Improved Selection of Technically Attractive Projects Using Knowledge Management and Net Interactive Tools

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ABSTRACT

Conventional technology forecasting and selection practices, in the Western World, suffer from several shortcomings including: weak criteria for developing and evaluating forecasts, limited tool sets for developing possible future states of implementation, anchoring in current functional capability and strong dependance on functional experts. Techniques enabled by the existence of the World Wide Web bring additional knowledge assets to assist in developing suitable forecasts and related technology selection. Additionally, techniques developed by Altshuller provide a powerful set of visioning tools, titled the Laws and Lines of (Technical System) Evolution, to enable improved identification of future product and technology constructs. The Laws allow for thinking about system evolution while the Lines provide insight into implementation. These techniques are integrated to form the majority of a proposed technology identification and selection process because they provide a criteria for developing and establishing technical forecasts that is rooted in extensive study of prior inventive results.

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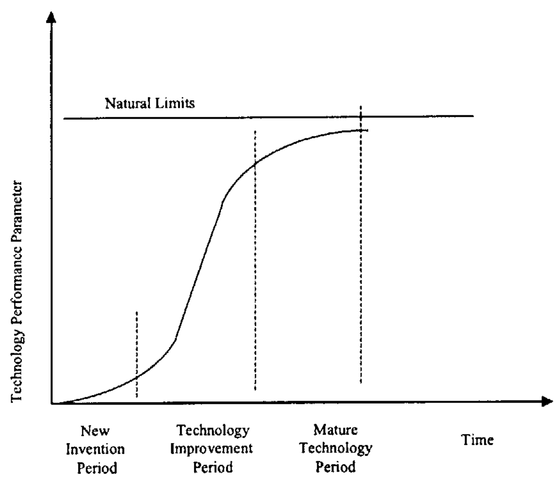
CHAPTER 1: INTRODUCTION – TECHNOLOGY IDENTIFICATION

Holistic technology strategy incorporates elements of competitor analysis, assessment of corporate competency and development of technical capability. Hundreds or thousands of technical persons working in given fields enable the last of these, technology capabilities. Engineers and scientists within an organization are often tasked to improve the functionality, reduce the cost and improve the overall effectiveness of a given subsystem by improving the performance of the underlying technology.

The organization develops deep specialization in key areas. Experts with deep knowledge in specific areas are developed, and the organization continues to work to extend the performance of their technological implementation. Experts outside of the organization are sought to increase the organization's effectiveness in the implementation of their key technology. Correspondingly, the organizational structure often comes to model the product structure in an attempt to maintain world class expertise and focus on specific technological implementations.

Eventually, work to improve the performance, via a given technological implementation, results in decreasing returns on investment over time. Incremental changes in performance are realized, however, the rate of progress slows. The organization continues to develop a deep reservoir of knowledge and deep insight into the technology that is now considered a competitive edge to the corporation. This growth in performance and the eventual leveling off that occurs is often represented by an S-curve as shown below in Figure 1.

Figure 1: General Form of Technology S-curve (Betz, pg. 308)



Unfortunately, for the corporation in this position, the leveling off of the S-curve often coincides with several behaviors. Often the advantaged knowledge in a given corporation starts to become more diffuse across the industry. The information diffuses across the industry via patent filings and disclosures of other kinds in technical journals or by reverse engineering. This diffusion is accelerated with the existence of the World Wide Web. Eventually organizations with lower cost structures, may start to "move in" and capture market share. The mature organization starts to feel threatened and works to continually differentiate its products. However, because the technology has become mature, product differentiation occurs in ways other than utilizing knowledge from the advantaged technology.

New technologies may be imbedded to give additional featuring to the product. Marketing, sales and branding techniques may be used to improve product positioning. Additionally, the organization may try to exploit its understanding of their current customer base to develop additional improvements in the product in historically advantaged areas.

Lastly, from a consumer perspective, there are few gains in performance of the product. It is harder to tell the difference between competitive products and decisions are made increasingly on cost alone. Deficiencies in the product are accepted as the status quo, and shortcomings of the product can become latent needs.

The description of this process may seem quite reasonable. The organization is trying to exploit its initial technological advantage and maintain performance leadership to allow it to grow and meet corporate and stockholder expectations. Unfortunately, competitive pressures eventually give rise to market share erosion as others "catch up". The organization inevitably looses some share of its technical advantage and must rely on other features of the corporation to maintain its leadership position. A competitor's successful implementation of an alternative, and superior, technological scheme can further erode this advantage. Additionally, the previous incremental performance advantage associated with a firm's leadership in the technology may not be valued as highly as alternative performance or feature criteria. The technology's performance is no longer at a differentiated level and therefore not recognized by the user. This provides additional opportunity for competitors that realize alternative performance and feature criteria and introduce products that address these needs.

Therefore, it is in the organization's best interest to anticipate shifts in technology that effect their competitive advantage. This paper proposes a process that can be used to assist in determination of an appropriate technology strategy.

Chapter 2 reviews some of the more common techniques used principally in the Western world. This includes a discussion of "normative" and "explorative" techniques and a brief discussion of apparent practice by several companies interviewed.

Chapter 3 reviews two additional areas of technique associated with the increased information assets of the World Wide Web and insights generated by Altshuller as part of his studies on the inventive process while in the former USSR. These techniques form the majority of the proposed process because they provide a criteria for developing and establishing technical forecasts that is rooted in extensive study of prior inventive results. Additionally the proposed process provides a set of powerful visioning techniques to assist in the identification of future product and technology constructs.

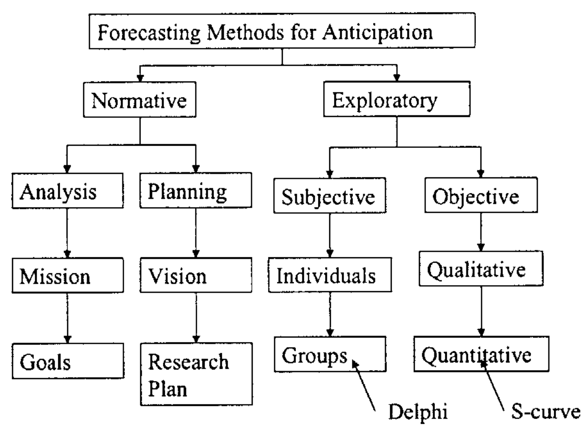
Chapter 4 integrates techniques introduced in Chapters 2 and 3 into a process of technology forecasting and selection. Appendix A.2 includes a graphic tying the process together to assist in understanding of the process. It may be useful to the reader to refer to this diagram while reading Chapter 4.

CHAPTER 2: GENERALIZED TECHNOLOGY IDENTIFICATION AND SELECTION PROCESS

Technology Forecasting Techniques (Normative and Exploratory)

Worlton (Betz cites (Worlton, 1988)) has developed a logic tree representing much of the literature concerning forecasting methods. His logic tree is shown in Figure 2 below:

Figure 2: Worlton Logic tree for forecasting approaches.



At the highest level the literature is generally split between exploratory and normative techniques. Betz points out that exploratory might be more clearly termed "extrapolation".(Betz, pp. 306) These techniques attempt to anticipate the future by looking at the trends in the past and "advancing step by step toward the future". This section of analytical techniques includes the generally familiar technology S-curve (objective, quantitative) and the Delphi method (subjective, group). Normative techniques are focused on "inventing some future and identifying the actions needed to bring that future into existence" (Betz cites (Worlton, pp. 312)). These techniques intend to develop strategy and processes that will bring about the desired future. In a sense these techniques are forecasting the future by putting plans in place to facilitate it's occurrence. Betz indicates, "The principle method here is a morphologic analysis of a technology as a system." (Betz, pp. 307) Explanations of these and other favored forecasting methodologies are discussed below.

S-curve

The general form of the S-curve as described by Betz was shown previously in Figure 1. The curve represents the change in a technology's performance parameter level, as perceived by the user of the technology, over time. It implies increasing value to the user and can generally be broken down into three sections.

The first of these sections is the new invention period. This is the point in time that discovery or "invention" occurs. The inventor is working to implement some new insight into a product framework. Once in a product implementation, the user can realize some benefit and the technology performance parameter increases. This is often a time of product uncertainty as a firm seeks to understand the long-term viability of the product or technology. The speed at which this alternative technology is adopted is often dependent on the state of the previous technology. (Altshuller, 1984, pp. 211)

The second of these sections is the technology improvement period. During this time the corporation has typically started to realize financial gain from early product technology implementations. The firm works to improve the technology and differentiate itself from alternative suppliers of the product technology.

The last of these sections is the mature technology period. It is at this point the physics and natural phenomena enabling use of the technology impedes further improvement. Monies spent by the firm typically result in diminishing returns because the science being exploited is nearing its theoretical limit.

In general, deciding which of these three sections a given technology is in is enough resolution to make many subsequent strategy decisions. It is not necessary to be completely certain which point the firm is at within each of these regions.

The transition points between sections in the S-curve do take on added importance. It is at these points that technological paths forward require conscience shifts in the firms strategy. At the first transition, when technology begins to rapidly accelerate in its improvement of performance, the firm needs to move from an investigative frame of mind to vigorous commercialization. If it does not, it is likely to be left behind by firms that more rapidly implement improvements. At the second transition, when gains in the technology's performance begin to level off, the firm needs to actively search for new technological implementations. Continued investment in their core technology is becoming less efficient and they need to be aware of alternative technologies that may supersede theirs.

The definition of a particular S-curve is matched to a specific technological implementation. This specific technological implementation is the basis for its definition and will be adopted for the balance of this paper. The convenience of the S-curve to describe growth patterns may result in some initial confusion when surveying the literature. Alternative definitions that have been used include tracking growth of a particular performance parameter independent of the underlying technology or growth in the market associated with introduction of product or technology concepts. These alternative definitions of the S-curve are beyond the scope of this paper. Betz has a thorough review of developing technology S-curves in his 1993 book. The process can be summarized as follows (Betz, pp. 325):

1. Identify a key technical performance parameter.
2. Collect existing historical data on technical performance since the date of innovation of the technology, and plot them on a time graph.
3. Identify intrinsic factors in the underlying physical processes that will ultimately limit technical progresss on the technology.
4. Estimate the magnitude of the natural limit on the performance parameter, and plot this asymptote on the graph of the historical data.
5. Estimate the time of two inflection points between the historical data and the asymptotic natural limit (first inflection from exponential to linear rate of progress and second inflection from linear to asymptotic region).
6. Expert forecasting of the exact times of inflection will likely be more unreliable than their anticipation of the research issues required to be addressed for inflection points to be reached.

Delphi

The Delphi technique essentially drives an expert panel towards a consensus opinion while preserving member anonymity. Group interaction is carried out by questionnaire, sharing of the results from the questionnaires and then cycling through the process again until the group comes to a common viewpoint. The technique appears evolved out of concern that group dynamics on "expert panels" were not ideal and that anonymity provided some advantages. (Betz pp. 328, Wissema 1982)

Betz reports on work by Rowe, Wright, and Bolger (Betz, pp. 330 cites (Rowe)) comparing the results using the Delphi technique to results using more conventional "panel of experts". They conclude, "that inadequacies in the nature of feedback typically supplied in applications of Delphi tend to ensure that any small gains in the resolution of 'process loss' are offset by the removal of any opportunity for group 'process gain'". This suggests that the gains in using Delphi's anonymity come at an offsetting cost. The process loss that Rowe is concerned with is the lack of introduction of particularly insightful analysis from some individuals of the team. This insight may not be communicated effectively in the course of providing anonymity and may result in a degradation of the results.

Morphological

While it is useful to the commercial enterprise to realize when they are reaching the limits of their current technology, they may still be left with the question of what technology to move to next. Additionally, even with a solid technology there is the possibility that an improved technology will arise which will quickly obsolete the firms advantaged understanding. Therefore, it is useful to anticipate the rate of technological change as suggested by the S-curve or Delphi technique *and* the direction of technological change. Morphological Analysis of a technological system has been promoted as one technique to anticipate the direction of future trends.

Betz reviews one such example done by Foray and Grubler. (Betz, pp. 354 cites (Foray)) The technique builds a "set" of system alternatives. The generic process is presented briefly as follows. The first step is to carefully define the system in terms of its functional capability. Define what the system transformation is to be. The second step is to abstract the key parameters of the identified functional capability. These parameters create the functional capability. A "matrix" of product concepts performing the functional capability can be developed with alternative levels and combinations of the abstracted parameters. Listing all possible combinations of the abstracted parameters at different levels essentially does this. This matrix of alternative products can then be examined for logical inconsistencies. When these illogical concepts are removed, a final set of possible product concepts that provide the functional capability via different parameters remains in the matrix.

Multivariable Extrapolation Techniques

Wissema discusses extrapolative techniques incorporating information from technology changes in multiple areas that may have an effect on future technology constructs. (Wissema) These techniques may have strong applicability in networked technologies that require complementary asset and complementary technology development for success. Wissema suggests the more important techniques in this field are cross impact analysis, mathematical models and scenario techniques.

Cross impact analysis: This technique essentially involves three general steps. The first step is for experts to judge the trend of technology growth and its value at some point in the future. Secondly, they are then asked to "weight" the interactions between various trends. This can be difficult because the number of interactions grows quickly with the number of parameters under study. A modeled score, for a given technology, based on the interaction values estimated and the trend of the technology can then be compared to the estimated score. Differences in the modeled score and the estimated score can then be compared to iterate expected trends and future values to arrive at a consensus opinion.

Mathematical models: System Dynamics is one field where future states are anticipated largely on multivariate inputs. Models are typically built by experienced model developers based on discussion with experts in the field of study. These models are then compared to individual "mental models" and models of actual history to gain consensus on their accuracy. Alternatively, individual companies may have forecasting models they have developed based on unique insight or experience.

Scenario Analysis: Scenario analysis creates a number of alternative "what if" or future states. These representations are intended to capture the effect of societal and technological trends on future technology states. As Wissema describes, "They are usually slightly schematic, archetypal descriptions, intended to make clear to the reader and researcher what the consequences of certain situations and actions are." (Wissema) What is particularly valued in this analysis is that the relationship between scenarios can be considered. Common valued technology elements of alternative scenarios might imply it is low risk to pursue a given technology because regardless of the specific scenario that results, the technological need develops in either scenario.

Schwartz suggests that scenario building is an art but indicates that there is a generalized process that can be followed. (Schwartz, pp. 28) He also suggests building of no more than three scenarios to help the users clearly envision the range of possible outcomes. The process steps Schwartz suggests are mapped to utility in technology identification as follows:

- Isolate the decision that is to be made. In technology forecasting and selection this is largely going to be to decide which, of a set of technology opportunities, is best suited for implementation.

- Think of societal and economic factors that might influence the decision. Examples include increasing environmental awareness, population growth in some regions and population stability in other regions, the emergence of Asia and China as a market, mapping of human DNA and the increased connectivity provided by the World Wide Web.

- Rehearse the implications. Determine how the technological path will be effected by the factors that have been listed. Look, in particular, for interconnections between possible scenarios and factors. Try to group the factors and effects into logical scenarios of no more than three to express a range of outcomes. Look for themes that pervade all the scenarios to help identify high probability outcomes.

Technology Forecasting in Practice

While extensive bench marking of practices in industry was not a major thrust of this work, several companies were interviewed to gain insight and perspective for writing of this paper. Typically, those interviewed had a forecasting strategy that was an informal hybrid of the some of the techniques discussed. As a generalization, the companies interviewed gathered experts with the principle emphasis on deciding what technologies would be needed in the future. This is to say that little time and attention was placed on rigorously identifying the maturity level of their current technology. The process used to make decisions was typically informal and structured around group meetings. With one exception, the decisions made were difficult to trace and the information that went in to making the decision was not visible to the community as a whole, or rigorously maintained in the organization. Extensive benchmarking of organizations may be suitable for future studies to allow for development of processes to alter current practices. Inferred from these observations is that much of the technology development that currently occurs is the result of unstructured expert opinion.

Critique of Current Technology Identification and Selection Methodologies

Firms faced with the prospect of a leveling off in technology improvement at the mature end of the S-curve, in a sense, are trying to recreate the initial technological advantage that gave rise to the firm's initial success. This initial technological advantage may of come about in many ways. It is often argued that the insight that generated this initial advantage came about serendipitously. Somehow a critical mass of insight, both technical and consumer was gathered and integrated to allow a novel product application to develop.

Early on in many major companies a single individual was able to integrate a variety of information sources without regard to organizational structure or anchored perceptions of how things should be done. However, the technologies and science needed to implement a particular product concept may have been available for years or decades before a given individual was able to develop a critical mass of insight and information. This time lag associated with realizing these product and technology concepts is another reason for improving the technology identification process.

Current forecasting techniques attempt to assist in recreating this technological advantage. However, as already alluded to they suffer from several weaknesses. They are summarized as:

- Exploratory techniques use growth in a single performance parameter. They, coupled with the experts understanding of the underlying physics, provide guidance in the ultimate performance capability of the technology. Ideally, they can anticipate this leveling off point and work to identify alternative technological implementations with superior performance and feature sets desired by the customer. However, there is little agreement on the effectiveness of these forecasts, and the exploratory methods do not purport to identify what the emerging alternative technology will be or what the alternative performance and feature sets will be.

- Normative techniques, especially morphological forecasting, do provide some assistance at determining possible future states of implementation. However, they suffer from a lack of objective criteria to evaluate them. Labeling of what are called "illogical technological implementations" is likely to be driven by the users known technology space and perception of unacceptable performance tradeoffs. This is problematic because an individual and their known technology space is small compared to all known technological effects in the science today.

