MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

22nd Annual International Symposium
October 22-24, 2019 | College Station, Texas

# Managing Tanks as a Portfolio of Assets

Phil Beccue[1], Dan Brooks*[2,3], and Philip Myers[2]
[1]White Deer Partners Decision Consulting
[2]PEMY Consulting
[3]Arizona State University
*Presenter E-mail: phil@pemyconsulting.com

## Abstract

The capital investment in tank storage is a critical component of most energy companies' business model. Decisions managing these assets are driven by the organization's overall performance objectives, business policies, balancing the risks and returns associated with different resource allocations. The discussion that follows in the body of this paper has two objectives: The first is to describe a foundation for evaluating decisions about managing tank risk that takes into account all the risk assessment techniques traditionally used but adds to this a way to incorporate these findings into a decision context that also views tanks as part of an organization's overall business model and managed as part of the organization's overall portfolio of assets supporting its business model. The second objective is to show there are basic analytical tools that add precision to the perspective described in the first objective through straight-forward quantification.

## Background

Managing significant asset investments based solely on compliance requirements, the recommendations of risk assessments output by QRAs, PHAs, or other risk assessment methods ignores the central role these assets (including their risks) play in creating value for the organization. Compliance guidelines provide boundaries on the range of decisions that are allowable, but compliance guidelines by themselves fall short of assuring good or even reasonable value-based and business-model driven investment decisions. This paper describes the way in which tank management can use traditional inspection results or risk assessment results such as probability risk assessments (PRAs) or layers of protection analyses (LOPAs) in a basic portfolio structure that links tank management decisions to the organization's business model and economic objectives at the corporate level.

An organization's overall business model and value-creation objectives should play the fundamental role in managing its portfolio of tanks. This decision context allows the organization to invest in the creation, maintenance, replacement or retirement of tankage based on the ways market conditions, technology, regulatory guidelines, and the organization's business objectives and strategies are changing.

Viewing the management of investments in the tank portfolio as primarily a matter of regulatory or internal corporate compliance is as ineffective as viewing compliance as the basis for the organization's investment in any other asset – personnel, real estate, financial instruments, marketing, logistics, acquisitions, or any other key component of the business model.

This paper describes an energy company's tankage as a portfolio of investments that play a key role in achieving the organization's business objectives. Investments in that portfolio, therefore, would be, within regulatory guidelines, driven by the degree to which those portfolio investments aid achievement of those objectives, balance risk and reward consistent with the organization's policies, and increase the overall value of the organization to shareholders and stakeholders.

Investments at the organization level functions something like bets: the forecasted benefits are compared to the forecasted costs and resources are allocated according to the organization's appetite for risk and the expectations of shareholders or owners. Investments in tanks have basically the same structure at the individual tank level. Inspections are conducted, risk assessments are performed, and estimates of various characteristics of the tanks are used to determine the level of further investment that is warranted. Industry guidelines play a key role in the subsequent tank investment decisions following inspections and risk assessments. This paper shows how tank investments can be viewed as a portfolio of investments serving the organization's business objectives.

Mission-based perspective of tanks as a portfolio of assets

**Overview**

Energy companies provide crucial products and services to any economy: they create and distribute stored energy in the form of fuels. Storage capacity is central to both the creation and distribution of fuels, so investments in tankage is key to mission success. The Department of Energy maintains strategic storage of hydrocarbons to help balance global shortages that could threaten the economic stability of a country or region.

The "mission" of an organization is the set of fundamental objectives or goals of that organization; the set of objectives that describe what the organization values, wants to accomplish, and uses as performance metrics for their operations. Energy company business plans typically include both tangible and intangible objectives; there are clear financial performance targets, but also efforts and investment toward achieving environmental sustainability, an injury-free workplace, satisfied customers and a respected corporate brand and reputation.

This means in practical terms that the organization's mission statement and corporate objectives need to be translated into explicit and measurable guidelines for managers making resource allocation decisions in the various divisions and business units.

Storage decisions considered at the "mission" level of an organization entail a number of strategic considerations. The list can be long or short, but often includes consideration of such things as overall capacity, capacity by product type, location, network connectivity (piping and manifolds), clustering in tank farms, right-of-way and transportation issues, environmental and regulatory considerations, investment and maintenance costs, estimated revenue and profit contributions, and more. Investments in creation and maintenance of storage should be considered in light of alternative investments in other aspects of the organization's business model, as well, but the complexity of technical management and local decision making make these comparisons rare and difficult to characterize. For example, how do returns on investments in maintenance of current storage capacity in some region compare to investments in new types of storage in new locations, or expansion of the organization's business model into new products or partnerships or alternative transportation modes? Since the business consequences of investments in tanks are often left unspecified, these types of business comparisons do not occur.

Consideration of corporate business-model concerns has become particularly important for energy companies over the past ten years and expectations are that shifts in overall business focus for many, if not most, large legacy energy companies will be shifting even more in the next ten years.

Signals of a fundamental and long-term shift in energy company business models include some of the following. In the late 1980s and early 1990s, six of the 10 largest organizations in the S&P500 list were energy companies. Now, only one is. Wall Street analysts used to value energy companies by giving significant weight to the size of their reserves because the organizations were considered to be something like utilities in terms of their ability to generate returns for investors over the long term. Now Wall Street evaluates energy companies more like speculative investments and values them increasingly based on their ability to generate profit for investors. This change in energy markets has shifted energy company business models to focus more on the bottom line and margins. In other words, it has changed the meaning of "risk" for these companies. The companies vary in size, market, operating expenses, capitalization, and other key features of their various business challenges.

In this changing economic environment, basing investments solely or even heavily on generic industry-wide compliance guidelines that are typically business-model agnostic and ignore an organization's specific competitive landscape may not be as helpful as it has been in the stable past for maximizing returns to those investments.

In summary, if tanks are viewed as a portfolio of capital assets and key contributors to the organization's overall business model, then decisions about investments in this portfolio of assets should be considered in light of the organization's overall business objectives and return on investment in storage compared to comparable investments in other aspects of the organization's overall business.

This might mean that, similar to other business units, investments in tank storage are viewed on a spectrum from speculative investment in high-risk, high-return ventures all the way to divestiture and abandonment of localized or regions unproductive business operations.

There would typically be a fairly wide range of tank investment decisions based on the organization's business model and the role that each tank or set of tanks plays in achieving the business objectives of the organization. For illustrative purposes, business-model decisions are consolidated in the remainder of this paper to four common types. These are tank investment decisions motivated by:

- Pursuit of new business opportunities
- Growth of existing business
- Sustaining current business
- Abandonment or divestiture of current business

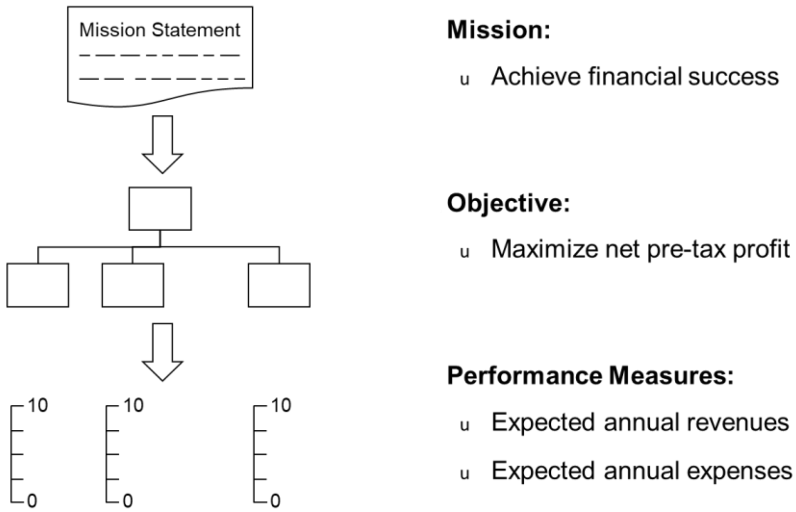
It's important to note that while these decisions are based on the organization's business model (that is, business purposes at the corporate level), the activities funded specifically at the tank or set of tanks level. So, for example, pursuit of new business may mean more frequent use of certain tanks that are in highly sensitive areas and are used for persistent or more toxic products. So more thorough and extensive investigations of risks associated with low probability but high consequence outcomes may be warranted. Is this level of investment a good idea? Figuring that out must include explicit consideration of the business opportunities presented by safely operating tanks – if the business opportunities are small, perhaps not, but if they are strategic, long-term, and large-scale plus are part of the organization's overall shift in business objectives, those investments may be very worthwhile when considered from the corporate point of view.

