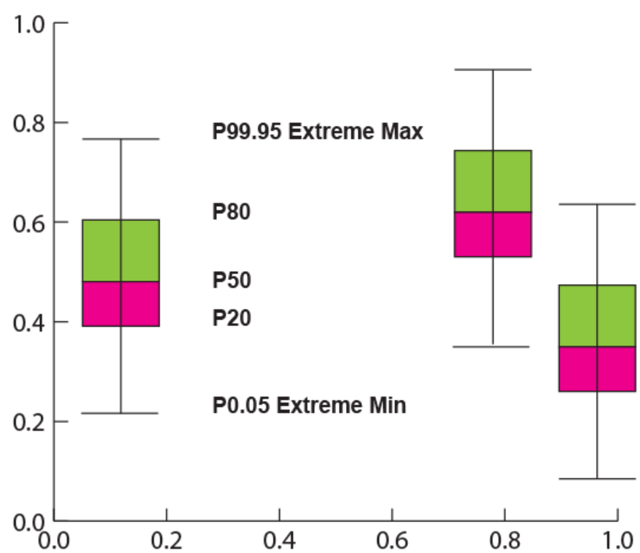
Similarly, in evaluating the economic return (if any) from a resilience investment, we need to understand the confidence level we require in order to undertake such an investment. This required confidence level may vary by stakeholder group. For example:

- Public sector investments in capital improvements typically use a P50 CAPEX value in their planning and budgeting (higher half the time, lower half the time); whereas
- Private sector providers of those capital improvements require higher confidence in achieving their targeted returns and may utilize an estimate associated with a P80 level (achieve their target profit 80% of the time).

This simple example illustrates the importance of establishing and understanding the implications of chosen confidence levels. How do we view these two resilience investments?:

- Investment #1 – Recovery time of lifeline capabilities, services and facilities within 48 hours 50% of the time; Probable economic losses of 5X
- Investment #2 – Recovery time of lifeline capabilities, services and facilities within 48 hours 90% of the time; Probable economic losses of X

The choice of confidence levels on inputs and outcomes is non trivial and requires special attention.