- Additionally, morphological forecasting is anchored in the use of a clearly defined "functional capability". While it is likely that a system will need to retain its principal functional capability there are many examples where technology is extended to additional capability not initially envisioned by the innovator. Firms anchor on their initial vision of the technology and, coupled with their desire to satisfy their current customer base, limit their awareness of the extensibility of their technology. Identification of this extensibility needs to be incorporated into a forecasting process.

- Underlying all of the current processes is the use of "experts" in the work. As already suggested, the initial technological advantage may of come from a single individual who was somehow able to integrate information from a variety of fields to come up with an advantaged system. While undoubtedly experts are an important part of any forecasting process there is no expert that is aware of the multitude of technological effects known to the world today. Typically, especially in mature companies, experts are recognized by their deep knowledge in a single or a few fields. As such, it is unclear that functional experts will be best at integrating information from disparate fields to generate a new insight enabling an advantaged product technology.

CHAPTER 3: ALTERNATIVE / INTEGRATIVE TECHNOLOGY FORECASTING

To address several of the shortcomings of conventional forecasting techniques several tools need to be utilized. These tools, mapped to the weaknesses previously described, should:

- Provide improved credibility of the forecasts, presumably rooted in some objective measure. Guidelines should be provided to enable the innovator to identify what an emerging alternative technology or alternative customer and performance set might be. Inherent in these guidelines should be some criteria for selecting a particular path. Guidelines have been established by Altshuller and incorporated in TRIZ. (TRIZ is a Russian acronym that stands for the Theory of Solving Inventive Problems.) Selection can be done by an assessment of ideality.

- Create an improved process for considering "illogical" technology concepts should be created. Illogical technologies are often considered illogical simply because of the limited knowledge and problem perspective the innovator has. Use of the World Wide Web (WWW) and the related knowledge assets can supplement the innovator's knowledge base and help the innovator circumvent what are initially considered illogical concepts. [1]

- Extend the system's functional capability. Again, Altshuller has codified observations associated with how functional capability is extended. Abstracted statements of functional capability can aid identification of these opportunities. These observations are embodied in TRIZ's Laws of Evolution and provide guidance for extended functionality based on historical patterns of system change.

- Provide additional knowledge assets to the expert. Provide a framework to integrate these knowledge assets to help generate insight and novelty of design. The WWW and the use of knowledge management tools allows the expert to increase their knowledge assets, increasing the probability that the innovator can integrate information from disparate sources and generate the insight needed for novel product technologies.

Although not directly suggested by the previously listed weakness, any forecasting methodology will have an inherent level of risk. Therefore, the process should incorporate some level of risk assessment and process for risk mitigation.

The balance of this chapter introduces several additional concepts that have been suggested to improve technology forecasting and identification. These concepts come

[1] TRIZ's disciplined approach to developing problem statements is helpful for recognizing and breaking "illogical" or contradictory facets of a particular design. While only alluded to in this thesis, problem formulation and resolution of conflicts is an important facet of problem resolution.

primarily from Russia or are enabled by information access via the World Wide Web. Chapter 4 then arranges these concepts and proposes a hybrid of conventional and "new" techniques to improve technology identification and selection.

Observation of Patent Patterns - Altshuller

One early user of patent databases that are now easily accessible via the World Wide Web was G.S. Altshuller. Altshuller's extensive review of patent databases allowed him to develop insight into the prevailing Laws of (technical system) Evolution. These observations can now be used to give some level of objectivity to decisions that the forecaster must make.

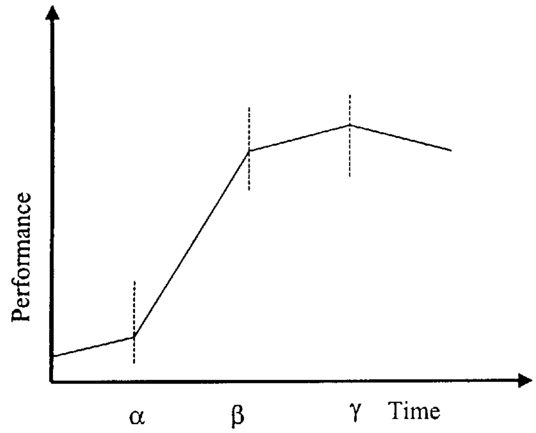
Criteria for patenting work largely centers around three general concepts. The idea must be novel, useful and nonobvious. As such, it represents a reservoir of information concerning innovation associated with products and technologies.

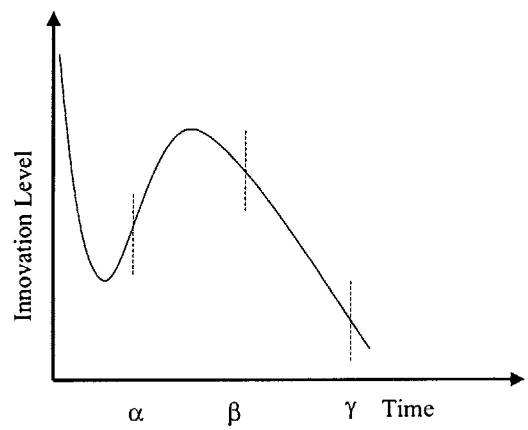
Observing patent strategies by firms it is clear that not all patents express the same level of novelty associated with the technology being patented. Patents are often written to cover as much of the technology space as possible without being overly broad. If they become overly broad the patent becomes more difficult to defend. Conversely, a given patent may be very narrow in its focus, especially when the surrounding technology space has a high density of patents. As such, the patent may not represent incremental maturation of the technology but simply a repositioning of elements to give an alternate implementation of the technology.

Altshuller, in examining the patent literature, classified patents in five general categories or levels. (Altshuller, 1984, pp. 16-26) Also, while reviewing and classifying patents under study he noticed trends associated with the patent "level" as it related to the maturation of technology. He expressed the maturation of technology generally as an "S-curve". (Altshuller, 1984, pp. 205-223) However, in detailing the S-curve he broke it into linear sections to enable easier visioning of the relevant sections of the curve.

Figure 3 and Figure 4 below show the performance increase with time as modeled by the S-curve and the corresponding level of invention over time as the technology matures.

Figure 3: S-Curve; (Altshuller, 1984, pp. 207)
Figure 4: Level of Invention; (Altshuller, 1984, pp. 207)





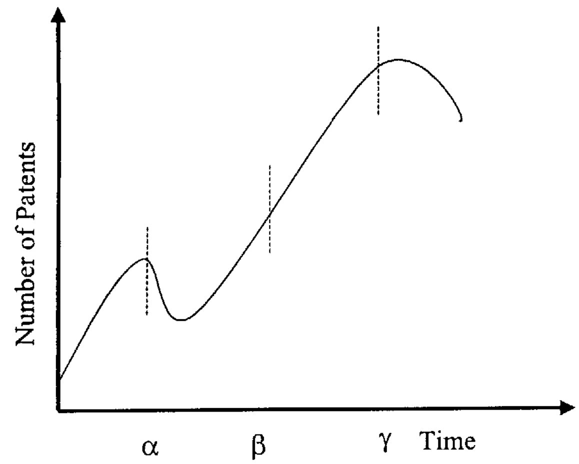
The rationalization behind Altshuller's observations is that early in the S-curve there are insights that represent a high level of invention. This is the point in time when the innovator's work borders on discovery. This is typically the result of several thousand experiments by many individuals culminating in the discovery of a new phenomenon. After this initial discovery phase the community of inventors struggle with understanding the discovery, resulting in several lower level innovations. These lower level understandings progress the technology, but more importantly, eventually allow for higher level innovations to emerge that drive accelerated improvements along the S-curve. Eventually, the technology reaches maturation and the resulting patents are of marginal importance to improving the technology. The Levels of Invention as described by Fey are shown below in Table 1. (Fey)

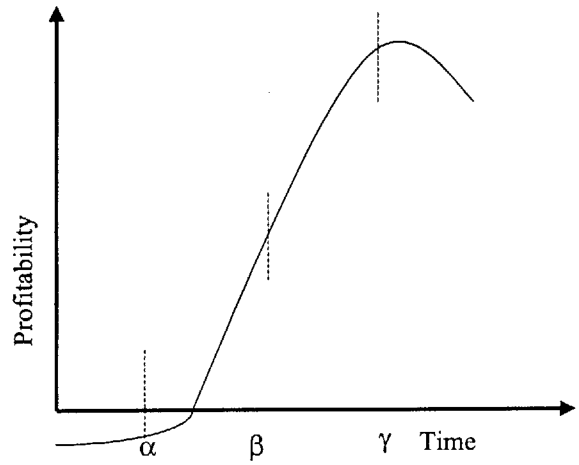
Table 1: Level of Invention

Level 1	Improvements that do not resolve any system conflicts and are localized in a single sub-system of the technological system.
Level 2	The conflicts may have been already resolved in similar systems (e.g., a problem related to cars is solved by a technique developed for trucks). [Author note: Solutions found to conflicts in similar systems are applied to resolve conflicts associated with the current system.]
Level 3	System conflicts are resolved within one discipline (e.g., mechanical engineering, chemical engineering). One element of the system can be completely changed, with a possibility also of partial change of other elements.
Level 4	Development of a new system. The system conflicts are resolved by interdisciplinary approaches, so a mechanical problem can be solved by chemical or electrical engineering techniques. The developed concepts can usually be applied to many other problems of the lower levels. Example: Electro-discharge machining.
Level 5	Pioneering breakthrough invention: usually a creation of a new engineering discipline. Examples: invention of airplane, invention of computers; invention of lasers, etc.

At maturation, the level of invention is relatively small. The associated patents are often related to cost reductions or additional “featuring” of the technology. The mature technology is facing increased cost pressure as its profitability decreases due to competition and diffusion of knowledge associated with the technology. In an attempt to preserve their advantage the mature industry may invest more. This typically results in more patents; however, they are at a lower level. The result, as observed by Altshuller is shown in Figure 5 and Figure 6 below,

Figure 5: Number of Patents; (Altshuller, 1984, pp. 207)
Figure 6: Profitability; (Altshuller, 1984, pp. 207)





As a practical matter, this technique complements conventional S-curve processes. Conventional techniques often rely on a standard performance metric. In some industries it may be difficult for all participants to agree on a most important metric. This increases the difficulty in determining the appropriate S-curve. Altshuller's observations provide an alternative methodology for verifying the maturity of a given technology and assist the strategist in determining the state of a given technology.

Observation of Patent Patterns - Mann

Darrel Mann (Mann, Web References) leverages Altshuller's observations and discusses two additional patent based methodologies to speed the patent review process and facilitate generation of the curves seen by Altshuller. The patent analysis that Mann proposes is particularly useful when a firm needs to understand if a given technology is reaching maturation and leveling off in performance progress. These are the number of cost reduction related patents and the number of symptom curing patents. Both of these patent types may be easier to detect than explicit mapping of invention level to each patent. By screening related patents for these criteria first it may be possible to ascertain if the technology is leveling off without review of all related patents.

Cost and symptom curing patents result as the mature technology attempts to improve itself by minimizing the inherent problems associated with the technology without necessarily addressing the root cause of the problem. Changing of the fundamental technology typically can address the root cause more efficiently but may require a much greater change in the organization and is therefore not generally desirable by the mature organization. An example of this type of "symptom curing" work might be to add a muffler to a design to reduce the noise in a product rather than reducing the amount of noise generated by switching to a fundamentally different design.

Observation of Patent Patterns – Aurigin , CHI Research Inc.

Use of the World Wide Web and related technologies to search and summarize information from patent databases coupled with Altshuller's observations provides a methodology for effectively utilizing patent databases to improve the forecasting methodology. However, given the extensive size of the patent databases it is clear this is currently a time consuming process necessitating the involvement of experts to classify the patents.

Use of Mann's proposal to classify patents based on "Cost" or "Symptom Curing" can help speed the process, especially if it is suspected that the technology is maturing. However, incremental improvements made during the course of evolution require that the patent data be normalized to see if cost or symptom curing patents are increasing with time.

Unfortunately, there is no official categorization of patents by "level" as observed by Altshuller or "type" as observed by Mann. The closest official description of the importance of a patent may be the Federal Court's designation of "pioneering patent". However, even this term is subject to broad interpretation with no objective standard or definition. (Hawley) A number of studies, as reported by CHI Research, have suggested that citation history is a relative measure of a patent's worth. One study of particular note was conducted at Eastman Kodak. Several expert evaluators at Kodak were asked to rank the importance of nearly 100 patents. After the ranking was completed, their ranking was compared to the number of subsequent citations of a patent. The study found that if a given patent was cited 5 or more times, it was ranked highly by the Kodak evaluators. (CHI cites (Albert, Avery, Narin, & McAllister, 1991))

Patents are cited if it is felt they provide relevant information to the examiner that aids them in determine a patents novelty, lack of obviousness or usefulness. Failure to provide relevant citations can result in invalidation of the patent. In addition, if the examiner identifies additional relevant patents, the examiner will include these additional patents in the citation record. (Hawley) As such, citations often provide a trail of related technological improvements as subsequent inventions overcome limitations seen in earlier inventions.

Citation tracking tools are currently available with products such as Aurigin. Therefore, use of citation records should provide a speedier way to identify patents of critical importance. Patents with a high citation count should be classified first. Patents early on in the "S-curve" will likely have high citation frequency with topic matter predominately focused on the underlying technology. Patents late in the "S-curve" with a high citation frequency are likely to be instances where the technology has been extended or focus solely on cost and symptom cutting measures.

Emphasis on classifying patents with high citation frequency should allow the forecaster to make speedier decisions about which part of the S-curve they are on. Coupled with the experts knowledge of the technology, this provides an objective means for the forecaster to challenge their conclusion about the maturity of the technology. If the expert's opinion is in agreement with the Level of Invention model that Altshuller cites the forecaster can be reasonably sure that the forecast is accurate. Unfortunately, this process is still left with at least two issues.

The first of these is associated with fast moving industries. In fast moving industries the patent database might be obsolete and of low value to the forecasting process. This is because patents typically take two years to issue. In these industries this is considered a very long time.

In these industries it is proposed that databases tracking "Scientific Journal" citation record and frequencies associated with journal articles be used[2]. Journal articles with a high citation frequency should be classified by the "level" of invention being discussed in the article. It is anticipated that articles in these journals may be, to a certain degree, self-selecting in the level of innovation discussed. Journals typically seek to publish information that is perceived as "cutting edge" and therefore many of the articles are likely to be associated with innovation at generally higher levels than the patent database. While this situation precludes matching inventive level to location on the S-curve using simply an average innovation level it will achieve several other benefits relevant to forecasting.

- Make the company aware of alternative technologies that are being studied. These, in turn, can be reflected on during technology selection processes that will be discussed later in this paper.

- Educate the expert on perceived shortfalls in current technology performance capability by informing them of alternative technologies intended to overcome these shortfalls. This, in turn, should assist the expert in determining factors limiting performance associated with their current technology.

The second shortfall associated with patent citation records is associated with technology fields having low citation history. In technologies that are extremely new, there may not have been enough time for a citation history to be built up. It is likely that these technologies can be identified very quickly because of their low citation frequency. Given that the forecast is intended to place the technology on the S-curve it is likely that this technology will be placed on the emerging section of the S-curve. Alternatively, an old technology that never matured will fall in this category. Assuming that it did not mature because alternative technologies were superior, it is unlikely that this technological path that should be pursued. However, care must be taken in concluding this. Technologies could be in a period of low inventiveness and low citation frequency because they are waiting for complementary technologies to mature to support their use.

Understanding a given technology's place on the "S-curve" does not assure a decision about which alternative technology to pursue. An ultimate decision about which technology to pursue goes beyond a forecasting analysis. However, the forecasting analysis can be used to provide information for development of the business strategy.

[2] One provider of this type of service is the Institute for Scientific Information.

Many of the business considerations involved are beyond the scope of this paper but may include issues of the firm's complementary assets and the firm's ability to purchase or develop alternate technology. The process for developing a specific technological path informing the corporate strategy process is discussed below.

Identification of Future Technology State

To develop a framework for predicting the future states of technology that goes beyond forecasting of the S-curve, it is first necessary to introduce Altshuller's observation of patent patterns he calls the Laws of Evolution. These Laws represent guidelines that describe how technological systems have typically evolved. They can be used to guide prediction of future states, and coupled with the S-curve, used to guide the corporate strategy making process.

While reviewing the patent literature, Altshuller also described several Lines of Evolution associated with particular generalized technological states. These Lines are useful for guiding the implementation of product concepts suggested by the Laws and are useful to the individual innovator working at the subsystem level. The Laws allow for thinking about system evolution while the Lines provide insight into implementation. The Lines will be discussed subsequent to a review of Altshuller's Laws of Evolution.

While the Laws may provide insight to generate several technological and product paths, it is still up to the corporation to decide which of these paths is favored. This paper will describe the use of "ideality" as a principle criterion for guiding the decision.

Lastly, it must be recognized that this entire process has an inherently high level of uncertainty. Therefore, the innovator must provide insight into the level of risk associated with implementation of the technology. This uncertainty can be mitigated with appropriate risk management tools. This topic is discussed further in subsequent sections.

Altshuller's Laws of Evolution

Altshuller's analysis of patents revealed patterns associated with the evolution of technology. He called these the Laws of Evolution. They are listed by Fey as (Fey):

1. Increasing Degree of Ideality

2. Completeness

3. Harmonization

4. Energy conductivity

5. Non-Uniform Evolution of Sub-Systems

6. Transition to a Higher-Level System

7. Increasing Flexibility

8. Shortening of Energy Flow Path[3]

9. Transition from Macro- to Micro-Level

10. Increasing Degree of Substance-Field Interactions

Each of these is discussed below.