This example of evaluating an investment in sophisticated risk assessment illustrates the importance of viewing tank storage viewed as a *portfolio* of capital assets. Such an investment isn't an investment in one or two tanks but part of the investment in tankage overall and the role it plays in the business model. Should the portfolio be rebalanced? Should other tanks get less investment as strategy shifts to other parts of the business model? This is consideration of how to optimize the whole of investment in tankage, not just the last or incremental dollar. This is different from a tank-by-tank decision process where each tank is viewed in light of some combination of compliance requirements or location-specific risks or current business uses. Portfolio considerations include the overall role of tankage at the organization level and looks to maximize the total return to investment with respect to that business model, not just the individual benefits of tank-by-tank compliance.

Portfolio analysis can be conducted at many levels of sophistication. What follows is a basic approach that can be tailored to an organization's business environment and situation.

**Conceptual approach**

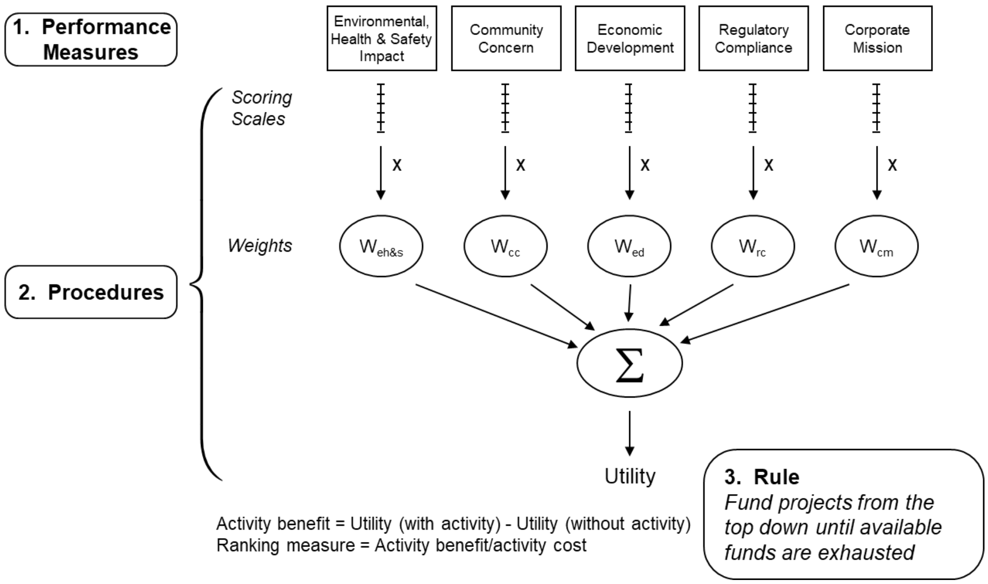
Translating an organization's mission into practical guidelines for decision making is key to prioritizing resource allocation, as illustrated in the figure below.



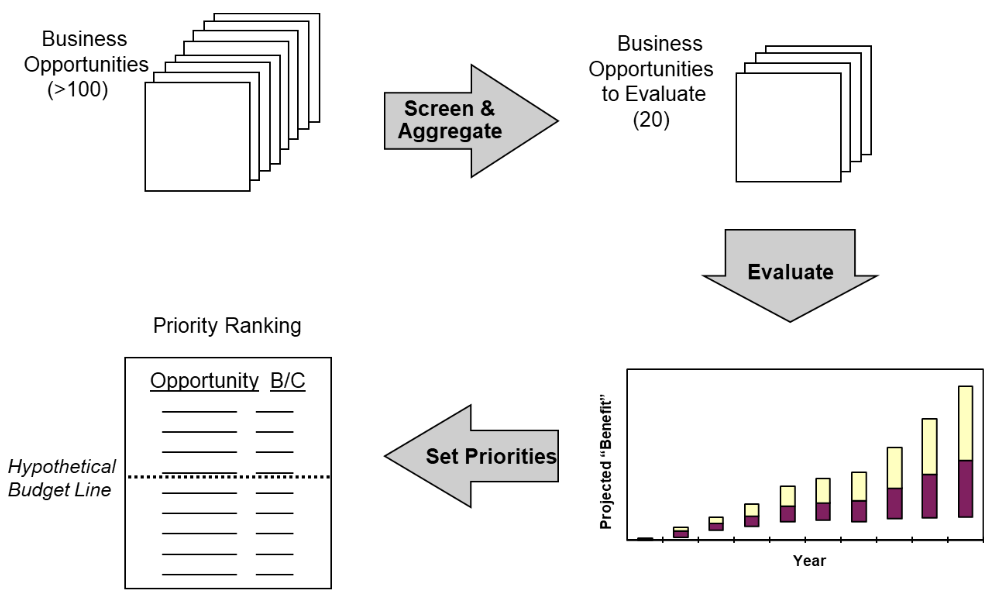

The goal of priority setting is to use limited resources in a way that maximizes the attainment of the organization's mission goals. If resources and time are unlimited, there is no need to set priorities, of course, but given resource constraints, investment decision making attempts to allocate them in a way that yields the most "benefit" to the organization.

"Benefit" is defined here as the degree of achievement of the fundamental goals of the organization as a whole, not the specific benefit to local operations of investment in tankage, maintenance or otherwise. In addition, the portfolio approach takes into account the timing of investments, the expected returns, and the expected risk consequences. Since these are spread over future years, the present value (or net present value) may be managed more precisely through manipulation of investment and risk prevention spending.

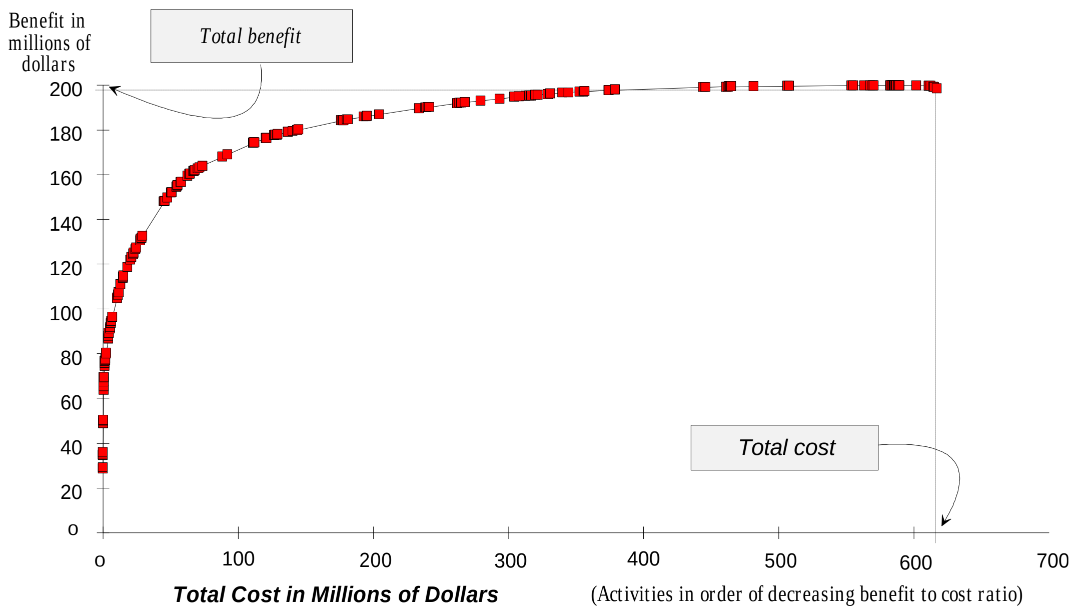
Translating the organization's mission and business model into constituent objectives and performance measures is the basis for estimating the "benefit" of an investment in any project. The diagram below illustrates this process for system designed to prioritize investments in risk-reducing activities for an organization. In addition to financial performance, there may be other key corporate objectives and the value of achieving these objectives can be monetized so that benefits and costs can be compared in monetary terms as a guide to resource allocation.




Once the "benefit" of an investment has been estimated quantitatively using defined performance measures, and the cost of the investment has been estimated using cost accounting, this investment can be compared to any other investment the organization is considering. The diagram below illustrates one way to organize these investment options for comparison relative to their achievement of the organization's mission.