Communicating Confidence Levels

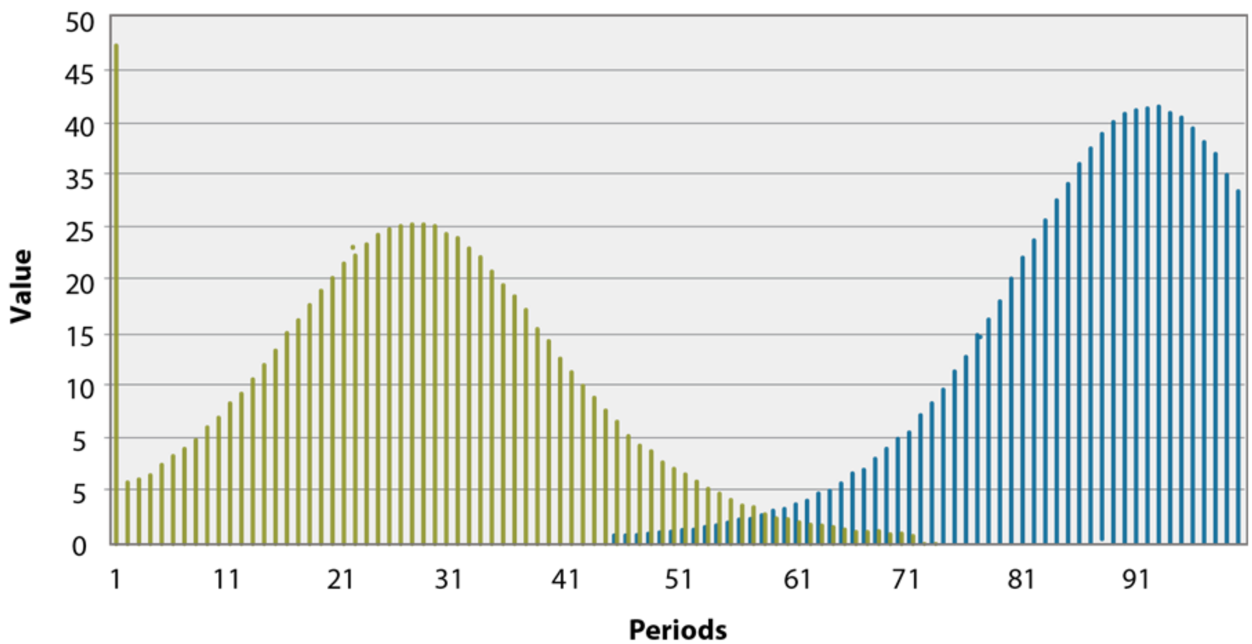
Stress Testing

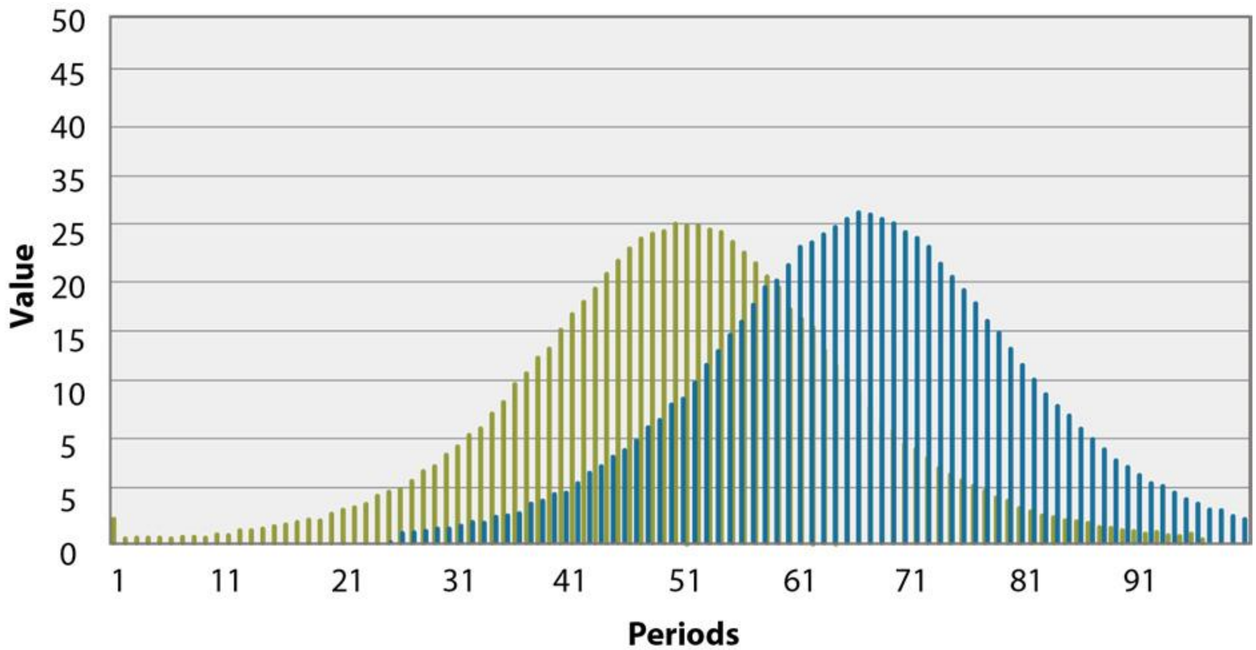
In the initial stages of a community resilience investment optimization, we conduct an LCA as previously described. This analysis is undertaken initially for a base scenario and set of assumptions (CAPEX, discount rate, threat development rate). Later as we reach the final stages of optimization, the preferred alternative can be stress tested by considering alternative assumption scenarios.

These alternatives can consist of both improved as well as degraded alternatives including alternatives that may be associated with extreme failure. The results of consideration of these alternative scenarios can be seen in the following figures showing the probable distribution of economic return on planned resilience investments.

In the first figure, the behavior of economic returns for the planned investment with changed assumptions (green) from the base case shows little overlap with the economic distribution for the base case (blue) performance model.

In the second figure, the base case and stress case show a meaningful overlap in anticipated performance, demonstrating the degree of resiliency in the community resilience strategy we are contemplating.