1. Increasing Degree of Ideality

Ideality is a principle concept within TRIZ. (Fey) Altshuller describes the concept as, "The ideal technical system is one whose weight, volume and area strive toward zero although its ability to carry on functioning at the same time is not diminished. In other words, the ideal system is when there is no system but its functions are preserved and carried out." (Altshulter, 1984, pp. 228) To evaluate ideality properly the principle technical performance parameter must be at the same level. Altshuller provides an example relating to the automobile. While automobiles have gotten progressively larger, if their size and weight is normalized for speed, the principal technical performance parameter, they have in fact gotten lighter.

2. Completeness

This law defines a system and helps develop a framework for interpretation of the other laws. Altshuller argues that, "Each technical system must include four basic parts: an engine, a transmission, a working organ and an organ of steering." (Altshuller, 1984, pp. 223) The imagery associated with this phrase is strongly biological in nature, presumably reflecting Altshuller's belief that technical systems evolve in predictable patterns, much like living organisms evolve. The definitions of these elements are clearer when studying the balance of TRIZ. Steering implies that some level of control is available. Working implies a useful function is the net result. Engine implies that energy is provided (or created) to the system. Transmission implies that the energy input is transferred to the organ creating the function.

Altshuller explains (Altshuller, 1984, pp. 224) that not only does this form the basis for the definition of a system[4], a most important consequence of this law is use of the relationship that exists between system parts to control the system. Specifically, it implies that for a system to be controllable, at least one of its parts must be controllable.

3. Harmonization

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[3] As a matter of historical accuracy, Laws 1-7, 9,10 are credited to Altshuller. Item 8 is credited to Fey and Rivin from work in 1993. (Fey)

[4] Altshuller classified three of the Laws of Evolution as being in the group of "statics" laws. (Altshuller, 1984, pp. 223) These laws must be minimally satisfied for the system to exist or for it's "start of life" to occur. The laws in this group are completeness, harmonization and energy conductivity. While the function of the parts within the system continue to improve, systems that do not minimally satisfy these laws do not exist.

Altshuller argues, "An essential condition for the living viability in principle of a technical system is the harmonisation of the rhythms (frequencies of vibration, periodicity) of all parts of the system." (Altshuller, 1984, pp. 227) One interesting example of harmonization involves the cooling fan on cars, which, in early implementations, ran all the time. It was not until 1951 that a clutch was added so that the fan only ran when the engine was hot, improving fuel efficiency. (Altshuller, 1999 pp. 31)

4. Energy Conductivity

As suggested by the law discussing system Completeness, there is a transfer of energy that occurs within a system. As systems evolve they provide improved transfer of energy to the subsystem that requires it. Altshulter points out, "Many inventive tasks boil down to selecting ... that form of transfer which is more effective..." (Altshuller, 1984, pp. 225)

5. Non-Uniform Evolution of Sub-Systems

Systems are made up of subsystems. Subsystems evolve at non-uniform rates. This non-uniformity creates conflict and opportunity at various points in time as subsystems get out of "balance" with each other. Altshuller cites an example of ocean going vessels that continue to grow in size and power while their braking systems have not evolved at the same rate. This has resulted in increased stopping times of these vessels. (Altshuller, 1984, pp.229) A more modern example is the disk drive in the personal computer. Components of the personal computer shrunk in size at various rates to allow for portable computing. However, some of the subsystems lagged behind. One such subsystem was the disk drive. Firm's that recognized the disk drive's shortcomings and responded to it enjoyed success in this market. (Christensen)

6. Transition to a Higher-Level System

Altshuller called this law, transition to a super-system. (Altshuller, 1984, pp. 229) This law addresses the combination of several "mono-systems" into a homogenous bi-system up to and including a heterogeneous poly-system. One such system that is currently being pursued is the combination of the Internet with wireless services and cellular using wireless applications protocol. (Holtstein)

7. Increasing Flexibility

According to this Law, technological systems develop from rigid structures to flexible adaptive ones. The development of variable position wings on aircraft is one example of this law.

8. Shortening of Energy Flow Path

Energy can be transferred in a variety of ways including physical linkages and fields. As systems evolve they transfer the energy more efficiently. Typically, intermediate subsystems result in energy loss. Therefore, as the energy path is shortened the system typically becomes more efficient.

9. Transition from Macro- to Micro-Level

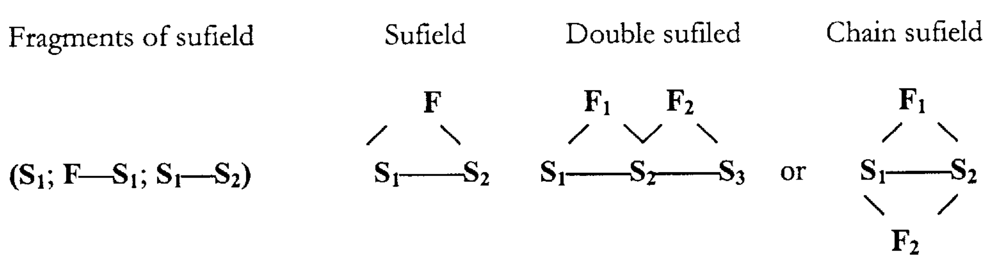
Altshuller argues that the transition from macro to micro may be the main tendency associated with development of modern systems. (Alstshuller, 1983, pp. 230) Many functions are carried out by equipment that is miniaturized. Even jet engine design is being effected by this evolutionary effect. With the availability of micro-machining and micro-fabrication jet engines are envisioned that could be used to power a variety of portable devices. (Epstein)

10. Increasing Degree of Substance-Field Interactions

To properly understand this Law involves discussion of the Su-Field (sufield) analysis that Altshuller proposed to identify and correct problems. At a high level there are three "active agents" present in any system. S1 is a substance that needs to be changed, S2 is the substance that acts as the "instrument" or change agent in the system and F is the "field" that provides the energy or force to change S1. The substances and fields are defined in very broad terms to encompass any two things that interact with each other by an interactive behavior defined as a field. (Altshuller, 1988, pp. 52)

Fey describes this law as follows:

"This Law (frequently also called the Law of Increasing Controllability) states that technological systems evolve in the direction of increasing degree of substance-field interactions, i.e., fragments of sufields evolve into complete sufields; then complete sufields evolve into double and chain sufields.



The advantage of double and chain sufields over single sufields is that the former have the higher degree of ideality (they need less [fewer] elements to perform more functions)."

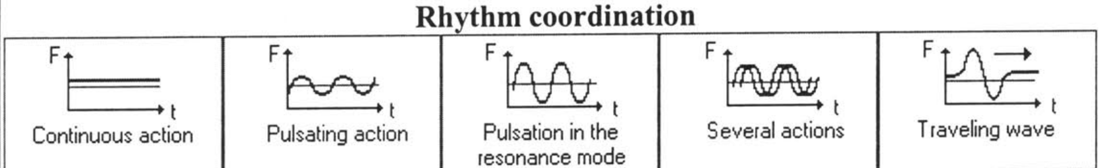
Lines of Technological Systems Evolution

While reviewing the patent literature, Altshuller also described several Lines of Evolution associated with particular generalized technological states. These Lines are particularly useful for guiding the implementation of product concepts suggested by the Laws and are useful to the individual innovator working at the subsystem level. Many of these Lines are suggested by the Laws, however, they typically represent specific manifestations of the Law. While the Laws allow for thinking about system evolution, the Lines provide insight into implementation.

One example, as incorporated in IMC's Techoptimizer™, Version 3.01 Professional Edition, that is related to the Law of Harmonization is the use of Rhythm Coordination. Invention Machine Corporation (IMC) provides an example of it as applied to an extrusion die as follows:

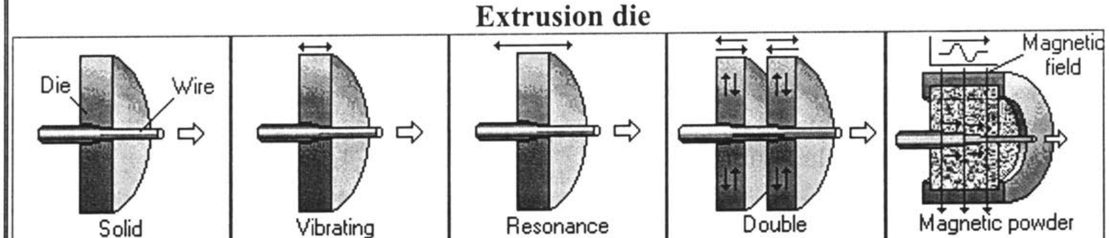
Figure 7: Example of Line with Application, Techoptimizer 3.01

Rhythm coordination



- New engineering systems are developed in such a way that effect of an object on another object, or a working member on a article becomes dynamic and matches operating onditions. Continuous action is replaced by a pulsating one, pulsation frequency is selected to match most operating conditions of engineering system. Additional actions are introduced and their efficient interaction is arranged.

Extrusion die



- A die is made of a plate of hard steel that has a tapered hole. A wire is drawn through the hole, which compresses it. This decreases the diameter of the wire.
- A die oscillates in the direction longitudinal to the hole. This makes it easier to draw the wire through.
- A die oscillates with the resonance frequency intrinsic to the wire. This decreases the force necessary to draw the wire through the hole.
- Two oscillating dies are mounted one after another. One die helps push the wire through the other die. This more easily deforms the wire and more quickly passes the wire through the dies.
- The die is a casing that contains ferromagnetic powder. A traveling magnetic field compresses the powder around the wire. The wire is efficiently compressed, and die wear is eliminated.

(used with permission)

World Wide Web to Speed Implementation

These Lines provide specific guidance to the innovator as they try to implement designs suggested by the Laws. In addition, they provide the individual innovator, working on the subsystem level with guidance on how their technology will likely move forward. Theoretically, this provides the innovator with insight to develop future technological states. An additional benefit of use of the lines is the firms increased ability to generate blocking patents ahead of their competition, moving the technology up the S-curve in advance of their competition.

With the advent of the WWW and search agents such as CoBrain , the innovator is poised to quickly act on the Laws and Lines cataloged by Altshuller. The Laws and Lines provide a set of guidelines, based on historical trends, that the innovator can use to envision future technological states. In some cases this may be enough for the expert to envision the state of implementation. TRIZ offers a disciplined process that helps the innovator define the problem properly and develop an understanding of what is needed for implementation. Use of the WWW to accelerate the team or the individual in envisioning of these implementation states is recommended.

Cataloging of scientific effects has historically been done on index cards. For example, Jules Verne had a card index containing more than 20,000 entries with information about technology, geography, physics and astronomy. (Altshuller, 1996, pp. 152) With the advent of the World Wide Web, inventors now have ready access to information describing a multitude of scientific effects and provide the innovator with increased understanding of alternative technological fields. Access to this information allows the innovator to consider a much greater solution space when solving problems. With the WWW, the innovator has access to "knowledge" existing outside of their expert domain that can now more easily be applied inside their domain. Codifying of technical effects observed by others has been done by some, such as Invention Machine. (CoBrain, Web Sources)

Invention Machines' CoBrain™ is one such commercial tool that works with the WWW to provide the innovator with a "catalog" of effects realized in many different fields. (CoBrain, Web Sources) Additionally, it has the capability to review information to develop additional sets of scientific effects. What is particularly attractive about CoBrain's™ approach is the use of semantic technology to identify solutions associated with a technical problem of interest, not a given "category" the information is placed in. Categories are typically mapped to a general topic, and often not to problems being solved. However, as suggested by Level 3 and higher innovations that are described in Table 1, solutions often come from alternative areas and fields. Current categorization practices therefore may actually restrict the identification of useful information from alternative fields. CoBrain's™ semantic technology attempts to circumvent this by using Subject-Action-Object engine to identify cause and effect relationships between Subjects and Objects in the text of a document. (CoBrain, Web Sources) This allows it to identify solutions to problems placed in documents in unexpected categories.

In future years it is expected that semantic processing on the web will further increase the users ability to access information than might be applied to their field. This capability already exists commercially with internal databases as manifest in CoBrain™, and Excaliber Technologies' Semantic Network technology. (CoBrain, Excaliber) These tools generally use abstracted forms of the search request to help identify relevant information to the user. A request to "dry paper" might be abstracted to "remove water" or "destroy water" to allow a wider set of solution alternatives from differing fields to be identified by the search. Often these abstractions are used in alternative scientific fields to solve similar problems. These alternative functional descriptions can provide insights to solve problems previously thought unsolvable.

Ideality – A criteria for decision.

Ideality can be defined as performance divided by cost. Ideality is a central theme in TRIZ. (Fey) Performance is the "level" of function associated with a given design or technology. Cost is wholistic. It is intended to include the cost with overcoming problems the design creates, the unit manufacturing cost, the cost to society as a result of system failure, or some wide scale detrimental effect such as pollution. In the limit its value is infinity as the cost associated with the design goes to zero and the performance is boundless. Tsourikov has suggested, that the level of ideality also relates strongly to societies acceptance of a particular concept. (Tsourikov, Interview Notes) As such, it is a useful criterion for identifying the strongest technological path forward.[5]

Some authors have chosen to express the denominator in the ideality expression as the sum of cost and harmful effects. This notation more clearly emphasizes the importance of recognizing problems and inefficiencies associated with a given technology's implementation. Therefore, in summary, ideality can be expressed as:

Figure 8: Ideality Equation

$$\text{Ideality} = \frac{\text{Performance}}{(\text{Sum of Costs} + \text{Sum of Harmful Effects})}$$

While the Laws and Lines of Evolution will guide the innovator in generating a path forward, it is inevitable that multiple future states will be suggested. Therefore, the principle task that the innovator faces at this stage of the process is deciding which technological paths to pursue.

It is proposed that the principle task at this point is to consider the design's ideality. Solid technical strategy will require additional analysis of the technologies under consideration. However, the resources should not be focused on specific product implementation. Instead the resources should be focused on determining the technology's ideality. This suggests that the work will largely be to determine and anticipate the ultimate leveling off in performance that should be expected, the cost that will be incurred at this point in performance, and the resulting harmful effects. This is anticipated to be a comparative study between technological possibilities and therefore does not need to have absolute measures associated with it.

[5] Strong, explicit examples of determination of ideality are not common in English. They are generally in Russian or held as property of the corporation sponsoring the study. (Fey) This provides opportunity for additional study in ideality and its related metrics.

Rating of ideality very early in the identification process can be imprecise and may require additional study after technology identification to properly consider a technology's promise. However, the cost can be expressed not only in dollars, but also in size, weight or availability. (Fey) The use of a relative assessment should aid the process because an absolute measure is not necessary.

Alternative decision strategies typically ask for the cost and benefit strictly in financial terms to the corporation. While this may be perceived as more quantitative, it is unclear that it is any more precise, and may not be wholly available early on in the technology selection process. Additionally, the eventual adoption of the technology may be largely a result of the "wholistic cost" and not the cost to the firm commercializing the product. Society will attempt to reject concepts that are deemed too costly. Modern evidence of this is increasing pressure on automobile manufacturers to develop a zero emissions vehicle.

Additionally, the innovator has the responsibility to educate the larger decision making process on the technological possibilities and a sense of their relative strengths. While ideality does ask for an assessment of cost, it is balanced with recognition of the ultimate benefits and realization of the problems that will results. Realization of the problems and improving the performance are directly actionable by the innovator. As such, constructs to improve ideality can be envisioned very early in the commercialization process.

One additional element of cost that deserves discussion, and is particularly relevant to mature firms, is implementation cost. In a mature company, with mature or improving technology, there is typically a high fixed asset base. As a result, the firm is likely to decide that the cost, even for a high performing new technology, has lower ideality than a current technological implementation. This is because the mature company will have high cost associated with converting their complementary assets such as manufacturing and distribution. This high cost will degrade the ideality determined by the mature company and encourage them to maintain their current technological position. This decision must be evaluated against the possibility that an alternative provider of the technology can do it more cheaply, resulting in a system with higher overall ideality. If the mature firm chooses to stay with its incumbent technology, when the ideality provided by their future competitor is greater, they are at risk. Maintaining their market share and dominance in the market will largely come from alternative competencies than their previous technological leadership.

Ideal Final Result (IFR)

The Ideal Final Result (IFR) was a tool developed by Altshuller to encourage the visioning of future technology states. Domb summarizes its purpose saying,

> "It will help you
>
> - Encourage breakthrough thinking.
> - Inhibit moves to less ideal solutions (reject compromises)

- Lead to the discussions that will clearly establish the boundaries of the project." (Domb, Web Sources)

Specifically, it is the state where the benefit is accomplished with no cost and no harmful effects. It is likely that visioning the IFR will initially be difficult. While most realize the intrinsic value in reaching the IFR, most may see little value in visioning the unlikely state suggested by the IFR. The IFR may not lead to immediate recognition of a solution to reach this state, but it stimulates thinking in new ways to progress towards the IFR, ultimately improving system ideality.

Risk Mitigation

The challenge of picking a given technology to move forward with is daunting. Even with forecasting and anticipation of some of the future technological states the process faces inherent uncertainty. In truth, any technological decision takes place within a larger corporate construct. This larger corporate construct and its decision-making processes[6] will interact with the technology decisions to arrive at a conclusion. The best that can be done is to provide the corporate strategy decision makers with information regarding the ideality of alternative technologies and a risk assessment judging the likelihood that the technology will eventually be implemented. In the face of this uncertainty there are several methods for minimizing the impact of mistakes on the organization and improving the quality of the decisions made. These techniques fall generally into the category of risk mitigation.