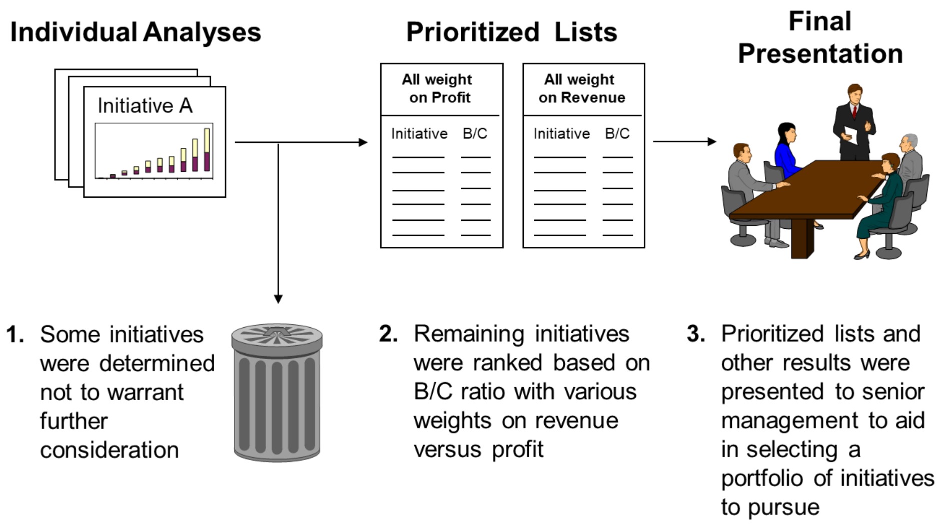

The optimal allocation for any given funding level might look something like the graph shown below. In that diagram, investments in different projects are prioritized based on the benefit-to-cost ratio, so that the incremental dollar is invested in the project with the next best return on investment. This maximizes the return on the marginal or incremental investment. The benefit-cost curve shown in the diagram below is from another prioritization project and some of the projects are investments in preventative and mitigating measures for large-scale risks. By assessing expected present value costs and benefits, these projects could be included in the overall budgeting decisions with other corporate investments.




This approach to prioritizing investments maximizes project-by-project investment decision returns, but it misses the portfolio effects and, in that way, can lead to suboptimal allocations. The remainder of this paper shows how analysis of decisions at the individual tank level can be combined into portfolio decisions that maximize the portfolio investment, not just tank by tank allocations.

"Portfolio" considerations can be included in various practical ways. For example, viewed qualitatively, if investments in tank maintenance are to be based on consideration of risk reduction, revenue maximization, and profit maximization, then performance measures for each of these considerations would be developed similar to the diagram showing performance measures above. Investments (purchase, out-of-service, maintenance, etc.) in specific projects would be evaluated in each of these areas (risk reduction, revenue, profit) at the organization level. Those scores would be combined based on the portfolio priorities of the organization: for example, suppose the financial weighting guidelines were 60% for risk reduction, 15% for revenue growth, and 35% for profit maximization. The combined weighted scores provide a basis for prioritizing investments for this portfolio weighted objective.

A first pass on identifying a portfolio of investments either across the organization or within a business unit (say, within storage management) follows this basic logic.




The overall benefits from a set of investment opportunities can be evaluated at different levels of investment, as illustrated in the next section.

There are challenges to changing the management of storage from a regulatory-driven, bottom-up, risk-driven transactional decision-making basis to incorporating it into the broader mission-driven decision making of the organization based on its mission and business model. There are, after all, many operational benefits and efficiencies to using compliance and broad industry guidelines as the basis for tank-specific decision making. This paper focuses, instead, on potential benefits of considering the portfolio of tanks as a corporate asset. The rationale for investing time in this pursuit with a more critical eye toward compliance-based decision making is similar to Thomas Paine's argument (in Common Sense), that "perhaps the sentiments contained in the following pages are not yet sufficiently fashionable to procure them general favor; a long habit of not thinking a thing wrong gives it a superficial appearance of being right and raises at first a formidable outcry in the defense of custom."

There is inertia and status-quo processes in every business process that make daily operations efficient, and these are necessary. But as technology, regulations, business models and economic markets change, these changes present opportunities for re-evaluation of approaches to decision making. The changes in energy markets over the past decade have brought new value to more integrated and rigorous resource management decision. Management of storage – and management of storage maintenance in particular – is an arena of opportunity because it has so long been left primarily to outside decision criteria in the form of regulatory and event specifics. As Paine said, a long habit of not thinking this was wrong has given it a superficial appearance of being right. That is an expensive assumption to make in today's markets given the alternatives.

### A well-designed portfolio management system

There are a wide range of project portfolio processes, models, and systems available ranging from simple "rank and add" valuations to proprietary "black box" simulations to LOPA and other company-specific techniques, to, finally, formal portfolio optimization models that are rigorous and complex.

What considerations are most important when deciding on how to prioritize investments in storage? In addition to the list presented earlier, special attention should be paid to the *performance* characteristics of the decision-aiding system.

An important consideration is whether the investment decision process provides useful and accurate assessments of the value of various competing investments? Just because a process has been around or used for a long time or because it is well-known or endorsed by well-known sources does not always mean the system is appropriate for the purposes of prioritizing storage investments. There are many approaches that combine relatively ad hoc scoring procedures with ad hoc decision rules to identify "best investments." The degree to which these measures accurately capture the true future performance of the investments being evaluated is questionable.

There is a wide range of commercially available approaches that use score cards, group consensus procedures, voting, value hierarchies and other guides for working toward an investment choice. But energy companies are typically held to a higher standard in the decision approach they take because, as the National Academy of Sciences recommends, decision processes addressing risk in the public interest should provide decision insights that are methodologically based, appropriate in their application, and provide timely and useful insights for decision makers.

Finally, decisions made at the *portfolio* level must take into consideration how decisions made at the *unit* level interact with each other, how they are combined, whether there are combination effects, and other system considerations. This includes the full range of routine tank management decisions such as risk assessment investments or risk management scaling.

The structure of decision analysis modeling meets these requirements for a sound decision support system and the way it can be used at the individual tank and the portfolio of tanks levels is shown in the next sections.

**Portfolio considerations**

Treating a set of assets such as tanks as a portfolio is different from considering these same assets as a collection of similar individual assets. In particular, viewed as a portfolio allows evaluating decisions at a different level and using more appropriate evaluation criteria for those investment decisions.

Sometimes the word "portfolio" is used to describe what is really just a collection of similar projects. The individual projects are evaluated one-by-one independently and the results of different allocations at the project level are aggregated into what are called "portfolio" returns but are often just the addition of the expected returns to the individual investment decisions. Sometimes there is additional sensitivity analysis that shows best-case/worst-case ranges of expected returns but the total returns are driven by the individual decision making. These decisions are often, in the case of tankage, the result of industry guidelines or best practices that ignore company specific financial and business issues and, worse, can be behind current technology and economic trends.

The result is that there can be significant impacts to the overall benefits of this collection of investments at the portfolio level, not at the project-by-project level of evaluation. Ignoring these portfolio-level impacts is a business risk that is often not even thought of, let alone taken into account.

For example, in a portfolio of similar assets – tanks in this case – there are the risks from fluctuations in the individual costs and business returns from each asset, but there may be portfolio-level risks if a large group of the assets are related to each other (for example, all are used for the same large customer so subject to a single-point market impact, or are all for the same product or use the same design or are the same age and condition so may suffer failure rates at the same time, or are all dependent on some market condition or single supplier, creating large-scale business impacts for the organization.

In the same way, a large energy company can benefit from considering investments in their storage portfolio not only at the individual storage device but also at the portfolio level. Portfolio risk and return evaluations are more accurate when used for a group of tanks that serve a key customer or tanks that pose risks for a single important environmental asset or tanks that are all impacted by a change to a particular regulatory requirement or availability of a particular product.

The next sections discuss the first objective of this paper: a description of a way to think about an organization's tankage that uses all the tools of tank risk assessment but also provides a basis for using the financial analyses associated with the organization's business model. In particular, the section discusses how investments – including acquisition, divestiture, maintenance, use plans, and more – in an energy company's storage units can be considered at both the unit and portfolio levels in a sound, practical, useful, and timely fashion with regard or the organization's overall business model, corporate returns and corporate risks.

**Analysis first on a tank-by-tank basis where required**

Using principles from decision analytics and predictive modeling, decisions about design and monitoring can be evaluated on a tank-by-tank basis, combining the inputs from the business demands, risk assessment findings, subject matter experts on tanks, and project management overseeing budgets and work structure.

The case illustrated below involves a decision on the design of a new tank and the type of leak monitoring system that would be most cost effective given the location, contents, and size of the tank.

The design options may be well-defined but how best to monitor for leaks may require some discussion and thought about different ways that could be implemented. The diagram below shows a strategy table that can be helpful to group discussion and combining different technical expertise into a single overall strategy.