Summary

This paper provides a framework for the economics of community resilience and touches upon some of the uncertainty factors. These have been summarized in Table 1. Table 2 captures some of the recommendations made throughout this paper with respect to managing these uncertainties.

Key points worth reiteration include:

- Perceptions of risks and uncertainties will vary for each of the four stakeholder groups comprising the "economic community" affected by community resilience action and inaction
- Resilience outcomes require consistency and clarity of definition in order to support high confidence economic evaluations. Three such outcome measures have been touched upon in this paper:
    - RTO – Recovery Time Objective
    - CRT – Current Recovery Time
    - RVR – Resilience Value at Risk
- RTO rationalization and selection requires a multi-stakeholder effort considering different economic framework elements:
    - Lifeline capabilities, services and facilities (response, sustaining and protecting)
    - Critical enabling capabilities, services and infrastructure (recovery and sustaining lifelines)
    - Restoration capabilities and services (long term recovery; economic recovery)

- Multiple futures exist and each may evolve at differing rates. Simplified modeling of temporal variance in longer time frames is required. The concept of Resilience Value at Risk is introduced for these longer time frames.
- Life cycle modeling of community resilience is essential and must include indirect costs and externalities in addition to economic benefits and costs
- Economic benefits can be thought of in terms of avoided costs related to direct damages and economic losses from business interruption
- Life cycle costs associated with economic modeling of community resilience investments include a wide range of risks and uncertainties (see Table 2)
- Indirect costs include those inherent in land use decisions; tax policy or other community resilience incentives; and a range of financial considerations
- Correlation of risks including coupling through constraints are important considerations
- Modeling must consider a range of scenarios and configurations
- Selection and understanding of confidence levels related to assumptions, inputs and outcomes is non-trivial and requires special attention.
- Stress testing of preferred scenarios for changes (better/worse) in key parameters is essential when dealing with an uncertain future

Does this approach to addressing economic uncertainties related to resilience offer an analog for thinking about other long-lived and broadly impactful project investments we manage?

Table 2 **Recommendations for Managing Uncertainty in Economic Evaluations Related to Community Resilience**
□ Develop simplified model for temporal variance of longer timeframe events
□ Fast track resilience related permitting
□ Expand basis of design to include construction, O&M and resilience considerations
□ Transition to performance based standards incorporating resilience
□ Improve methodologies and tools for assessing performance based design adequacy
□ Improve guidance and resilience standard on Threat Hazard Identification and Risk Assessment
□ Improve quality of resilience related estimating design bases (reference class forecasts)
□ Establish national policy on regulatory taxes and subsidies related to resilience
□ Establish national liability protections associated with resilience mitigation

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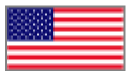
About the Author

Bob Prieto

Senior Vice President
Fluor
Princeton, NJ, USA



Bob Prieto is a senior vice president of Fluor, one of the largest, publicly traded engineering and construction companies in the world. He focuses on the development and delivery of large, complex projects worldwide. Bob consults with owners of large capital construction programs across all market sectors in the development of programmatic delivery strategies encompassing planning, engineering, procurement, construction and financing. He is author of "Strategic Program Management", "The Giga Factor: Program Management in the Engineering and Construction Industry" , "Application of Life Cycle Analysis in the Capital Assets Industry" and "Capital Efficiency: Pull All the Levers" published by the Construction Management Association of America (CMAA) and "Topics in Strategic Program Management" as well as over 500 other papers and presentations.

Bob is a member of the ASCE Industry Leaders Council, National Academy of Construction, a Fellow of the Construction Management Association of America, a member of the World Economic Forum Global Agenda Council and several university departmental and campus advisory boards. Bob served until 2006 as a U.S. presidential appointees to the Asia Pacific Economic Cooperation (APEC) Business Advisory Council (ABAC), working with U.S. and Asia-Pacific business leaders to shape the framework for trade and economic growth and had previously served as both as Chairman of the Engineering and Construction Governors of the World Economic Forum and co-chair of the infrastructure task force formed after September 11th by the New York City Chamber of Commerce. Previously, he served as Chairman at Parsons Brinckerhoff (PB). Bob can be contacted at Bob.Prieto@fluor.com.