Mistakes associated with strategy are difficult to undo quickly. However, a quick cycle time associated with product development is a principal defensive measure that firms can take. Gomes-Casseres describes market experimentation strategies observed with Personal Digital Assistants that might be used to iterate product definitions by introducing, presumably quickly, alternative product constructs to the market place. (Gomes-Casseres, pp. 350) These strategies essentially experiment with products in the field to determine which product and technology constructs are superior. This requires a very fast product development cycle to respond to learning and a tolerant customer base. They go as far to say that, "Market experimentation to identify customer groups and product features is critical in uncertain environments." (Gomes-Casseres, pp. 363)

Clearly, this process is not desirable. It is preferable that the right technologies be selected to enable the right product features. Determination of a technology's ideality is proposed as a principle mechanism to doing this. However, there will be differences in perceived ideality. The following methods of handling uncertainty and related risk are proposed.

One proposal for assessing the risk associated with a project is proposed by Hartmann and Lakatos. The construct is shown in Figure 9 below.

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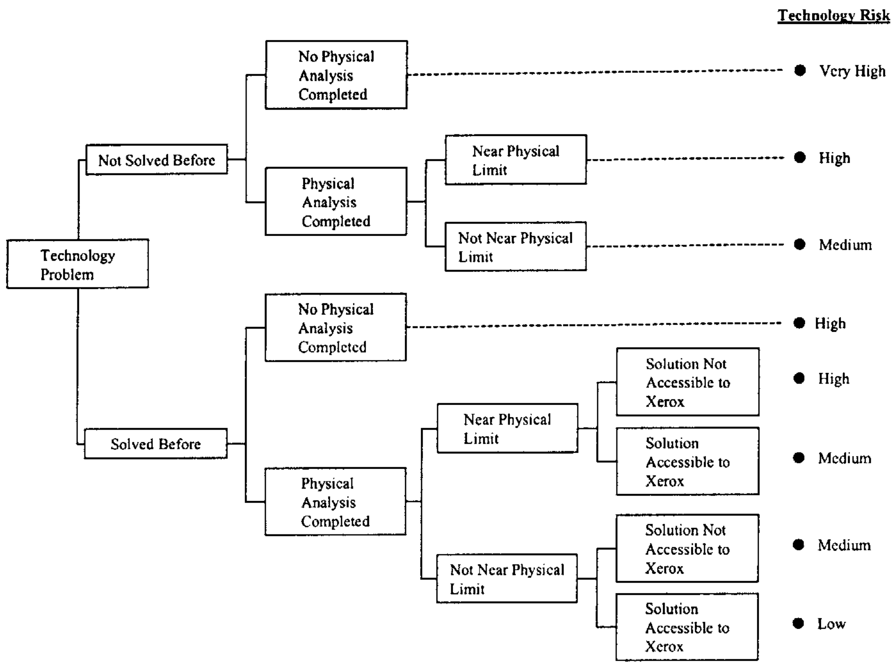
[6] Decision analysis is an extensive field unto itself. See Kumamoto for a discussion of decision analysis and utility functions. Also, see Kirkwood for an extensive review of techniques with extensive references to additional literature.

Figure 9: Risk Categorization Algorithm (Hartmann, Lakatos, pp. 37)



Each of the technology risk areas, Very High, High, Medium, Low are then coded numerically as 8,4,2,1. This allows for a relative ranking of the proposed technology as applied to a given product problem.

There are three principal criteria driving the risk assessment. The first is familiarity with the technology as expressed by the problem being solved[7] and completion of physical analysis. The second is available implementation latitude as expressed by nearness to physical limits. The last is accessibility of the solution to the firm.

These risk metrics relate directly to a firm's capability to identify, in advance, problems that will need to be solved. Concepts may face high risk, independent of their ideality. This is particularly true if the technology is not well understood within the firm. This lack of understanding may result in a tendency to underestimate the scope of the problems associated with a technology and overestimate its ideality. This process for assessing the technology risk will provide an additional perspective on the technological path chosen and educate the larger business strategy.

With the advent of the World Wide Web, identification of problem solutions and knowledge associated with the physical limitations of the technology is more accessible. As discussed, CoBrain™ provides for more comprehensive consideration of solutions spaces available that a given expert or company may be aware of. With this awareness

[7] TRIZ provides an extended methodology for problem formulation.

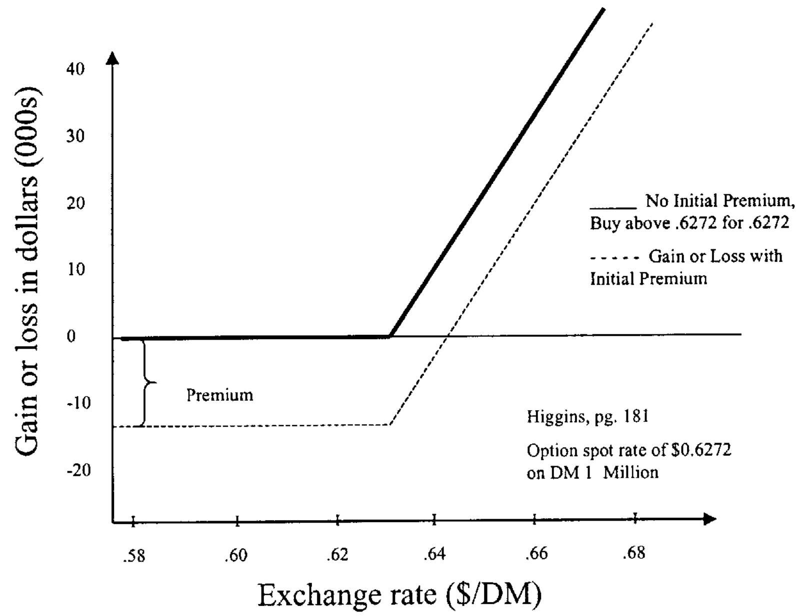
comes the related ability to access relevant experts in the "new" knowledge domain and assess more accurately if the system requirements will place the technology near its physical limits. This, in turn, allows for a more realistic assessment of risk.

In the highly uncertain technological domain of pharmaceuticals, Merck uses options analysis to determine project justification. (Nichols, 1994) Inputs from Research, Manufacturing and Marketing are placed in a model. Constraints and relationships are placed in the model as well. Then a "monte-carlo" simulation is done, where parameter values are drawn from a range of inputs considered optimistic, expected and pessimistic. The model then calculates the expected distribution in the expected value of the project. This process integrates information from the innovators and their assessment of risk with the larger corporate needs and constraints associated with a publicly held company.

The sorting criteria suggested by Hartmann and Lakatos provides a pragmatic methodology for assessing a paths given risk. The options analysis used at Merck may be useful to develop larger corporate strategies, but in the initial stages of technology identification and development, complementary information on marketing and manufacturing may be impractical to get. Instead, it is useful to view the investment process to gain additional technological insight as a hedge, in the financial sense.

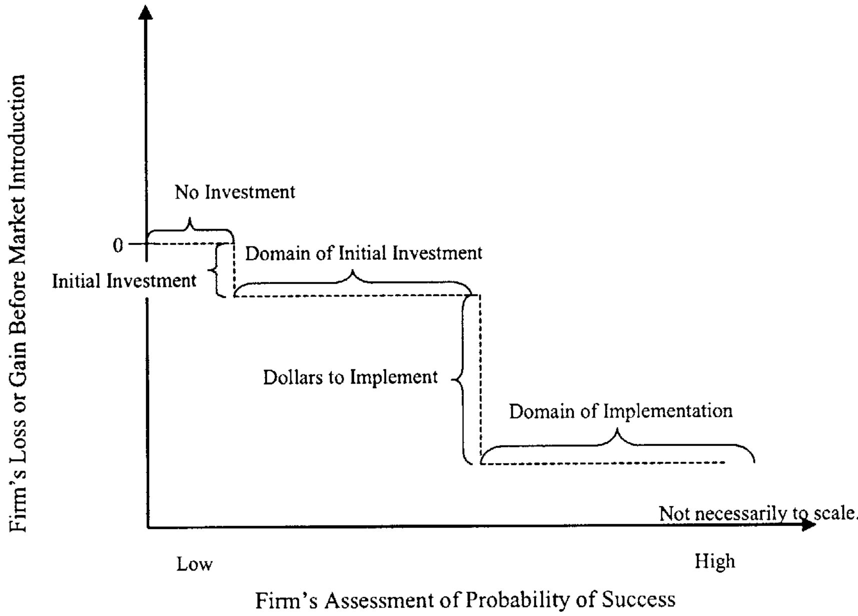
Hedging, in general, is characterized by protection against downside effects associated with a financial decision. (Higgins, pp. 178-187) An investment is made to minimize a possible loss, while preserving the opportunity to benefit. It involves investing some premium to protect against the downside while enabling the firm to benefit from an upside. An example, applied to a call option in currency markets from Higgins is shown in Figure 10 for clarification. An initial premium is paid to secure the option at a fixed price. This allows the firm to "purchase" DM 1 Million at a fixed price per DM. If the exchange rate degrades the firm effectively looses their premium but is protected from the degradation in the exchange rate. Their loss is minimized to the value of the premium. Alternatively, if the exchange rate improves, they have the right to purchase the currency (DM) at a fixed rate, effectively realizing a profit because the currency is worth more than the price they are purchasing it at.

Figure 10: Call Option Example (Higgins, pp. 181)



These general concepts can be utilized when making technological decisions. In the technological sense, some level of spending will typically allow a firm to develop some expertise associated with the technology in question. This is analogous to the premium paid in the example above. If the technology does not mature, the firm looses the premium that they paid. However, if a given technology becomes important to the firm, the company now has the ability to invest additional funds to accelerate its development and commercialize the technology, realizing some profit. The specific points at which a firm invests to understand the technology or to commercialize the technology are likely to be rooted in many factors, including the firm's assessment of the probability that the technology will be successful. The specific determination of these points, and subsequent decision points to continue spending is not studied here. Instead a framework is established to simply categorize technological solutions into three general domains associated with an options framework. The domains are no investment, initial investment, and implementation. These domains are shown in Figure 11 and discussed below.

Figure 11: Hedging - Applied to Technology



There are several attributes of this figure that are worth additional discussion. The first is the relative magnitude of "Dollars to Implement" versus "Initial Investment". It is likely that Dollars to Implement will be orders of magnitude larger than the Initial Investment to develop capability to be prepared for implementation. As seen later in Chapter 4, "Initial Investment" spending is intended to allow the firm to better assess the ideality and reduce the risk associated with pursuing a given technology. "Dollars to Implement" includes all dollars spent after initial studies. This is a simplification for the purposes of this analysis. In practice, these dollars are not spent all at once and typically milestones must be reached to justify additional capital.

The second is the decision point associated with investing dollars. At some assessed probability point the firm may judge the technology worth commercializing, if they view the expected success of the technology as high enough. This decision point will involve higher level corporate strategy and a complete discussion of this is beyond the scope of this paper. However it is useful, and usually prudent, to minimize expenditures while additional information on the success or the ideality of the technology is being evaluated. This can not go on indefinitely. At the point in time that the performance starts to accelerate in its rate of improvement, at the first transition point (alpha in Figure 3) on the S-curve in time as the technology matures, the firm MUST make a decision on implementation. The technology is about to undergo rapid performance growth. Failure to invest is likely to result in a disadvantaged technological position for the firm. Choices include developing the capability, purchasing or partnering with firm's that are developing the capability or choosing not to participate in the technology. However, the strategist has a responsibility to encourage the corporation to make a conscience decision.

The third feature of the figure is the realization that the eventual profit generated from implementation is uncertain. The profit is a function of many corporate features and is a reason why corporate strategies must drive the decision to implement.

There are several assumptions imbedded in this framework. A principle assumption is that the initial investment positions the firm for success. Too low an initial investment may not enable the firm and simply be a waste of money. Conversely, too high an investment may be inefficient. An additional assumption is that no investment leads to some harm. Firm's that do not invest in replacement technologies often find themselves disadvantaged when replacement technologies start to mature. However, it may be possible to delay spending for some period of time with marginal impact on the mature firm. A third assumption is that capital constraints do not exist. If capital constraints do exist then decisions on which technologies to invest in should be based on relative risk and ideality assessments. It is likely that the acceptable level of risk and ideality to accept varies by industry sector and perhaps by an individual firm's utility function[8].

These assumptions are reasonable and can be managed. The firm needs to revisit its decision periodically to assure that the assumptions still hold. As the technology changes it may be necessary to adjust the level of spending. If the technology appears to be loosing favor as suggested by low ideality, the spending should be trimmed or eliminated. If the technology appears to be gaining acceptance as likely under high ideality, careful study of the firm's competitive position should be done. The firm should work to understand when the technology will start rapid maturation so that it can invest and participate in the corresponding market growth.

With regards to capital limitations, the strategy proposed may actually relieve some of the constraints depending on the current corporate culture. Focusing early on a concept's ideality and risk, independent of a specific product concept, allows for more efficient funding. Technologies can be evaluated based on first principles, other experts in the field and modeling without constructing specific concept proposals. Money to manifest the technology in product concepts can be held until larger corporate decision making processes are complete.

[8] A utility function is a measure of risk aversion or risk acceptance. For a review of utility functions and their use in decision analysis see Kirkwood and also Kumamoto.

CHAPTER 4: INTEGRATIVE PROCESS

Techniques for extrapolative forecasting used in the Western world, as summarized by Worlton, rely heavily on the use of experts and as such have several shortcomings:

- There is not a criterion for evaluating the credibility of the forecasts.
- The knowledge domain of the expert limits the forecasts.
- The knowledge domain limitations of the experts are aggravated by organizational policies that encourage deep insight in specific fields.
- They rely on judgments associated with a single performance parameter.

Techniques for normative forecasting used in the Western world, as embodied principally in morphological techniques, suffer from a lack of guidance for selection criteria of alternative technologies. Additionally, visioning of alternative constructs to realize the functional capability is constrained by current implementations. Therefore, it can be difficult to envision alternative extensions of the technology and function. Techniques characterized by Altshuller overcome several of the limitations imposed by conventional extrapolative techniques.

Altshuller's observation of the Laws and Lines of Evolution enable the innovator with a pattern of behavior associated with society's improvement of technology. These observed patterns grew out of analysis of the patent database. Societal need and acceptance of concepts drive technologies that are patented. Therefore, they are good guidelines to use in thinking about improvements of technologies and systems for commercial implementation.

The Laws allow for thinking about system evolution while the Lines provide insight into implementation. Coupled with increased understanding of technical effects that exist in the world, enabled by semantic processing knowledge processors such as CoBrain™, the innovator is poised to act quickly on concepts envisioned using the Laws.

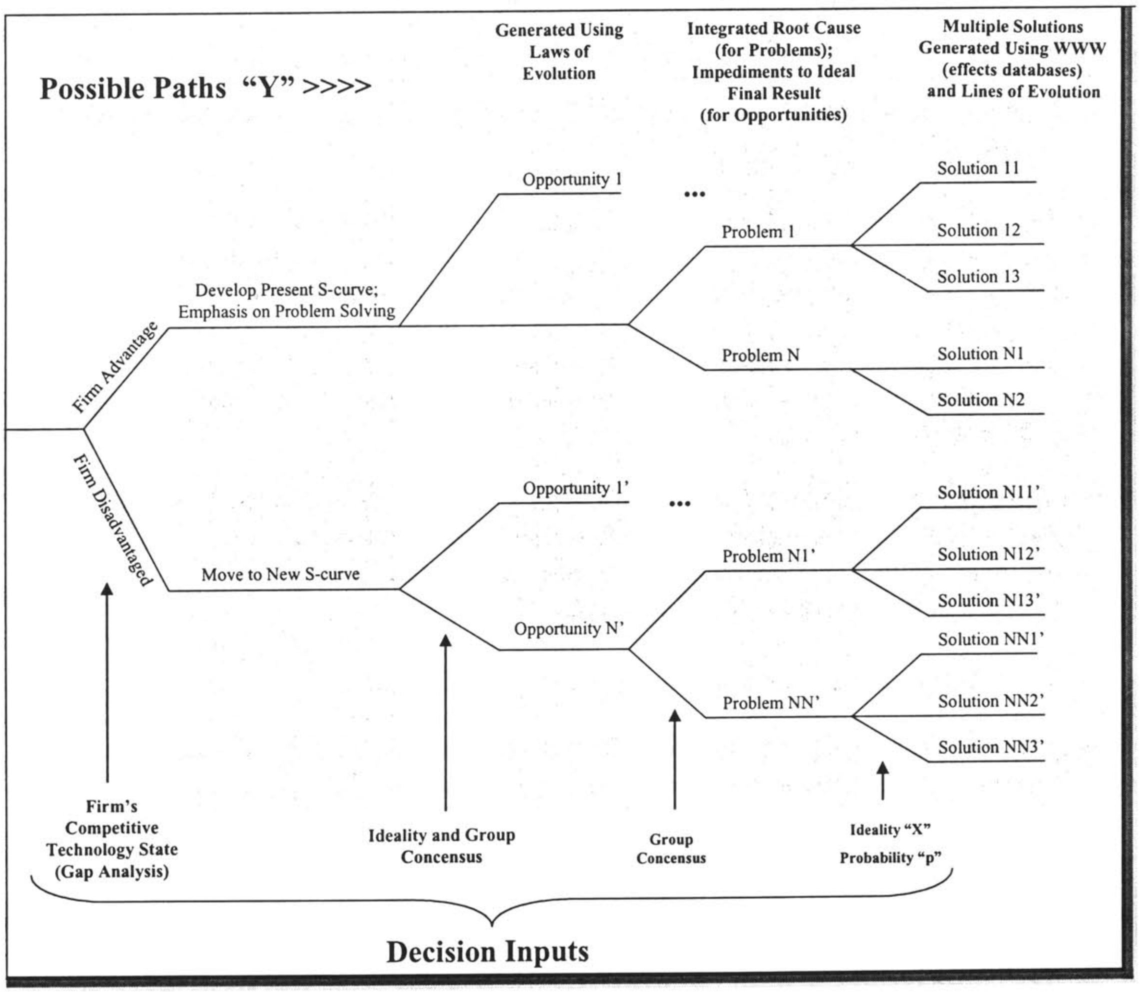
Ultimately, the decision to commercialize any technology is a business decision and involves a number of criteria beyond the scope of this paper. However, the innovator has a responsibility to assess the ideality associated with their technological construct and the risk associated with their proposal. These ultimately provide the inputs to the corporation to enable an informed business decision.