Each column represents an aspect of the leak monitoring system that is a decision variable for the tank team. The lists below the column headings are the different options available for that characteristic of the monitoring system.

Different strategies can be considered by looking at different combinations of these various decision variables. Not all combinations make sense, but the strategy table still provides a proven useful took for keeping a larger number of alternatives actively in discussion before jumping right away to one or two alternatives to pursue in depth.

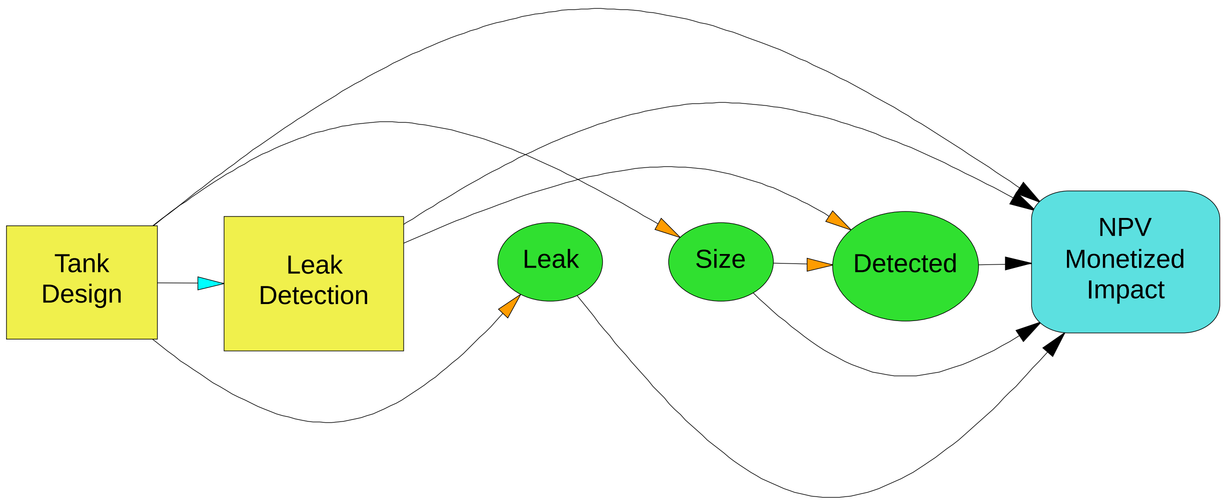
### Strategy Generation Table

| Strategy | Frequency (per yr, per tank) | Frequency variation | Tank use | Type of testing | Test precision | Test-data use |
|---|---|---|---|---|---|---|
| Base case | 0 | Uniform | Demand driven (no testing) | None | N/A | N/A |
| Minimum | 1 | By tank | Testing driven by tank demand | Tightness | Low (20K gal) | Individual test |
| Medium | 2 | By tank location | Tank use linked to testing | Inventory: level | Medium (10K gal) | Test averaging |
| Thorough | 3 | By tank contents | Driven by testing schedule | Inventory: mass | High (3K gal) | Test trending |
| Aggressive | 4 | By tank history | | Soil vapor | | Process control stats |
| | 6 | By tank features | | Integrated combo | | |

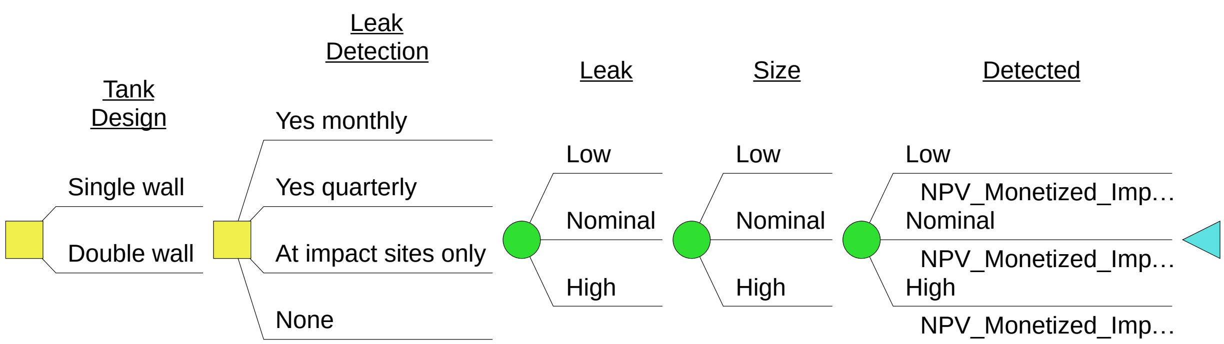
The color-coded combinations represent different monitoring strategies. The table is a template for 6 x 6 x 4 x 6 x4 x 5 or more than 17,000 different combinations. No one would ever look through all those, but the idea is to aid collaboration across disciplines, skill sets, experience, and points of view to find those combinations that might be appropriate for further investigation.

The three strategies identified as examples here are a "Base case" which is to do no systematic or prescribed testing for leaks and only check driven by demand. The "Minimum" strategy is drive by demand at the tank by checking inventory levels with high precision and using test averaging. The "Thorough" strategy tests quarterly by both tank contents and tank history, both by level and by mass, and a high level of precision and includes both test averaging and trending.

These strategies cost different amounts, have more or less disruption on tank use, and provide different levels of protection against undetected and expensive leaks. Using economic analysis from both the costs of testing and the costs of undetected leaks and remediation, estimates can be made of the best overall (in this case, the lowest expected cost) alternative for both design and leak monitoring. The influence diagram below shows the relationship between decision variables (yellow rectangles), uncertainties (green ovals or "bubbles") and the payoff metric (blue rounded rectangle). The arrows show "influence" of the source entity on the target entity.




The decision tree version of the influence diagram above is shown below where the specific alternatives for each node are shown. The blue triangle at the end represents the summary calculation, in this case the expected net present value over ten years of tank life.




The decision tree structure shows, in addition to the two decision variables, three uncertainties explicitly modeled in this example:

- The probability of a leak, labeled here as low, nominal, or high, (where leak probabilities are inserted for each) where these probabilities are influenced by the tank design used, so two conditional distributions;
- The size of the leak, with three possible levels, each with an associated probability based on the tank design and empirical data for the tank, age, contents, weather and whatever other considerations are included in the analysis;
- The probability of detection, which is influenced by the leak monitoring strategy employed and the size of the leak.

Using a set of hypothetical values motivated by an actual application, the decision tree is used to compute the following values:

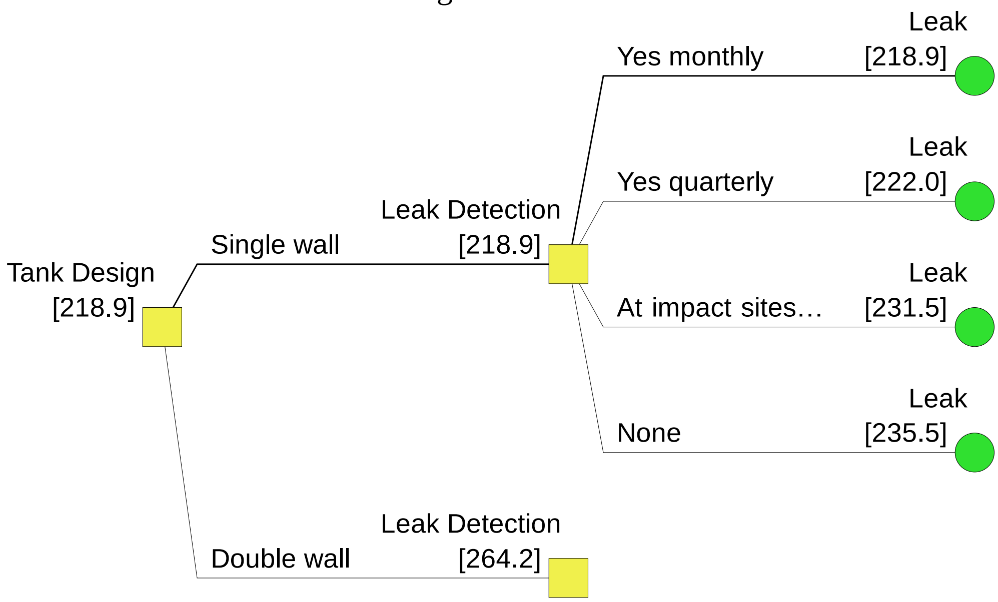
- Monetized values

- NPV of design choice
- NPV of lead detection policy first ten years
- Expected present value of a leak impact to
- People
- Environment
- Assets
- Reputation

- Probabilities, conditioned as shown in the influence diagram

The expanded decision tree below shows the expected values for each strategy combination in square brackets.