The balance of this chapter utilizes many of Altshuller's observations to improve historically favored techniques. The majority of the proposed process is enabled by Altshuller's observations, as conventional techniques do not provide criteria based on patterns of behavior observed to date and insight to historical trends in Technology Evolution. This process is summarized in a diagram in Appendix A.2 and may be helpful to refer to while reviewing the proposal.

As additional perspective on the proposed process, Professor Clausing noted that a majority of the proposal is working toward determination of an Improvement Ratio "X" that Proposed Project Path "Y" will produce [be successful] with probability "p". (Y,X,p) is the information that is needed to make the technical assessment. (Clausing, correspondence)

The project paths "Y" are generated using the Laws of Evolution to envision future product states. The Lines of Evolution, coupled with use of the World Wide Web, assist in product implementation. The specific path chosen, early in the process, generally depends on the competitive state of the firm's technology. The suggested process guides the user in determining the firm's competitive state using S-curve methodologies. This results in a generalized framework as shown below in Figure 12.

Figure 12: 'aths "



Once possible paths are generated, the firm attempts to identify the Improvement Ratio "X" associated with the technology. In the process proposed, ideality is "X". Determination of ideality provides additional information to the decision making process.

However, implementation risk must be considered as well. Concepts with high ideality are of no direct commercial consequence if they cannot be implemented. Implementation risk, "p", must be determined to provide additional insight into the decision making process.

Even though "un-implemented" high ideality concepts are of no direct commercial consequence the proposed process recognizes them as a powerful tool for visioning future concepts and suggests high ideality concepts deserve limited corporate funding under an options framework. This is especially important when doing technology selection at a corporate level when decisions need to be made very early in the product or technology life cycle.

Questions to be Answered

When considering what technical direction a firm must pursue there are three questions that should be answered. These questions are:

- What is our technological capability relative to alternative technologies and relative to our competitors?

This question concerns itself with the historical trends associated with the technology and the firm's position relative to those trends. This allows the firm to develop a realistic assessment of their position relative to the technology's evolutionary state. Companies leading in technical capability will attempt to exploit their capability. Companies lagging in technical capability will need to decide if they want to remain a follower in the field, increase activity to become a leader in the field or perhaps abandon the technology in favor of an alternative.

This question also concerns itself with a firm's realized performance level in a given technology and a developed understanding of alternative technologies it may want to involve itself with. This includes developing an understanding of their competitive position so that they can understand where they are advantaged.

- What does our technological capability need to be?

This involves identifying a future technological state or readiness that the firm would like to achieve. Identifying current problems does this. Additionally, opportunities for additional products can be envisioned using the Laws of Evolution. The Laws of Evolution provide powerful criteria to evaluate future states against.

- What technology or technologies are we going to pursue to enable this capability?

This question concerns itself with eventually committing resources to a path or set of paths to pursue. Technological options need to be generated and advantaged alternatives should be pursued with consideration of the technology's ideality and risk.

Framework for Answering the Questions

This paper has already discussed many of the concepts that are needed to answer these questions. Several are mapped to the questions in Table 2 to clarify the process for answering these questions.

Table 2: Process Steps Mapped to Questions

Question	Process Steps
What is our technological capability?	Determine Expected Level of Innovation Associated with a Technology Determine Actual Level of Innovation Associated with a Technology Determine the Firm's Performance Relative to Competition and Technology Limits
What does our technological capability need to be?	Problem Identification and Formulation Identify and Evaluate Future Opportunities Prioritization and Sequencing of Problems and Opportunities
What technology or technologies are we going to pursue to enable this capability?	Create a List of Superior Solution Concepts and Technologies Determine Ideality and Risk Associated with Concept Technologies Narrow the Candidate List and Place Solutions in an Options Framework

What is our technological capability?

Determine the expected and actual level of invention associated with the technology.

This essentially involves developing an understanding of the "S-curve". Conventional techniques require the gathering of historical performance data and plotting it with time. Forecasting using the "level of invention" provides the expert with an alternative way to assess the current level of maturity on the S-curve, and build related insight on the technology's specifics. These two techniques complement each other and provide the strategist with a way to check their suppositions regarding the development of the technology. Altshuller's methodologies help characterize the inventive behavior to date and map the behavior to the performance expected. They do not inherently forecast the eventual level of performance, especially with technologies that are emerging or in the early growth phase. Therefore, the expert still needs to provide this function. The process for developing the related information associated with performance and level of invention is enhanced by the existence of the World Wide Web. Commercial software packages that work with web accessible information helps track the citation history associated with developments of technology and speeds the analysis by the forecaster. A recommended procedure to do this is as follows:

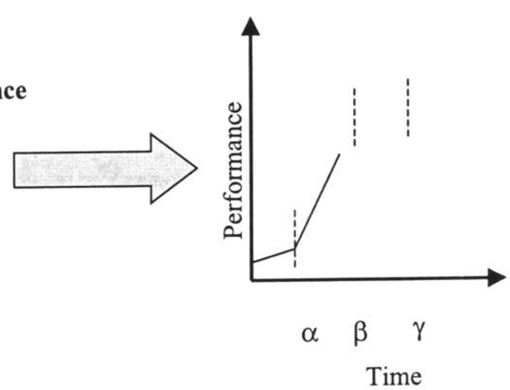
1.1. Expected Level of Invention

1.1.1 Determine the principal performance parameter. (Note: This parameter may change with the life cycle of the technology or vary by market segment. Performance is defined in a rather broad sense to include issues such as cost, life or availability,)

1.1.2 Collect existing historical data on technical performance parameter since the date of innovation of the technology. Plot the performance with respect to time.

Figure 13: Plot Historical Performance

Time	**Performance**
X	Y
XX	YY
XXX	YYY
...	...



1.1.3 Determine the expected level of invention by reading the level of invention from Figure 4 corresponding to the location on the S-curve plotted. This is illustrated below. Additionally, the corresponding level of innovation with respect to the S-curves growth is tabled below for convenience as related to critical strategy time periods.

Figure 14: Expected Level of Invention

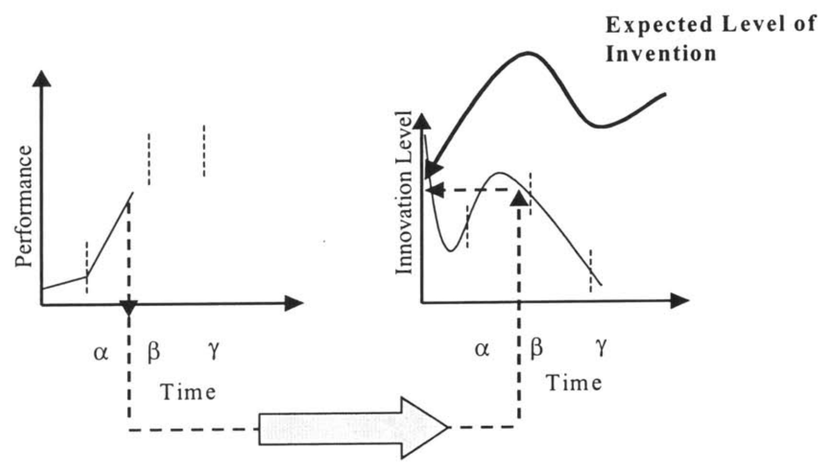


Table 3: Level of Invention Corresponding to S-curve Location

Location on S-curve Critical Strategy Time Period	**Expected Characteristics of the Level of Invention**
New Invention Period (α)	High level of innovation followed by rapid decline.
Technology Improvement Period (β)	Rapidly increasing level of innovation. Accelerated level from prior level of low innovation.
Mature Technology Period (γ)	Rapidly decreasing level of innovation after second peak of innovation when the technology was profitable.

1.2. Actual Level of Technology

1.2.1 Identify relevant patents to the technology. This can be done more quickly with search engines such as Aurigin.

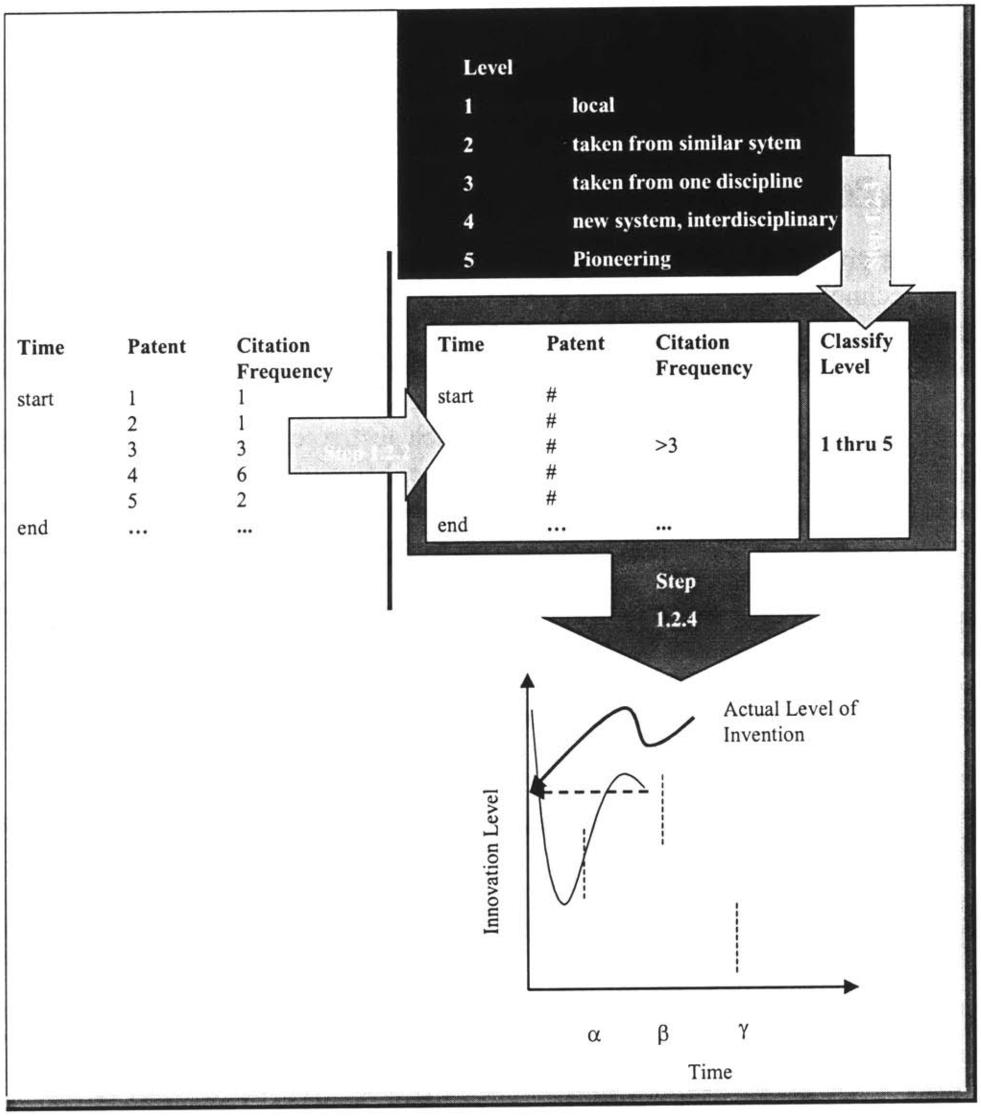
1.2.2 Sort patents initially by citation frequency. (If low citation history exists, the technology may fall in one of two special cases: (i) immature technology that is low on the S-curve and has not had time to build citation history. (ii) Obsolete technology that never attracted additional study.)

1.2.3 Patents with high citation frequency, greater than three[9], should be classified according to Altshuller's levels of invention. These levels were shown previously in Table 1: Level of Invention.

1.2.4 Plot the average Patent Innovation Level at various time intervals.

[9] This may vary by technology but was chosen as an initial screening criteria for patents to speed the work and make execution of this part of the process practical. It is based on work by Albert at Eastman Kodak that five or more citations suggest patent importance. (Albert)

Figure 15: Determination of the Actual Level of Invention



1.2.5 Compare actual level of invention, and history of level of invention with the expected level of innovation determined as in Step 1.1.2. The history of the level of invention should be consistent with the prediction expected. If the conclusions are different, additional review of the patent literature and consideration of the historical data should be done to reconcile the information.

Figure 16: Reconcile Information

Expected Level of Invention	$\stackrel{?}{=}$	Actual Level of Invention

1.3. Firm's Performance Relative to Competition and Technology Limits

Often times a given level of performance can be attained by competitors with similar or alternative technologies. For the firm to have a realistic understanding of their position, their performance level may need to be plotted on alternative S-curves, independent of the underlying technology. Additionally, it is necessary to develop the ultimate performance level associated with alternative technologies. The gap in ultimate performance between technologies indicates which technology is likely to be superior, assuming equal harmful effects. In cases where harmful effects are not equal, the relevance of these harmful effects to the business and society must be considered. Additionally, gaps between achieved performance level and ultimate performance level suggest the strategies that respective firms should be operating under. A suggested process for implementing this is as follows:

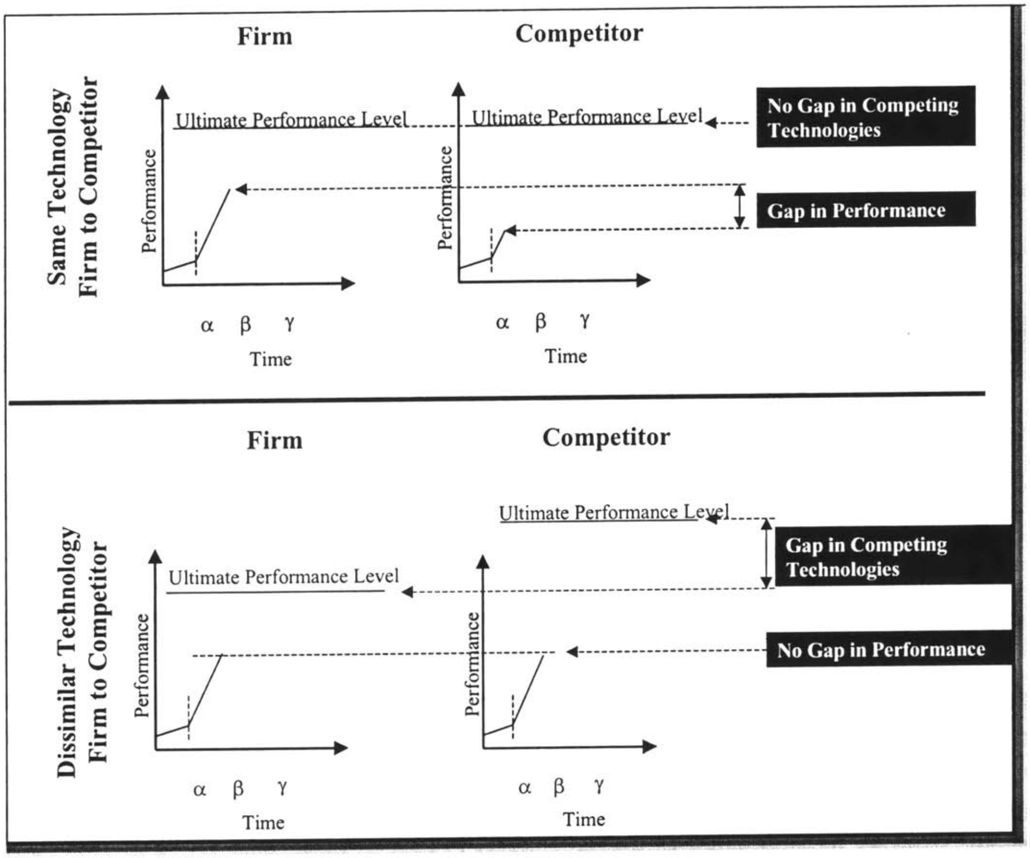
1.3.1 Develop S-curves for competitive technological constructs as discussed previously using historical performance data and "level of invention" indicators described by Altshuller. (Steps 1.1 and 1.2 above)

1.3.2 Determine the ultimate performance of firm's technology and alternate technologies.

1.3.3 Determine gaps in performance capability between the competing technologies.

1.3.4 Determine gaps in performance capability between the firm of interest and their competitors.

Figure 17: Example Case Scenarios - Gap Analysis



1.3.5 Use this gap analysis to inform and educate the strategy and related decision-making process. The recommended strategy decisions based on the gaps are tabled below.

Table 4: Strategy Directions from Technology Gap Analysis

Gap Analysis		Competitor Performance Level to Firm Performance Level: Competitor Advantaged	Competitor Performance Level to Firm Performance Level: Firm Advantaged
Difference in Technologies' Ultimate Performance Level	**Competitor Advantaged**	Consider minimizing investment in pushing technology forward. Seek advantaged technology or move to competitor's technology.	Exploit advantage. Quickly seek alternative technology when performance limit is nearing.
Difference in Technologies' Ultimate Performance Level	**Firm Advantaged**	Recognize opportunity. Must accelerate growth in performance to catch up and surpass competitor's performance.	Exploit advantage. Seek to accelerate growth toward maximum performance.

This section was intended to address the question,"What is our technological capability relative to alternative technologies and relative to our competitors?" Use of the S-curve helps to assess the firm's position relative to alternative technologies and their competitor's technologies. Gaps in the firm's capabilities inform and educate the larger corporate strategy as suggested in Table 4. The process is represented by its inputs and outputs as shown below.

Table 5: Inputs and Outputs to Determine Technological Capability

Inputs	Outputs
Historical Performance Data	S-Curves
Expert Knowledge	Patent Level Curves
Relevant Patents (aided by commercial tools)	Technology Maturation Points
	Gaps with Respect to Competitors
	Strategic Recommendation associated with Firm's Current Technology

What does our technological capability need to be?

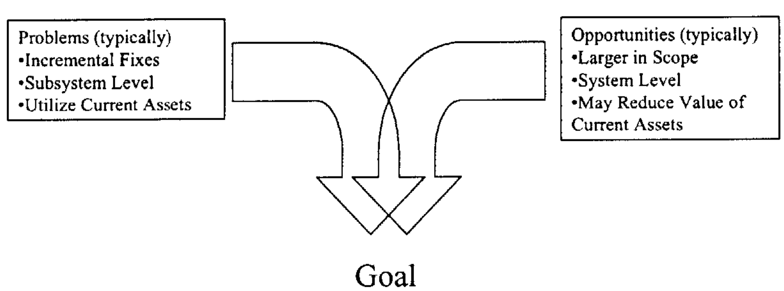
The basis for this section is to provide the innovator with an understanding of their goal. The goal is presented in two forms. The first is solving of problems. The second is identification of opportunities. The construct being proposed presents these as two different possible goals with prioritization on problems versus opportunities driven by the previous technology and competitor gap assessment.

Problems are typically solved when innovative solutions are introduced at the subsystem level as incremental improvement. This is because firm's typically having complementary knowledge or organizational assets enabling the product have a disincentive to make drastic changes. Radical innovations typically devalue these assets and therefore incremental improvements are more efficient.

Opportunities, as discussed subsequently, come largely from consideration of the Laws of Evolution and Marketing input. Introduction of technology to satisfy these opportunities may require more extensive repositioning of assets to execute design, development and manufacture of the product. Therefore, these events are less frequent for the mature company.

This description is not meant to be exact, but is meant to help frame the following sections of this paper. Real situations are likely to fall in a continuum. For example, opportunities associated with extending a system's use into a higher level system, as suggested by the Laws of Evolution, could leverage entirely the current assets but force the company to create access to additional assets. Conversely, when problems are grouped together, a common root cause may be found. Eliminating the root cause to solve a set of problems could also destroy the value of current assets.

Figure 18: Goal Inputs



2.1. Problem Identification and Formulation

Proper problem identification and statement is an important part of improving any system. Problem statements anchor the innovator's thoughts and can make it more difficult to envision solution states. Much of TRIZ, not discussed in this paper, helps the problem solver to properly envision the problem. Two insights to problem statement formulation are discussed below.

Often designers resign themselves to trading off one useful performance characteristic for another. Fundamental to TRIZ is the identification and resolution of conflicts. TRIZ encourages identification of these areas of conflicts and encourages inventive practices to resolve these conflicts. As a result, tradeoffs are minimized, genuinely treating the problem as an opportunity for advantage.

Additionally, especially with complex systems, it is increasingly difficult to identify the root cause of problems. Careful description of the system, including tracing of the flow of energy associated with harmful effects can help the problem solver identify the correct problem to solve. Too often, engineers are tasked with solving what is effectively a symptom of the root cause and not the root cause itself. As suggested by Mann earlier, firms concentrate on this approach, especially as technology matures. Solutions purely of a symptom curing focus do not result in increased ideality systems.

Therefore, careful identification of problems is critical to identifying inventive solutions. General guidelines for identifying problems are suggested below.

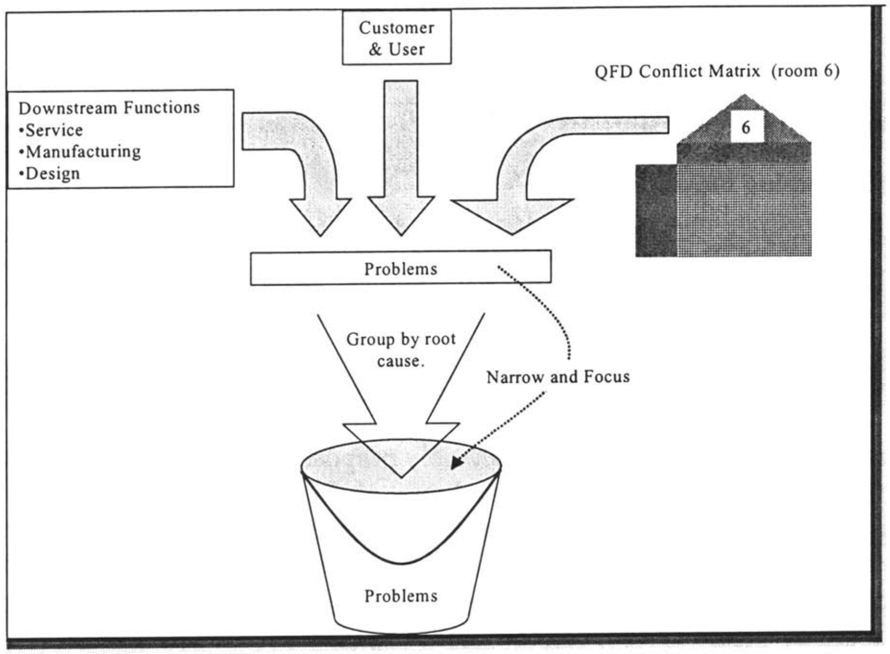
2.1.1 Collect problem statements from downstream functional organizations. This should include service, manufacturing and design.

2.1.2 Collect problem statements from customers and users of the product. Be particularly aware of the "value chain" associated with the product and speak to all individuals in the chain.

2.1.3 Revisit Room 6 in a given system's QFD matrix. This area can be thought of as the "conflict-of-interest" room. (Clausing, pp. 67) As such it provides additional insight, consistent with TRIZ practice, to identify areas of technical conflict.

2.1.4 Integrate information from the previous three steps to formulate the problem description in technical terms. Attempt to group problems by root cause. The intent is to identify the root cause of the problem, and not simply the symptom. Typically, the problem should not simply address a symptom or a problem caused by a solution attempting to address another symptom. This is particularly true during technology selection.

Figure 19: Problem Identification



2.2. Identify and Evaluate Future Opportunities

An opportunity map of evolving technology constructs can be envisioned using the Laws and Lines of evolution. They provide a vehicle to anticipate future product states because they are based on observations of societies behavior. Therefore, while some may view this simply as a mechanism to push technology, it is not. Instead, use of the Laws of Evolution represents a vehicle for anticipating future states. The Laws, in conjunction with Scenario planning and the Ideal Final Result can be used to develop an opportunity map as follows.

2.2.1 Envision the Ideal Final Result as discussed in Chapter 3. As Altshuller states about the ideal machine, it "plays the role of a beacon illuminating the direction in which to proceed." (Altshuller, 1999, pp. 86) This should be placed on the far end of the opportunity map. It represents a goal and a statement of where the technology will eventually evolve.

2.2.2 List product constructs or features that are consistent with the Laws of Evolution. Activation techniques to think in the direction of these Laws are suggested in the Appendix. These Laws, as listed by Fey follow. (Fey)

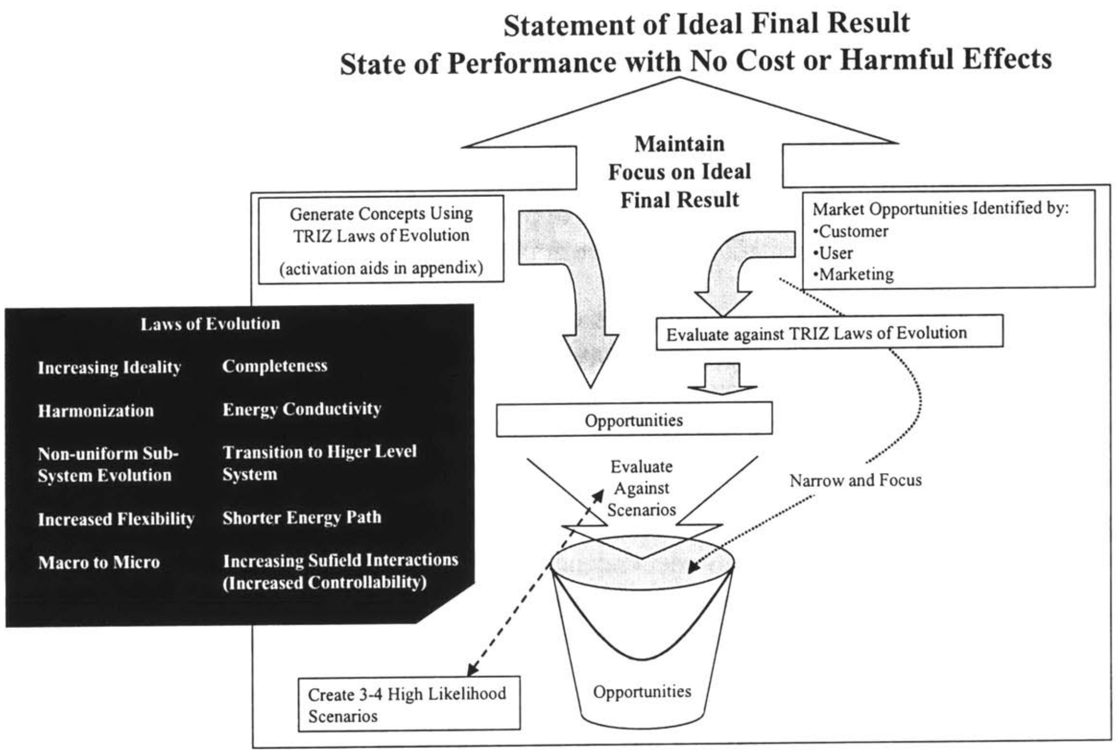
- Increasing Degree of Ideality
- Completeness
- Harmonization

- Energy Conductivity
- Non-Uniform Evolution of Sub-Systems
- Transition to a Higher-Level System
- Increasing Flexibility
- Shortening of Energy Flow Path
- Transition from Macro- to Micro-Level
- Increasing Degree of Substance-Field Interactions

2.2.3 Marketing pull opportunities, presumably proposed from customer insight, should be evaluated for consistency with Laws of Evolution. The Laws have been derived from observation of patent patterns, which have been driven by product technology success and need. As such, they represent criteria, of historical basis, for product/technology manifestations. If proposals are not consistent with the Laws, they should be challenged.

2.2.4 The previous two lists of opportunities, those generated by the Laws and those generated by Marketing, must be screened against high likelihood scenario possibilities. Candidate opportunities excluded by these scenarios should be rejected. This is particularly true if complementary asset or infrastructure issues exist in these scenario's that preclude the success of a product technology. Additionally, consideration of these scenarios may help vision additional opportunities previously missed.

Figure 20: Opportunity Identification



2.3. Prioritization and Sequencing

At this point, the organization has a comprehensive list of problems, opportunities, and a solid understanding of their position relative to their competitors. It is likely that the problem faced by the organization is that they will have too many possible paths to pursue. Therefore, to determine which paths to develop and pursue a process must be put in place to rank the problems and opportunities logically, and decide on the most promising technologies to pursue. The use of scenarios may have eliminated some items from the list but additional measures can be taken to focus the selection efforts.

2.3.1 Initially screen opportunities and problems as separate lists using high level strategy positions as suggested in Table 4: Strategy Directions from Technology Gap Analysis. This screening will give general priorities to opportunities or problems as described below.

- ♦ If the firm is disadvantaged in its technological position, then current problems should be addressed only as absolutely necessary and opportunities that have been identified should be pursued vigorously[10]. Perfecting an

[10] Note that this does not mean that a firm must develop the capability themselves. Mature firms are often positioned well to partner, collaborate or purchase companies to gain access to alternative technology.

inherently weak technology should only be done with a complete business analysis and justification.

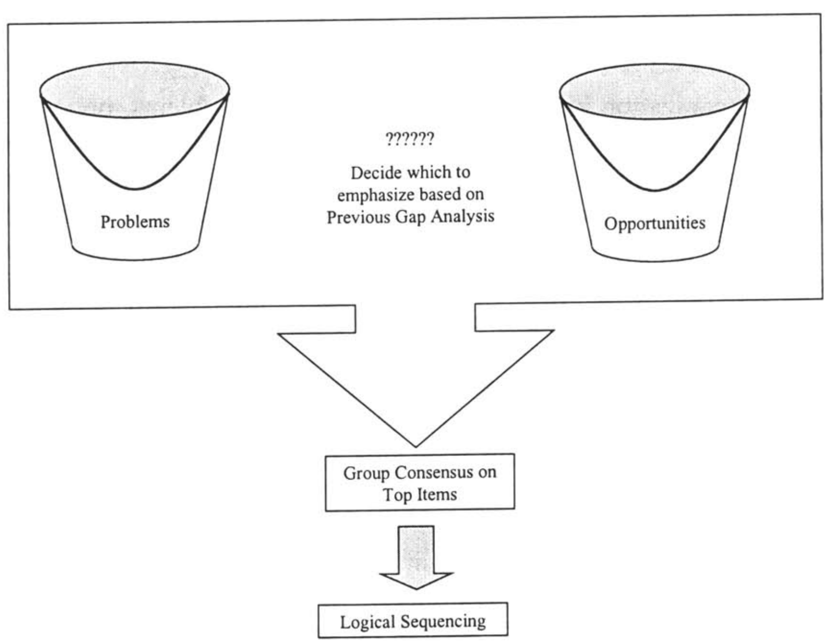
- If the firm is disadvantaged in its competitive position but has a fundamentally better technology, problem resolution should be emphasized.

- If the firm is advantaged in both its competitive position and technology position they should accelerate solving of problems to extend their lead. Additionally they should exploit opportunities that allow them to extend their technology to suitable alternative applications.

2.3.2 It is likely that a top opportunities or top problems list can be generated readily from the remaining items using experienced personnel. This should be done to focus the organization and team on the most relevant items. Group voting, with individuals who have participated in the majority of the process to date, is advocated as one straightforward method to do this identification.

2.3.3 Logical sequencing of items should be done. The criteria for sequencing should primarily be based on dependencies of one implementation on another implementation. Opportunities should be sequenced, leading to the Ideal Final Result. The sequenced product concepts can be used to improve conventional road-mapping processes.

Figure 21: Decision Strategy



The process steps detailed have principally generated statements of problems, and identified general opportunities from customer insight and as suggested by the Laws of Evolution. The inputs and outputs to accomplish this work are shown below.

Table 6: Inputs and Outputs to Determine Capability Need

Inputs	Outputs
Upstream Function Problem Statements Conflict Matrix (Current Products) Marketing Opportunities Strategic Recommendation associated with Firm's Current Technology	Ideal Final Result (IFR) Understanding the relative priority of Problems to Opportunities Logical Sequence of Top Problems Logical Sequence of Top Opportunities Leading up to the IFR

What technology or technologies are we going to pursue to enable this capability?

3.1. Create list of superior solution concepts and technologies.

After this initial sorting and sequencing process, more specific understanding of technological alternatives is likely to be necessary. The process detailed to date has had a low level of effort expended on developing a specific understanding on how to solve the problems identified as conflicts or how to implement the opportunities. The innovator, having chosen which problems to solve and opportunities to exploit, must now determine what are the possible ways to solve them. Initially, this will create an expanded set of solutions that will need to be sorted and prioritized so that final selection can be made. Alternatives to solving these problems and implementing these opportunities can be generated as follows.

3.1.1 If opportunities are to be the main focus, develop related problem statements associated with its implementation. Problem statements should discuss areas of technical conflict. This places the opportunity statements in the same framework as problems for subsequent resolution.