This analysis shows that the lowest expected present value cost for the near-term life of the tank is to use a single-wall construction and test monthly using the combination taken from the strategy table. This is better than double-wall no matter what testing is conducted, including "none." Interestingly, the "none" monitoring approach has the highest expected cost due to the impact of an undetected leak. Although these are hypothetical numbers, the motivating example was a large tank location above an aquifer and water system supply reservoir for a city, so the potential for consequences of an undetected leak were significant.



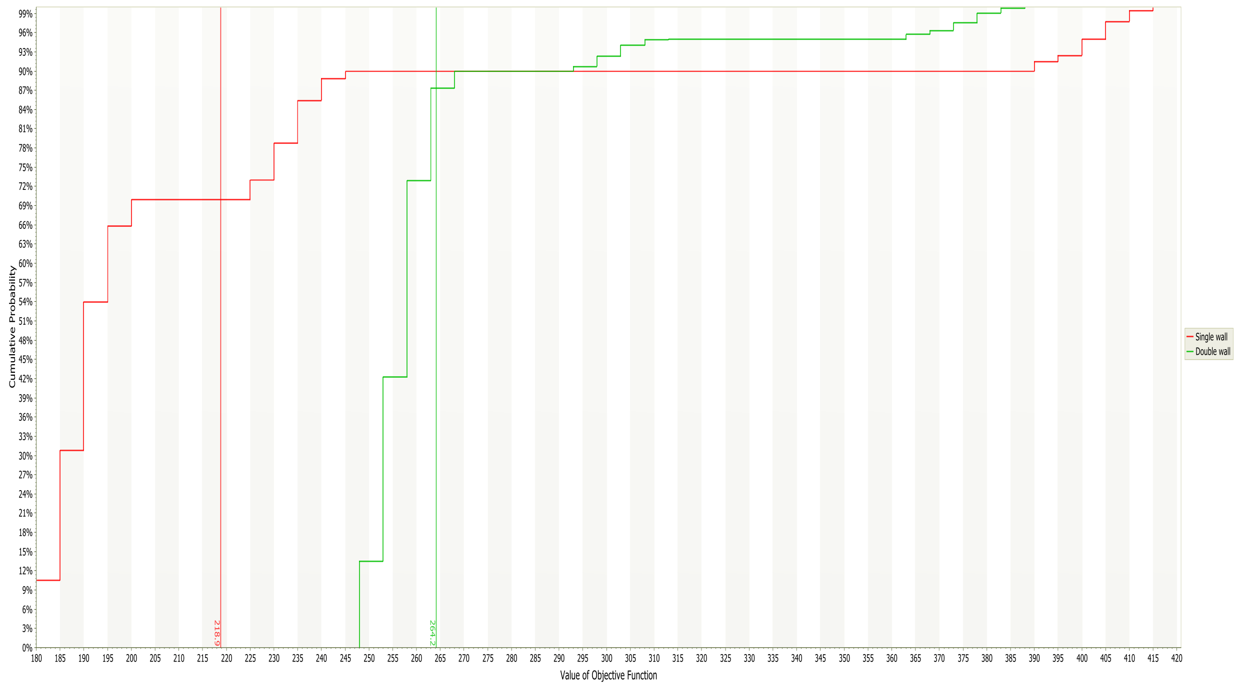

The preferred strategy is a single wall, leak detection monthly. The numbers in brackets are expected NPV in millions over first 10 years of the tank life.

A more detailed assessment of the expected costs can be obtained, if desired, by considering the cumulative probability distributions of the two main design options, as shown in the figure below.

The red line is the cumulative probability of the single wall design and monthly testing. The green line is the cumulative distribution of the double wall design and optimal monitoring strategy for that design.

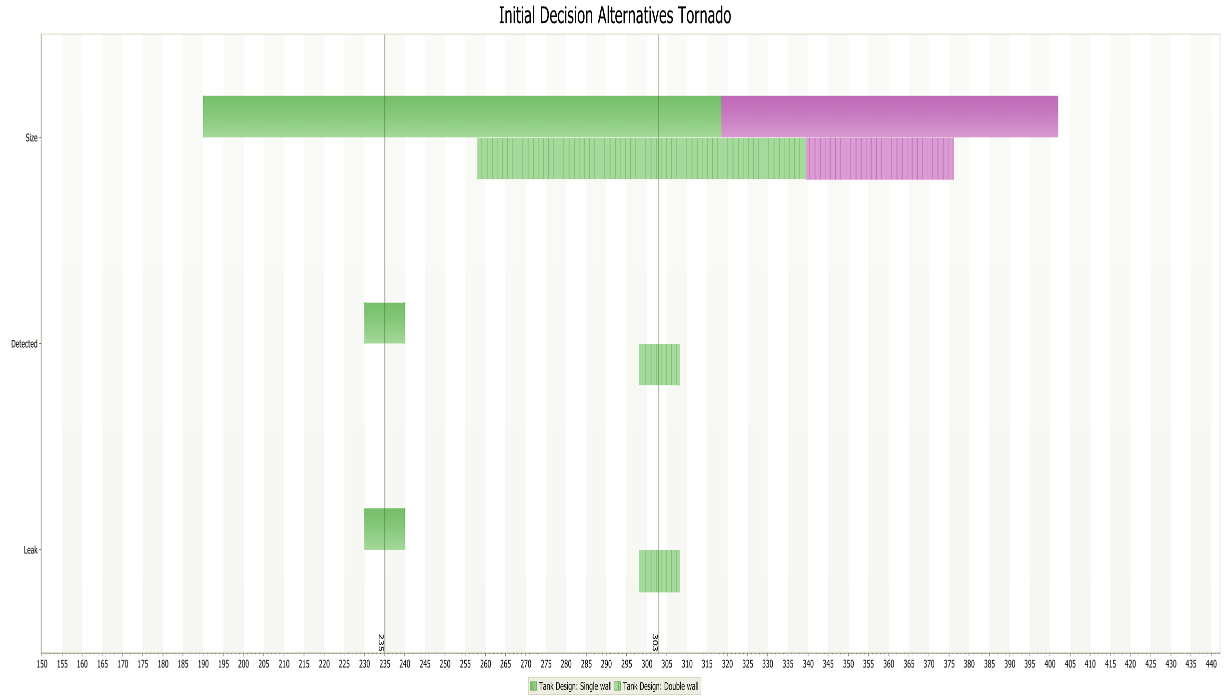
From this, for example, the analysts can see that there is about a 75% chance the actual cost will be less than the expected value (shown by the red vertical line) and a 25% chance it will exceed the expected value with the potential of being a large multiple of that cost, though with only about a 15% chance of a very high cost.

This kind of information can aid re-design considerations or financial planning or insurance coverage decisions.




The cumulative distributions on NPV for each of the alternative designs. Single wall stochastically dominates double wall for these made-up numbers.

This is quite a bit of uncertainty in the actual cost that the tank owner is exposed to. It might be useful to understand what about the tank and the monitoring system is driving this high degree of uncertainty. The tornado diagram below answers that question; the driver on uncertainty in cost is uncertainty about the size of the leak. A large leak can incur a lot of cost before it is detected. In fact, for the larger amounts of leak sizes, the double wall design would actually be the preferred design option, as shown by the change in color to purple.




The tornado diagrams (one for each of the initial design alternatives, single or double wall) for these hypothetical numbers shows that the biggest contributor to uncertainty in the NPV of costs is uncertainty about the size of the leak. If this probability estimate is refined, the uncertainty in future costs will be reduced.

To repeat, a key finding of this sensitivity analysis is that if the chances of a large loss of containment are high enough, the optimal design changes to double wall instead of single wall. This finding may motivate the analysis group to refine the probability estimates to make sure the chances of a large leak are below those cut-off levels. Also note that the risks associated with serious event risks (fire, explosion, over-fill, etc.) are grouped with large-scale business risks such as loss of a key customer, a significant new competitor or regulatory constraint. All of these ultimately matter to the organization at the corporate level and now can be compared directly to each other.

**Tanks as a portfolio of financial assets**

The previous section illustrates detailed analysis at the individual tank level. Once these financial estimates are acquired for each tank, the next level of decision making is to evaluate the allocation of resources across all tanks.

This section addresses the second objective of the paper: a description of how to think about tanks as a whole and their fit in the organization’s business model and strategies. To do this effectively, the tankage should be viewed as a portfolio of investments. There are a number of initial steps in the portfolio approach that are skipped over here due to length constraints. These include consideration of combinations and dependencies in tankage due to business lines, common customers, refinery needs, product and supplier types, and more. Once these dependencies are known and included, they determine the realistic combination of different portfolio options that are available to the organization's management.

Employing a portfolio approach and making decisions at the portfolio level for tanks routinely faces several organizational challenges, some of them hurdles to that management:

- No repair guidelines (at corporate level)
- Localized and disparately-located knowledge
- Localized priorities for project managers
- No best practices at corporate level
- No common objectives
- Questions about applicable specs
- Reason for repairs
- Level of effort: maximum, minimum, satisfactory, local decision?
- Interaction of repairs proposed and impact on which specs become applicable

Making decisions about tank maintenance projects can often end up being governed primarily by considerations not only outside an organization's business model and business objectives but by considerations completely outside the organization: industry guidelines, compliance requirements, "best practice" summaries that come from very different business environments, and other outside sources.

Not only does this reliance on outside guidelines often ignore particular business or economic issues specific to an organization, industry standards routinely lag economic changes, regulatory adjustments, and the necessities of staying competitive in energy environments that are encountering new competitive, now customer demands, and shifting international barriers to free trade.

Viewing tank maintenance projects as investment decisions moves them from being viewed primarily as compliance expenditures to being evaluated in terms of their contributions to the overall performance of the organization in terms of the organization's business model and business objectives.

This implies that business-model based guidelines should be employed when determining what investments should be made in managing storage assets. This has several benefits to the business unit within which the storage assets are located but also to the organization more generally. For example, this approach motivates a reassessment of the overall benefit of the business operations supported by storage, it improves tracking the relationship between investments in storage maintenance and repair to the overall corporate business objectives.

Viewing tank investments in terms of corporate return on investment to business objectives enables project managers and subject-matter experts to more effectively collaborate with their respective skill sets. SMEs can provide insights on the most effective repair strategies for achieving the organization's business objectives which the project managers provide guidance and management for efficiently implementing those repairs or other investments.

Budgets are influenced much more transparently by the expected return to business objectives for specified levels of investment than the tank-by-tank compliance approach that often is most influenced by getting the necessary repairs done within budget using industry compliance guidelines. In this way the organization's overall business model direction business decisions regarding repair expenditures, additional investments in capital assets, operations, on-going maintenance, and metrics for performance of these various expenditures.

Viewing tankage as a portfolio of asset investments views future investments in tankage through the lens of investment decision making:

1. Not all tanks are the same
   - In terms of importance to overall business model
   - In terms of the risk posed to achieving business model objectives
2. Not all investments in tank management are the same
   - Value (importance) of tanks vary
   - Need for repair varies
   - Like all capital investments, the range of "repair decisions" can be large:
     - Repair like new (most stringent specs)
     - Minimal repairs (least stringent specs)
     - Take out of service temporarily
     - Remove from service permanently
     - Remove and replace

Since tank value is based on an organization's business objectives, it motivates explicit consideration of such things as their location in the business network, the customers served, the risk posed to business objectives under different levels of investment and the overall benefit to cost comparison at different levels of investment.

Different approaches to tank maintenance include regular budget allocations (such as a fixed annual percentage of total spend) versus "bandaid" fixes all the way up to expansion and business development investments. Examples of organizational business objectives serving portfolio investment guides include some of the following:

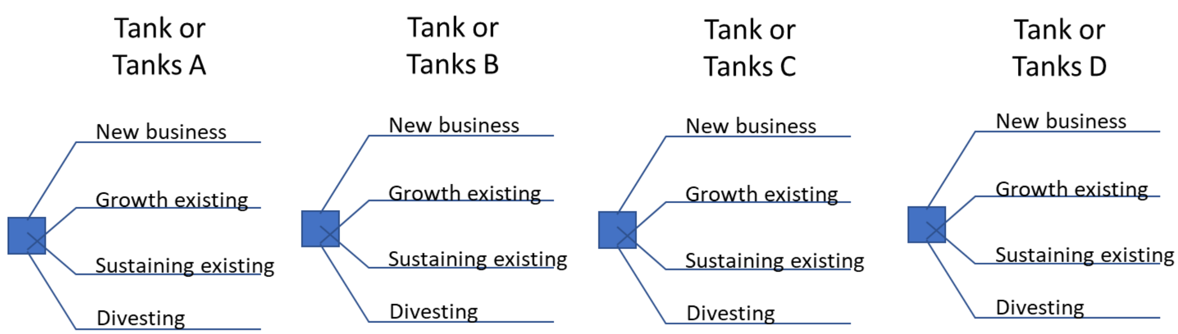
- Example business *objectives*
  - Financial
    - Contribution to revenue stream now (e.g., approximate NPV past five years)
    - Contribution to revenue stream future (e.g., approximate or probability-weighted NPV next five years)
  - Customers served
    - Level of importance to business model now
    - Level of expected importance to business model future
  - Costs of operations
    - Level of operating costs now (e.g., NPV past five years)
    - Level of expected operating costs future (e.g., NPV next five years)
  - Technology age for role
    - Legacy technology and adequacy now and near future

- Example business *contribution*s (and risks to business objectives)
    - System importance
        - Role in overall management of product inventory
    - Item importance
        - Overall importance to product or customer service

It is possible to include monetized versions of investments in safety, health (employees, contractors, the public), environmental enhancement, regulatory rapport, corporate citizenship and other relevant business objectives valued by the organization.

**Portfolio investment evaluation**

Consider, for example, investment decisions for four tanks (or tank groups), as shown below. The specific tank decisions from the previous section have been conducted and now the tanks are being looked at from the perspective of the organization's business model and where those tanks fit into that business model. This may be a time of market stagnation, tight capital, or a time of growth or expansion – whatever the current business emphasis is at the organizational level, that is translated into tank usage. For illustrative purposes, the investment options are reduced to the four alternatives described in the earlier section.




Note that the decisions are not characterized in terms of the activity itself (maintenance, take out of service, etc.) but the *purpose* or business objectives of the organization motivating the activity. This means that the role of the tank in the overall business model has been considered. For the simplified example here, each tank set (A, B, C, D) represents storage capacity that is serving a business purpose and investment in that storage is seen in light of the four objectives shown (assumed here the same for each of the tank sets):

1. Investment in new business opportunities
2. Investment in growth of existing business activities
3. Investment in sustaining current levels of business activity
4. Investment in divesting the storage assets

The range of tank investments might include traditional maintenance or upgrades, but would obviously be broader in that they would include adding new tanks, renting excess storage in another area, joint ventures, or other more complicated business investments revolving around storage management.

When viewed as a connected set of decisions about this portfolio of storage assets, there are 4 x 4 x 4 x 4 ways to combine these sets of  alternatives, or 256 different *combinations* of investments options for this portfolio of tank sets.  The organization would want to pursue the best possible strategy for a given level of total investment, considering the portfolio as a whole.

One way to approach this would be to consider each option for each tank (or set of tanks) in terms of the investment required and the expected benefit from that investment over the decision horizon that is being considered.  So, for example, the organization might consider the present value of the investment, considering the next five years, and the expected net present value of the benefit over the next five years achieved by that investment.

Quantifying benefits can be in terms of financial considerations alone or may include intangibles such as customer support or environmental sustainability objectives.  If intangible objectives are included, their value has to be monetized in some fashion.  There are a number of broadly accepted ways to do this, both by government agencies as well as investments in the private sector.

To maximize the overall value of this portfolio investment, the organization would compare the expected net present value of returns from the investment to the size of investment required for the various combinations of portfolio investment.