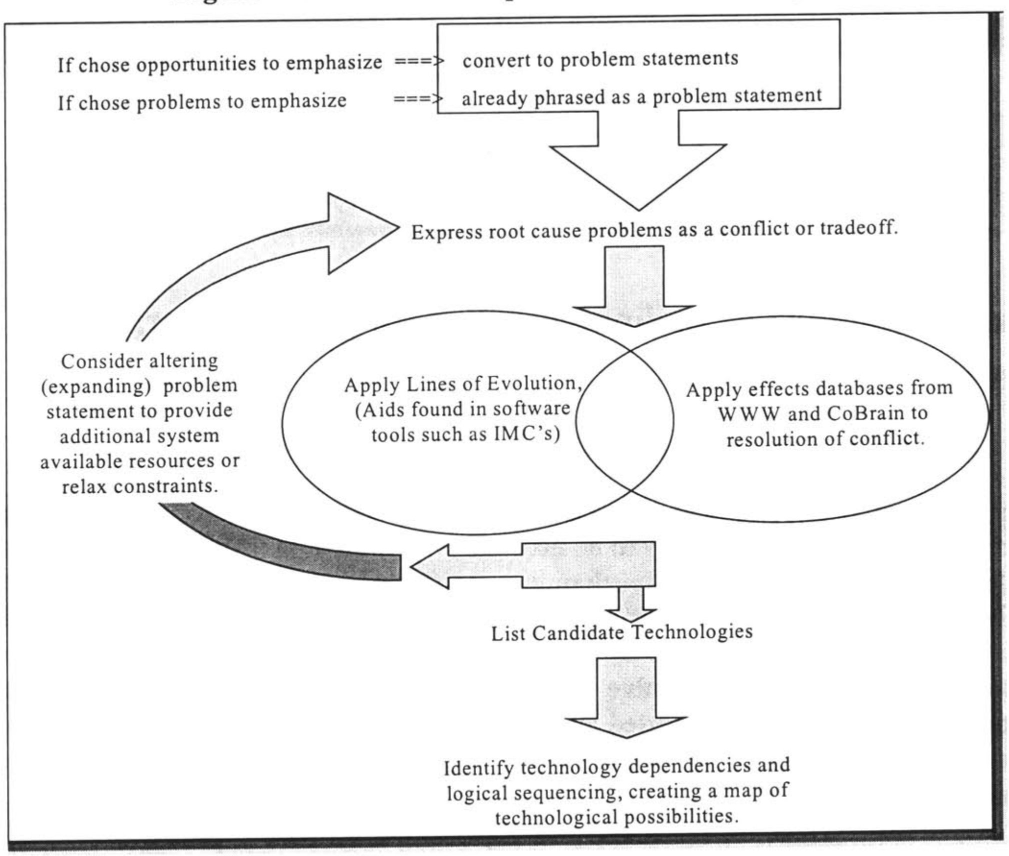
3.1.2 Apply the Lines of Evolution to solve problems at their root causes as grouped previously. While effective use of these will grow with experience they are embodied in commercial software such as IMC's Techoptimizer™. The Lines represent a vehicle for implementing these future states.

3.1.3 Break illogical technology states by applying information from effect databases and information from the WWW. IMC provides a product that attempts to activate this search for effects that can break illogical constructs by providing known scientific effects using CoBrain™. (Note: Full use of TRIZ provides an extended methodology for solving contradictions or illogical problems.)

3.1.4 Consider altering the problem statement to provide more resources, or relax problem constraints, and provide an alternative way of solving the problem.

3.1.5 List the candidate technologies associated with implementations envisioned using the Lines of Evolution.

Figure 22: Determine Superior Solution Concepts



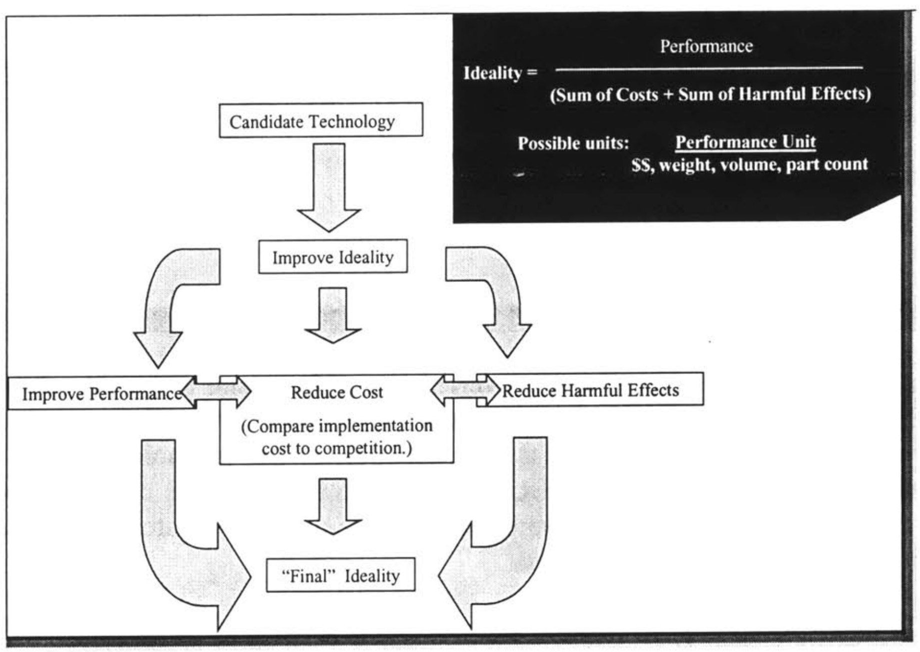
3.2. Determine Ideality, Risk

The proposed process is likely to generate alternative technological implementation states. Final selection is often based on a company's familiarity with a given technology. However, with the advent of the WWW and its implied access to knowledge and the global nature of business providing a variety of partner possibilities, this should not be a principle criterion. The following process is recommended for selecting between candidate implementations.

3.2.1 Develop candidate technology's effect on relative ideality. Specifically, think how to eliminate harmful effects, reduce cost or increase performance. Develop an understanding of the technology's ultimate performance and cost. Express ideality as performance divided by cost, volume, weight or a similar metric. Do not be overly concerned with proof of concept or specific concept implementations.

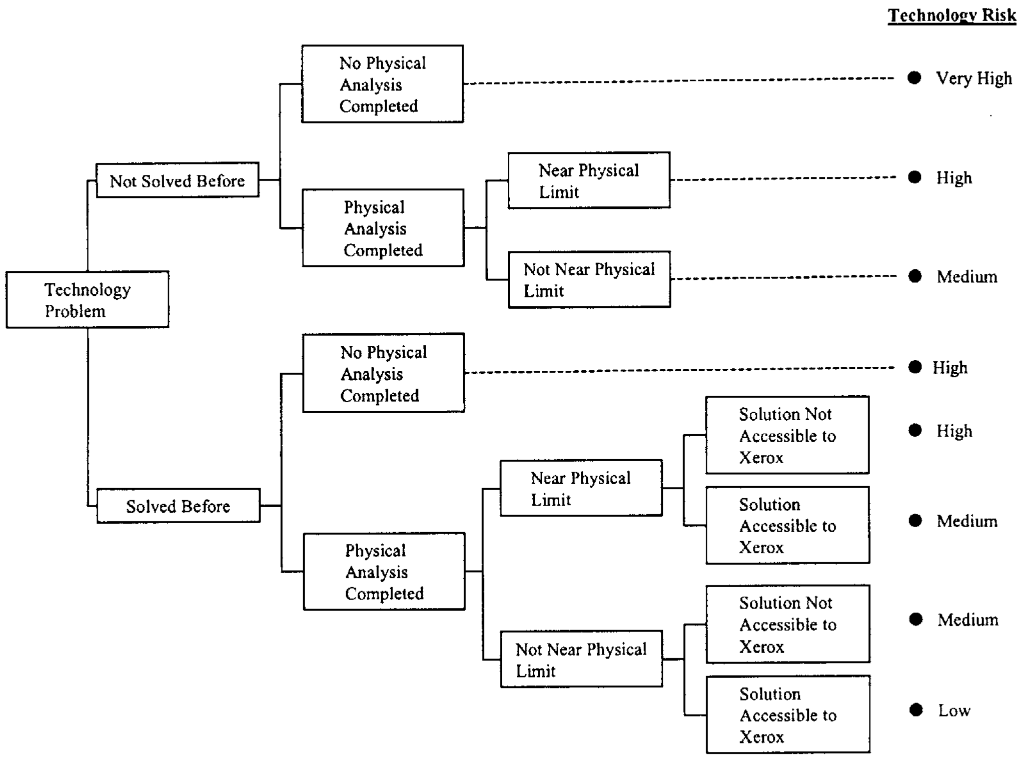
3.2.2 Alter assessed ideality if necessary. Consider the mature company's high cost to convert to an alternative technology and its effect on ideality. This high cost may encourage remaining with a given technology too long. Consider particularly, if competitors have a higher ideality based on lower implementation cost. The performance associated with determining ideality should be obtainable from earlier work judging the S-curve and the firm's competitive position. These concepts are represented below in Figure 23.

Figure 23: Determine Candidate Technology's RELATIVE Ideality



3.2.3 Assess risk using framework discussed previously associated with Figure 9 this is repeated below in Figure 24 for convenience.

Figure 24: Risk Assessment



3.3. Narrow the Candidate List and Place Solutions in Options Framework

At this point opportunities have been converted to problems and technical solutions for all problems have been identified. An initial assessment of different technology's promise has been made with an initial determination of the technology's ideality and associated risk. Now the best solutions, as mapped to the problems chosen, need to be pursued. Multiple solutions to the same problem should be evaluated and placed in a framework for additional work as follows.

3.3.1 Group solutions to problems together.

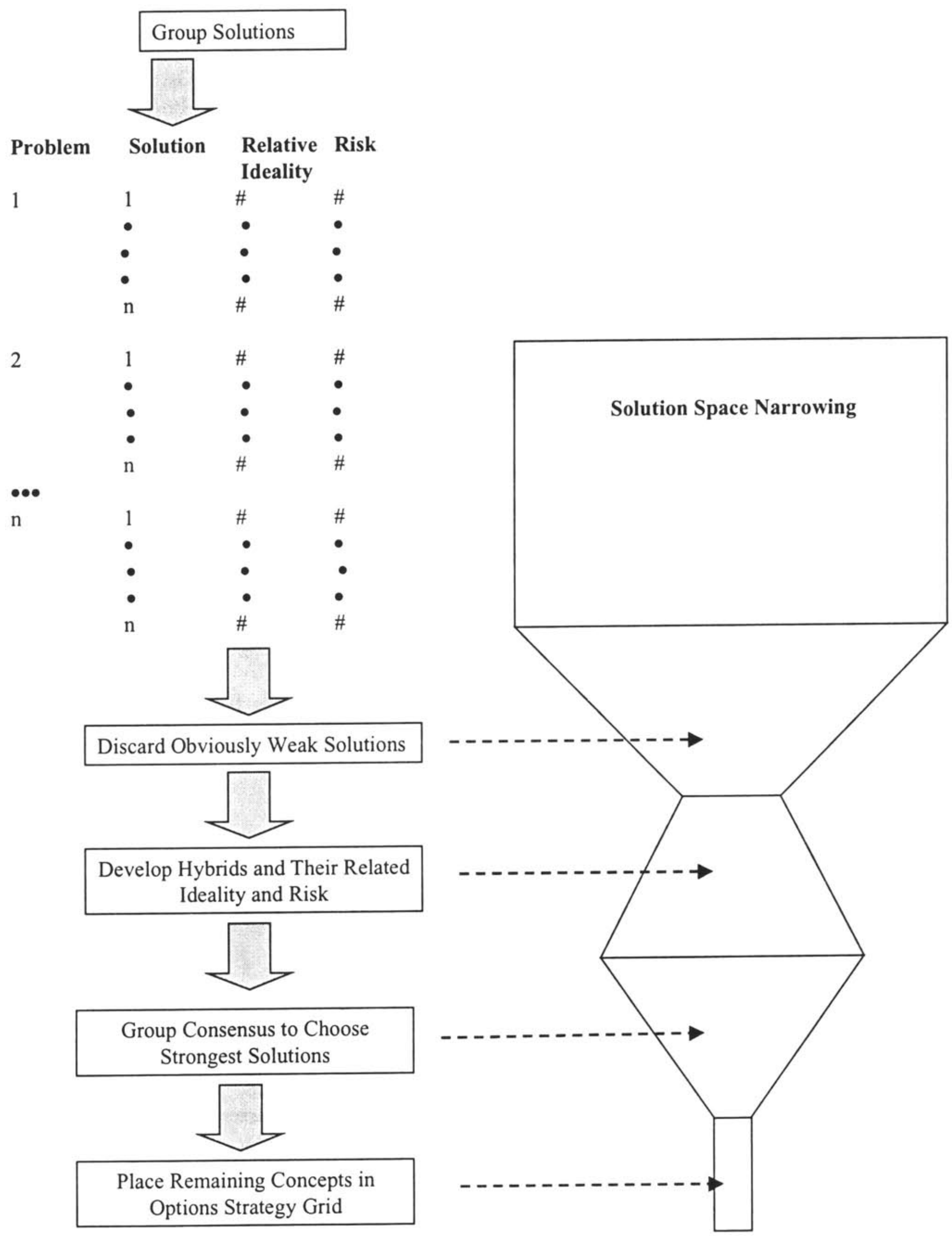
3.3.2 Discard solutions that are obviously weaker relative to other listed solutions.

3.3.3 Rank order and generate possible hybrids of solutions.

3.3.4 It should be possible to select best candidate solutions using the risk and relative ideality as the principle criteria. This is done separately for each problem.

3.3.5 Identify technology dependencies and logical sequencing of technologies. (The output can be used to improve a conventional road-mapping process.)

Figure 25: Solution Narrowing and Selection

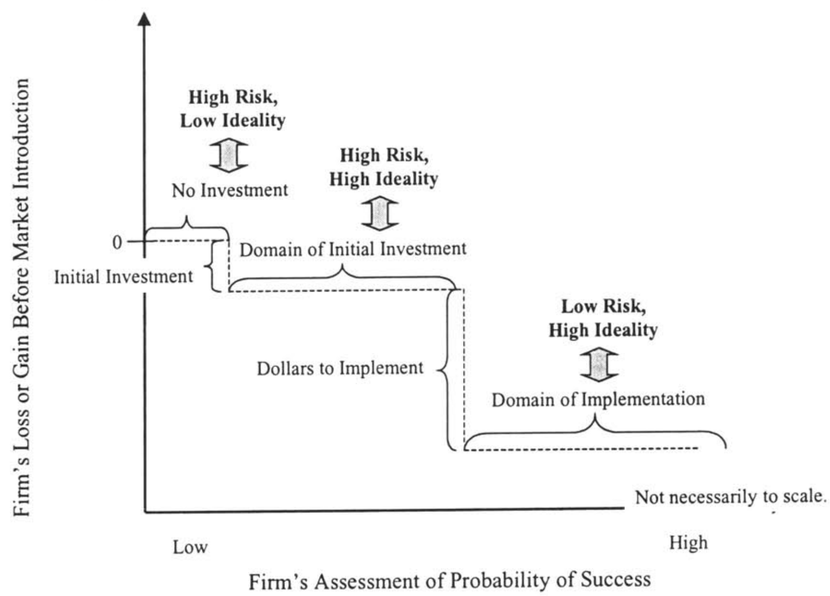


3.3.6 Identify solutions position on the strategy grid as shown below in Table 7 and Figure 26.

Table 7: Strategy Grid for Options Framework

Strategy Grid		Ideality: Low	Ideality: High
Risk	High	Weak Solution; Do Nothing with Solution Identify Alternatives	Verify Ideality Identify Ways to Mitigate Risk
Risk	Low	Unlikely to be a survivable solution to an opportunity unless there are strong complementary reasons to pursue. May be an acceptable solution to a short term or immediate problem.	Pursue Vigorously

Figure 26: Solutions Mapped to Options Framework



The process steps detailed have generated possible solutions to high priority problems and opportunities. A criterion for selection of the best solutions has been proposed using ideality and risk as the principle metrics. These solutions are then mapped to an options framework to allow for ongoing study of the technology, implementation or discontinuance as demanded by the solutions ideality and associated risk. The inputs and outputs of this process are described below.

Table 8: Inputs and Outputs to Select Technology's Disposition

Input	Output
High Priority Problems High Priority Opportunities	Candidate Solutions to Problems and Methods to Implement Opportunities Assessment of Solutions Ideality and Risk Strategy Statement about General Level of Funding and Disposition of Solution

Organizational Alignment and Environment for Executing Process

For the proposed process to have any practical utility it must be properly introduced and embedded in the firm's culture. Corporate cultural dynamics are difficult to generalize. However, several themes of resistance are expected when implementing the proposed process[11]. They include:

- A desire to frame technology identification in common technology road-mapping processes. These processes are earmarked by high emphasis on customer need driving product features and the underlying technological need. Using a set of Laws to drive technology selection may run counter to "customer focused" vision that many firms encourage.
- Difficulty in aligning the organization to the decisions made.
- Inability to incorporate tacit knowledge in the decision making process.
- Low acceptance of technological concepts outside of the knowledge domain of the firm or individual.
- Low ability to properly identify problems and provide relevant solutions.

Each of these themes is discussed below.

[11] The themes highlighted are based on discussions with several individuals and firms interviewed while preparing this paper. These contributors are mentioned in the acknowledgements.

Road-mapping

To support future product constructs it is important that technologies be chosen early to enable them. Road mapping is one process used to align corporate resources to future market need. (Groenveld, Willyard) Typically, this is done with a cross-functional team, defining future product needs and working backwards to envision the related products, technologies and R&D projects needed to fulfill the market needs.

It is clear that attributes of the proposed process are often imbedded in current road-mapping processes. This is because road maps are the plans that many firms follow to evolve their product line. The Laws have been developed while observing patent literature generated as firms evolve their product constructs. Therefore, the proposed process will generate similar product line states to what road mapping should eventually create. As a result, the process can be used to improve conventional road-mapping techniques particularly in steps 2.3.3 and 3.3.5. These steps are when product concepts and their related technologies are logically sequenced. As an example, an excerpt from a road map at Philips (Groenveld) demonstrates the link between ideality principles inherent in the Laws. As shown on their Product/Process map, metrics relevant to ideality - weight, volume and price generally decrease with time as follows.