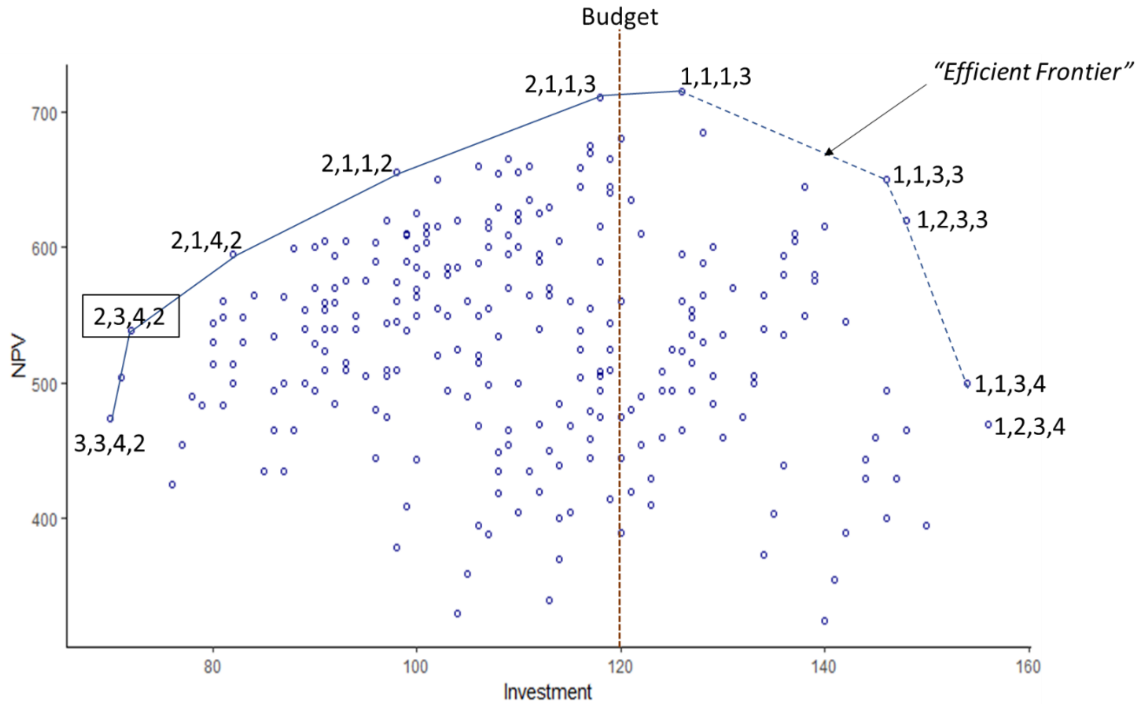
To illustrate the process, consider the following examples of investment and expected NPV for each alternative for each tank set.

| Tank set | Alternative | Expected investment | Expected NPV | Expected benefit-to-cost ratio | Priority |
|---|---|---|---|---|---|
| A | 1 | 20 | 150 | 7.5 | |
| | 2 | 12 | 145 | 12.1 | x |
| | 3 | 10 | 80 | 8.0 | |
| | 4 | 11 | 110 | 10.0 | |
| B | 1 | 22 | 180 | 8.2 | |
| | 2 | 24 | 150 | 6.3 | |
| | 3 | 12 | 124 | 10.3 | x |
| | 4 | 18 | 75 | 4.2 | |
| C | 1 | 40 | 200 | 5.0 | |
| | 2 | 33 | 150 | 4.5 | |
| | 3 | 60 | 135 | 2.3 | |
| | 4 | 24 | 140 | 5.8 | x |
| D | 1 | 35 | 140 | 4.0 | |
| | 2 | 24 | 130 | 5.4 | x |
| | 3 | 44 | 185 | 4.2 | |
| | 4 | 52 | 35 | 0.7 | |

The “x” in the chart above shows the investment with the greatest return *rate* on investment for each tank viewed independently. These tank investments and returns can also be combined to create different “portfolios” representing different alternative investments in these storage assets as a combined business asset group, as shown below.

| Portfolio alterna-tives | Tank investment choices / alternative | | | | PV of Invest-ment | Expected NPV |
|---|---|---|---|---|---|---|
| | A | B | C | D | | |
| 1 | 1 | 1 | 1 | 1 | 117 | 670 |
| 2 | 1 | 1 | 1 | 1 | 106 | 660 |
| 3 | 1 | 1 | 1 | 1 | 126 | 715 |
| 4 | 1 | 1 | 1 | 1 | 134 | 565 |
| 5 | 1 | 1 | 1 | 2 | 110 | 620 |
| 6 | 1 | 1 | 1 | 2 | 99 | 610 |
| . | . | . | . | . | . | . |
| . | 2 | 2 | 2 | 2 | 93 | 575 |
| . | . | . | . | . | . | . |
| 256 | 4 | 4 | 4 | 4 | 105 | 360 |

The portfolio alternatives can be plotted to show the cumulative benefit and cost of each combination of tank investments, as shown in the figure below.



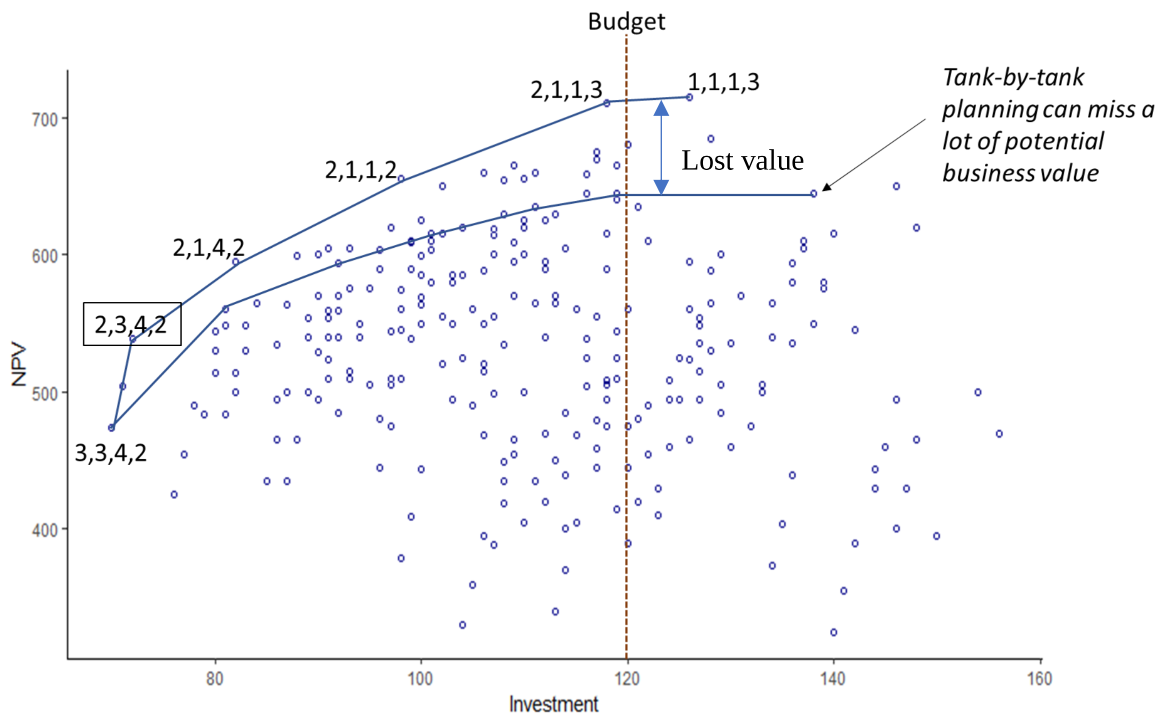

The graphic above shows all 256 portfolio investment alternatives (each characterized by a different combination of investment alternatives in the four tank sets) in terms of the total expected investment on the horizontal axis and the total expected NPV return (on the vertical axis).

A portfolio on the "boundary" of efficient frontier of this collection of portfolio investments shows the greatest return (expected NPV) that can be obtained for a specified level of investment. The hypothetical budget line gives business planners direction in prioritizing the allocation of resources.

Using these example investments and returns, the plot shows that for an investment of $98,000 (if dollar units are thousands for this example), the largest return that can be obtained is $655,000 and that is obtained by investing in alternative 2 for Tank set A, alternative 1 for Tank set B, alternative 1 for Tank set C, and alternative 2 for Tank set D. That is, for this level of expenditure, the best investments are to grow Tank sets A and D and invest in new opportunities for Tank sets B and C. Total return starts to drop for investments above about $130,000, so it would make no sense to invest in these portfolios.

The portfolio shown in a "box" on the graph is the combination of highest return rate on investment for each Tank set – this portfolio has the steepest slope (return rate per dollar invested). However, if the organization is pursuing a growth strategy and is willing to invest more, there are portfolio investments that have greater than even return. The efficient frontier aids the business unit and the organization in setting budgets and allocating resources across business units.

This financial analysis of the tank portfolios can be used to compare investment in storage to investments and expected returns from investment in other parts of the business or other business units or divisions within the organization. So an overall optimal strategy can be designed at the organizational level by combining portfolio investment analyses from these business units or divisions.




Tank-by-tank planning, as illustrated in the graph above, is less effective than portfolio prioritization of investments because the decision framework ignores comparisons of all possible combinations of asset alternatives when considering how to allocate resources. The result is that the organization can be very effective in local decision making yet leave substantial amounts of potential gain on the table.

**Additional valuation capabilities**

This portfolio structure provides the organization with a number of ways to make more specific investigations of tank investments. For example, sensitivity analysis is now possible at the portfolio level so that the impact of uncertainty about either investment amounts or expected returns can be easily incorporated into the evaluation process.

Because the individual tank investment decisions are characterized in a decision tree structure, tornado diagrams or other sensitivity analyses can identify key uncertainties. The organization can use these insights to pursue possible new efficiencies or evaluate the "value of information" more precisely to spot areas where additional testing is warranted. The "value of control" can be estimated in the same way, where additional investment can reduced uncertainty in either total costs or assure less variability in expected returns.

The value of flexibility – "option valuation" of a type – can be estimated. This may show approaches to tank investments that is conducted in stages where the degree of investment in each stage is determined based on the findings obtained in the previous stage of maintenance. These kinds of 'sequential' maintenance strategies have been shown to sometimes provide a much more tailored and cost-efficient approach to managing tanks in service where the primary cost of maintenance is sometimes opportunity costs of being off line.

The description of portfolio evaluation is illustrated in this paper using a basic model of interactions. There are easily available software platforms that allow the analysts to fully integrate the risk assessments and decision analyses that are applied to each tank or set of tanks and include it directly in the portfolio analysis treating all the tankage as a portfolio of investments so that correlations between uncertainties, common vulnerability and more can be included in the investigation of how best to invest in the organization's storage assets in light of the tanks' conditions and the business objectives.

**Summary and examples**

The two objectives of this paper were, first, to describe a way of viewing tanks as both individual assets and also as a part of the organization's portfolio of assets used to achieve its business objectives. The second objective was to describe basic and easily employed analytical tools that add precision to these points of view through quantification. Together, these two points provide a valuable aid to those making very practical and sometimes vexing decisions about how to allocate scarce resources in an increasingly competitive business environment.

One important follow-on to this approach is that this structure buckles the information gathering associated with risk assessment directly to the decision making regarding how to allocate scarce resources at the corporate and business model level. The decision on what to do or not to do with a tank one the risk assessment has been completed should be made in a way that maximizes the value of the overall portfolio of tanks to the organization's business strategy. In the same way that risk is diversified by portfolio thinking with other capital assets and investments, risks should be managed both at the tank and at the portfolio level of tank management for corporate risk management to be as effective as possible.

To summarize, these are the basic steps outlined in the preceding discussion:

1. Tanks: The first level of analysis is the individual tanks. This evaluation can use traditional decision analysis tools to develop a set of strategies based on the age, content, condition, location, and other relevant tank attributes, as illustrated in the leak monitoring example. This analysis aids both project managers and SMEs in determining the timing of inspection and the alternatives that should be considered in managing the tank.
2. Tank sets: Tanks can then be grouped based on dependencies. For example, if the configuration of tanks requires that tank X by taken out of service of tank W or manifold Z are out of service for maintenance then those assets would be combined into a "tank set" as illustrated in the portfolio section.
3. Cost estimates: The result of activities 1 and 2 provides the tank managers with estimates of the potential cost of either inspection or maintenance (or both) activities. These estimates may include more rigorous risk assessments using PRAs or LOPAs as guidelines as well as industry guidelines and regulatory requirements.
4. Value estimates: The organizational business model is now used as the basis for estimating the business value of the tank or tank set. That is, based on the organization's current

business strategies and practices, the contribution of the tank to that business plan is monetized. There are numerous ways this is done; the main point here is that this step links the tank or tank set to the organization's (or business unit's) business plan by quantifying its contribution financially.

5. Cost and value in common units: The expected net present value of the costs associated with different levels of maintenance or other alternative investments and the expected net present value of financial contribution from the tank are put in common units so they can be meaningfully compared.
6. Valuation of final tank alternatives: The final set of alternatives for tank management decision at this budget planning point are finalized and predicted values for costs and contribution finalized.
7. Portfolio valuation step: All combinations of tank or tank set alternatives are constructed, as illustrated, for each portfolio (by region, by business unit, or by other relevant organizational business model structure).
8. Efficient frontier of tank investments: All the combinations of tank alternatives are valued in terms of total expected cost and total expected value gain and plotted. The efficient frontier of portfolio investments is identified.

The efficient frontier of portfolio investments is a useful guide for prioritizing investment in the organization's storage capacity and capabilities. Factors outside the portfolio analysis play a role in determining the ultimate priority of investments, but the efficient frontier is an aid in planning by providing an optimal reference point.

**Example applications**

The following scenarios illustrate situations where tank management decisions might be aided by portfolio considerations that link these decisions to the organization's business objectives:

Example 1: Tank inspection programs. Companies with hundreds or thousands of tanks apply significant resources to programs where the decision rule for resource allocation is strictly time based using the guidelines of industry standards such as API 653, API 510, or other similar approaches. At first glance it may seem that these approaches are the only way to be "good corporate citizens" because the approach is clearly defined by the industry guidelines. On further consideration, it is always possible to reduce or increase the inspection intensity based on both the tank condition and the degree to which the tank supports the organizations objectives.

Example 2: Tankage obsolescence: Tanks are "wasting assets" and are affected by both age related and event driven damage. Age related deterioration has fairly good guidelines in the industry standards. However, traumatic damage such as natural disaster effects (e.g., hurricane, settlement, flood, seismic, lightning) are often subjected to a "repair or replace" objective. Industry standards such as API 579 have been developed which tell an owner if and whether a tank can reasonably continue to operate in its damaged state. But these standards are applied in a one-off approach. Few companies have developed universal approaches that provide guidelines that generally apply to dealing with these assets at the portfolio level.

Example 3: Capacity expansion and business growth: Acquisition of tank facilities of one organization by another is a common happening in the oil industry. These transactions often involve large transfers of oil storage capacity. Because the acquired assets almost always have guidelines and standards for their storage that will differ significantly from the acquiring organization, the condition and costs to either upgrade the facilities to the acquiring companies standards is an ideal application of portfolio theory. On the one hand, by acquiring storage and letting it run for a while to see how it performs has the benefit that it is simpler to do, takes less work than the alternative, and maintains status quo. However, applying the portfolio approach during or after the acquisition allows management to plan changes for the new assets in a way that are going to provide longer term benefits that support the corporate mission and objectives.

Example 4: Market shifts: As markets change the profitability of the various stored petroleum products changes as well. Decisions about adding storage capacity (or reducing it) are often considered within the local business unit but not constrained by the overall framework of an overall corporate portfolio approach to storage.

Example 5: Almost everyone in the storage business has heard of the Buncefield or Caribbean Petroleum tank overfill disasters. New API standards have even been issued that attempt to reduce this potential. What these standards cannot do is to provide the optimal path forward in adoption of new technology for companies that have large portfolios of diverse tank storage systems. Decisions about how to reduce risk in the context of potential risk reduction projects such as the use of safety instrumented systems, how fast to upgrade tank overfill control systems or whether or not and on which tanks these upgrades should be made cannot be addressed by industry standards. The portfolio approach is the optimal approach to answering these questions.

**Concluding comments**

Tankage and other storage capacity are important capital assets supporting an organization's business model. The way in which they support the organization's business objects can change as the business model of the organization shifts in response to new technologies, regulations, market competition, economic factors, and other influences. Viewing tankage through the same lens as other capital investments provides a basis for evaluating investments in maintenance, expansion or divestiture in light of the degree to which that contributes to the current business model objectives.

There are software packages that support both the detailed risk assessments at the individual tank or set of tanks levels as well as the portfolio allocations that are best. Syncopation software's Enterprise and Portfolio models can be used to support decisions made at the tank level, including constrained optimization, uncertainty and risk analysis, and the value of building flexibility and options into the investment strategy so that changes can be made as "learning" occurs during the assessment stages of tank investment..

The portfolio approach to evaluating investments alternatives in tankage opens the door to inclusion of other investment evaluation techniques. Common and sound approaches to evaluating portfolio management decisions include the following theory-based approaches. These have been helpfully grouped in a book on risk analysis by Lee Merkhofer:

1. Decision analysis including tree structures, influence diagrams, uncertainty and utility modeling, and value of information analyses
2. Multiattribute utility analysis, a special application of decision analysis used to evaluate decision alternatives when value or success entails simultaneous consideration of the achievement of multiple objectives.
3. Financial portfolio optimization
4. Financial and real options valuation

The employment of these and related evaluation techniques enables energy companies to allocate resources in the most effective ways as their business environment continues to change. It also provides a context for more efficient and effective collaboration of skills both within and between different business units.