Table 9: Excerpt from Philips Product/Process Roadmap Reinforcing Ideality

(Groenveld, Figure 3, pp. 51)

Product Characteristic	Weight		100	80	35	20	20	20
	Volume		100	70	40	25	30	30
	Positioning		Business	Business	Consumer	Consumer	Consumer	Consumer
	Price		100	70	50	40	30	20
			1995	**1996**	**1997**	**1998**	**1999**	**2000**

There are a variety of marketing tools used to develop what might be called the customer "insight" used to develop these road-mapping processes. Insight represents a customer perspective that arises from developing an intimate understanding of customer needs and wants. Phillips applies this "insight" to develop a QFD matrix. The corresponding technologies needed to implement the resulting technical product characteristics described by the matrix are envisioned in parallel and placed on the road map.

While there is no denying the importance of customer insight to develop the road-map, it is not clear what the technology selection criteria is in these processes. The principle criteria discussed by Groenveld and Willyard, is the suspected time to develop the technology well enough for commercialization. Unfortunately, the solution space studied is constrained by the expert's knowledge base. Additionally, unless there are unusually insightful customers and users of the technology involved, it is unlikely that they will articulate the Ideal Final Result which can trigger particularly inventive product constructs.

The proposed process seeks to anticipate future product states using Laws, which are essentially representations of the patterns of innovation that has existed historically. At a minimum, they become useful "filters" for evaluating the insights generated by marketing and others. More importantly, they themselves provide the insight to "leapfrog" the customers ability to articulate their need. The Laws provide a framework and criteria to evaluate the firm's interaction with the customer that leads the technical person to an implementation state. The key criteria become the ideality of the product concept. Because ideality has a strong relationship with societies acceptance of a product it suggests the commercial success of the product. Risk assessment and logical sequencing of alternatives provides an alternative for time as used in conventional road-mapping processes, and can be used to develop a technology road map. However, output from the proposed process used to develop a road map has an increased probability of success. This is because it is based on well established patterns of system evolution, provides additional criteria for generating and evaluating future technology states, and attempts to anticipate product evolution states that customers may find difficult to articulate.

For additional clarification, some typical terms associated with road mapping and their derivation using conventional road mapping is contrasted with their derivation using the proposed process as follows.

Table 10: Comparison of Implications to Road-mapping

Typical "Terms" of Road-mappping	Definition, Process or Attribute in Conventional Road-mapping	Definition, Process or Attribute in Proposed Process
Product	Meet needs of customer. Goal is to satisfy or "delight" customer.	Increase ideality. Goal is ideal final result.
Technology	Consider technologies to enable product. Integrate known technologies.	Consider evolution of current product construct. Actively integrate other technologies (known and previously unknown).
System	Anchored in current system.	Expected to change. A given that the current system will be imbedded in larger system.
Market Pull	Develop customer insight to understand market pull. Work to identify lead users. Articulate customer insight.	Improve ideality. Anticipate customer insight.
Technology Push	Functional expertise is exploited to extend current product manifestations.	Alternative technologies are brought forward as solutions.

Alignment and Insight

Alignment of organizational resources is difficult in normal situations. In situations of high uncertainty, such as technology selection, this is made more difficult by the ease with which alternative constructs can be created by subsets of the organization.

Additionally, much organizational knowledge often lies as tacit knowledge in the organization. Western culture places a high emphasis on codifying this information as explicit knowledge, but tacit knowledge continues to exist. Insight often consists of tacit knowledge that individuals may have difficulty articulating. As argued by Nonaka and TNO-FEL, it provides a rich source of knowledge and competitive advantage. (Nonaka, Dexel) As a result, TNO-FEL exercises their technology forecasting process in a framework that attempts to codify and share tacit knowledge as explicit knowledge, and with implementation, creates additional tacit knowledge. The process then repeats itself, providing an ever-expanding knowledge capability in the organization while educating ing the organization and creating alignment. (Dexel)

While this paper is not prepared to fully advocate use of all the principles embodied in Nonaka's work there are several features of the process exercised by TNO-FEL that can enhance the current proposal. These features help to align the organization to the strategy while allowing the organization to capture tacit knowledge in the organization and improve subsequent strategy. The techniques are the comprehensive dissemination and collection of information using an intranet based system and the use of organizational team redundancy.

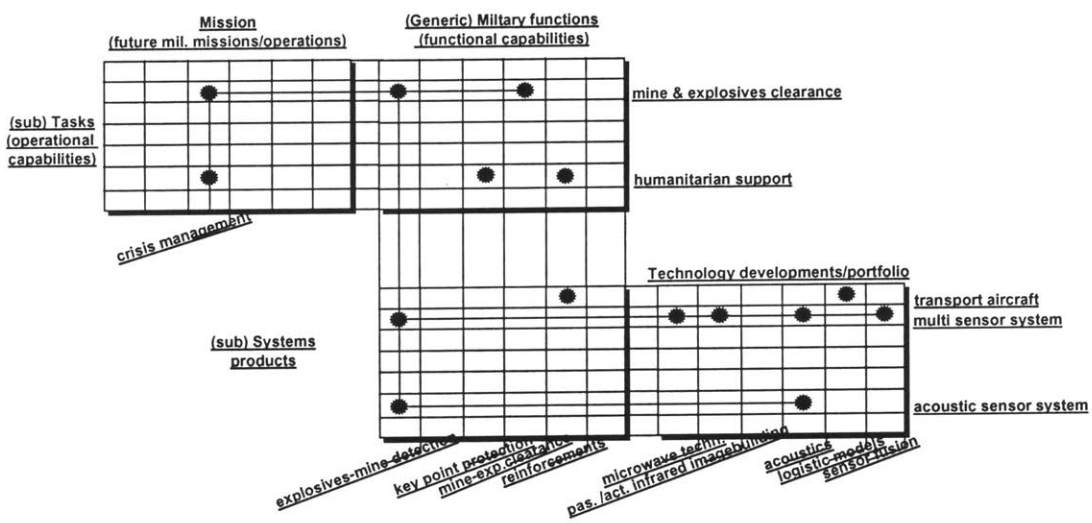
The first of these is combination of the information using a Knowledge Management System (KMS). Web based sharing of the decisions made enhance organizational alignment and expand the knowledge generated to the entire organization. These advantages, as proposed by TNO-FEL, include accessibility, security, central management and maintenance, automatic version-update, platform independent, easy to use, low cost scaling and rapid application development. (Dexel, slide 19)

More importantly, the organization of the information allows individuals to contribute their insight to the developing strategy. Technological constructs are mapped against requirements in a matrix much like QFD. "Clicking" on points of intersection allows an individual to view, and contribute, perspectives on the linkage. Additionally, full linkage of technology to subsystem, manufacturing process need, and product constructs provides a road map to the organization. This reinforces the technological need, creating improved organizational alignment. Differences in perspective can be recorded and used to improve subsequent strategy by interrogating the system. This helps to move information across organizational boundaries and involve tacit understanding in subsequent decisions.

Therefore, codifying the information related to technology selection is proposed. As implemented by TNO-FEL this is most effective by creating matrices relating one domain to another domain. This matrix is likely to include a customer need domain, a product domain, a subsystem domain, a manufacturing process domain and a technology domain. Creating matrixes relating the domains, showing the relevant linkages and creating databases justifying the linkages provides the organization with a powerful interactive tool. Provided with the relevant information the organization should more readily align to the strategy and more effectively offer tacit knowledge and insight, fueling additional strategy iteration.

Graphics showing matrices as implemented by TNO-FEL are shown below for clarification. The domains expressed in the graphics are different for industrial and commercial applications. In commercial applications it is expected that the domains will be market, product, subsystem, technology and process (manufacturing).

Figure 27: Methodology for Mapping to Technology Developments



(Excerpt TNO-FEL, Dexel, slide 12, used with permission)

The second feature, organizational and team redundancy, appears to be largely unique to Japanese companies. As explained by Nonaka, "What we mean here by redundancy is the existence of information that goes beyond the immediate operational requirements of the organizational members." He argues that, particularly during concept development, it is important to attempt to articulate concepts, even if not used immediately. "At this stage, redundant information enables individuals to invade each other's functional boundaries and offer advice or provide new information from different perspectives." (Nonaka, pp. 80-81) TNO-FEL institutionalizes this redundancy by having separate sub-teams develop concepts. These sub-teams then meet as a larger group and work towards a consensus. This practice creates redundancy and allows hybrid states of concepts to be generated more readily, especially for complex system level problems. Use of this technique when envisioning the Ideal Final Result, product constructs suggested by the Laws of

Evolution, specific implementation proposals suggested by the Lines of Evolution, use of effects databases, and determining of ideality is recommended. (Process steps 2.2.1, 2.2.2, 3.1.2, 3.1.3, 3.2.2) It is likely that sub-teams – perhaps two, with different insights and different tacit knowledges will create alternative paths. Reconciling the differences provides a mechanism for this tacit information to be expressed in explicit terms.

Table 11: Possible Process Steps where Redundant Teaming can be Used

Process Step	Description	Rational
2.2.1	Envisioning the Ideal Final Result.	Agreement on the Ideal Final Result should help gain team alignment and reveal any hidden biases within the team members.
2.2.2	List product opportunities consistent with TRIZ's Laws of Evolution.	The Laws anticipate future product states. It is likely that teams will sense differences in the marketplace and the specific product constructs will be different. Bringing the teams together afterwards will provide additional insight that may be missed by a single team.
3.1.2	Apply TRIZ's Lines of Evolution.	The Lines enable the product states envisioned by the Laws. This is a creative process relying on access to information on technologies and understanding of their current state of evolution. Again, different teams will generate different implementation constructs, allowing for reconciliation of the concepts into stronger constructs.
3.1.3	Apply effect databases such as WWW and CoBrain™.	Rational is the same as associated with step 3.1.2. It is likely that these two steps will be done at the same time.
3.2.2	Improve the candidate solutions ideality.	Again, redundant teams may generate alternative solutions. Reconciling the differences in solutions may provide additional insight and allow tacit knowledge to be expressed.

Anchored Technology Space

Low acceptance of technological concepts outside of the knowledge domain of the firm or individual is reported as a common issue for practitioners of TRIZ. The organization is inevitably more comfortable with the use of their standard technologies. Use of

CoBrain™ or the Lines of Evolution to identify alternative technological constructs are of little merit if the organization discards superior concepts simply because they are not immediately familiar with the technology.

Overcoming this organizational inertia is likely to require strong leadership. Sun Microsystems Inc. has a colloquialism in their corporate culture which is, "Be lunch or eat lunch" to reinforce the importance of change. Staying fixed on a path too long, even when faced with evidence that the firm should change, can result in disaster. The firm will be eaten as their competitor's "lunch".

From a business perspective, low acceptance of an alternative technological path, is likely to be from a fear of obsoleting fixed assets. This has been discussed in the framework of the process proposed. It is the reason that "cost" associated with implementing new technology and determining its ideality must be evaluated from both the firm's position and the competitions perspective. If the competition can deliver higher ideality, because of lower fixed assets, the firm must consider change. This is additional justification for adopting an options framework to pursue technology. It allows the firm to further consider a technology's viability without committing resources to commercialize. This lower funding level allow the organization to introduce alternative technological constructs more orderly and with less organizational resistance.

Problems and Solutions

Much of the proposed process incorporates concepts from TRIZ. This is intentional because the concepts provide useful criteria for forecasting technology states. Perhaps more importantly, TRIZ has developed problem statement and solution processes to solve seemingly illogical problems. Use of the Laws of Evolution may result in the formation of illogical problem statements as well. Western industry biases will tend to frame the problem as some sort of trade-off. TRIZ is rooted in resolving conflicts so that tradeoffs are minimized or eliminated. In truth, often what is called a "problem" is only the initial situation or current state, and does not immediately reveal the true or root problem. Some of the process steps included attempt to overcome this limitation in conventional thinking such as trying to group problems by root cause and trying to trace the energy flow in the system. While increased access to knowledge via the WWW will help envision solution states for the problem, full use of TRIZ is an additional aid the organization should consider.

Summary

At its simplest level, the process suggested is very generic. It asks the firm to consider:

- Where are we?
- Where do we want to go?

- How are we going to get to where we want to go?

Constructs built on each of these questions are principally framed around leveraging the insights of Altshuller. These constructs help objectively assess the firm's technology position. This is aided using information and web based tools to speed the process. The constructs use patterns of observed behavior as expressed in patents to guide identifying future opportunities while collecting information on current problems. These are powerful visioning tools and is very different than relying primarily on Marketing and customer insight to drive future product states. Decisions to emphasize problems or identified opportunities are made based on competitive assessment of the firm's competitive position and group consensus on priority. Lastly, processes are offered to help in generating and then selecting implementation constructs using the Laws of Evolution, ideality, and a risk assessment using an options spending framework. These Laws are exercised more efficiently by identifying information from alternate knowledge domains using the World Wide Web and semantic processors to speed the identification of solutions and assessment of a technology's viability.

The questions, with their related constructs are tabled more concisely as follows. Additionally, a flowchart integrating all process steps in presented in the appendix.

Table 12: Integrated Process : Technology Forecasting and Selection

Question	Process Step (Appendix has full diagram of process detailing information flows.)	Source(s) of Influence
What is our technological capability?	1.1 Determine the expected level of invention associated with the technology.	
	1.1.1 Identify customer's performance parameter of interest.	Betz
	1.1.2 Collect and plot historical performance parameter data. This generates an "S-curve" associated with the technology.	Betz
	1.1.3 Using Altshuller's observations described in Figure 4, determine the expected level of invention.	Altshuller
	1.2 Determine the actual level of invention associated with the technology.	
	1.2.1 Identify patents enabling the performance and the related citation history for these patents.	Aurigin
	1.2.2 Sort patents by citation frequency. Start by eliminating all patents cited less than three times.	Aurigin
	1.2.3 Determine level, as defined by Altshuller and shown in Table 1: Level of Invention, of remaining patents.	Altshuller
	1.2.4 Calculate and plot average level of invention with time. Determine the actual level of invention associated with the firm's technology.	Altshuller
	1.2.5 Compare the expected level of invention to the actual level of invention to assess the accuracy of the S-curve generated in step 1.1.2.	
	1.3 Determine the firm's performance relative to competition and technology limits.	
	1.3.1 Develop S-curves for alternative competitive technology using steps 1.1 and 1.2 above.	
	1.2.2 Determine, using expert knowledge, the top performance the firm and competitor's technology can achieve.	Betz
	1.2.3 Calculate gaps in firm to competitor technology at the top possible performance level.	
	1.2.4 Calculate gaps in firm to competitor at their respective realized (or actual) performance level.	
	1.2.5 Use Table 4: Strategy Directions from Technology Gap Analysis, for subsequent decisions.	Germeraad (Aurigin)
What does our technological capability need to be?	2.1 Develop "root" problem statements. Too often symptoms are fixed and the root problems remain.	
	2.1.1 Collect problem statements from internal functions including service, manufacturing and design.	
	2.1.2 Collect problem statements from customers and users of the product. A firm's customer is not always the user. Users should not be neglected.	
	2.1.3 Identify conflicts in the design by revisiting Room 6, the Conflict Matrix, in the quality function deployment (QFD) matrix.	QFD/ Groenveld (Philips)
	2.1.4 Group problems by root cause. Consider if problems have similar underlying causes. Consider the flow of energy through the system to assist in root cause identification.	
	2.2 Identify and evaluate future opportunities. Exploit principles inherent in the Ideal Final Result (IFR) and TRIZ's Laws of Evolution. These represent technology states that will occur and can be anticipated.	
	2.2.1 Envision the IFR. Define what is the state of performance desired with no cost and no harmful side effects.	Altshuller

What does our technological capability need to be? (continued)	2.2.2 List product opportunities consistent with TRIZ's Laws of Evolution. (The Lines of Evolution will assist with visualizing possible implementation states.) 2.2.3 Screen product opportunities voiced by the customer, user and marketing against TRIZ's Laws of Evolution. Discard ideas that are inconsistent with the Laws. 2.2.4 Screen product opportunities against scenarios that anticipate widespread societal, environmental or technological trends that are likely to occur. 2.3 <u>Prioritize and sequence problems and opportunities. (Problem resolution is typically associated with incremental improvements of a given technology. Opportunities are typically associated with more drastic alteration of the underlying technology. Fixing a fundamentally weak technology or moving to an alternative technology too soon results in a waste of money.)</u> 2.3.1 Use the results of step 1.2.5 to guide strategy. Decide to emphasize problems or opportunities. 2.3.2 Use group consensus to identify top problems or opportunities. 2.3.3 Logically sequence resolution of problems or opportunities. (These can be used to inform and improve a conventional road-mapping process.)	Altshuller Wissema/ Schwartz Germeraad (Aurigin)
What technology or technologies are we going to pursue to enable this capability?	3.1 <u>Create list of superior solution concepts and technologies.</u> 3.1.1 If opportunities are to be emphasized as decided in step 2.3.1 they should be converted to problem statements. Problems associated with implementing the opportunity should be listed. 3.1.2 Apply TRIZ's Lines of Evolution to identify candidate solutions to problems. 3.1.3 Apply effect databases from the World Wide Web and semantic processors such as CoBrain™ to expand the set of possible solutions considered. 3.1.4 Consider altering the problem statement to provide additional system available resources, such as electricity to a mechanical sub-system, and to relieve imposed constraints. 3.1.5 List candidate technologies. 3.2 <u>Determine the ideality, a measure of society's acceptance of a concept, and implementation risk associated with various solutions. Ideality and risk are to be the principle criteria for solution and technology selection.</u> 3.2.1 Develop relative ideality of the solutions. Candidate units include performance per dollar, kg, or cubic meter. 3.2.2 Improve the candidate solutions ideality by improving performance, reducing cost or reducing harmful effects. 3.3.3 Determine the associated risk based largely on technological familiarity, implementation latitude and technology accessibility as shown in Figure 9 : Risk Categorization Algorithm. 3.3 <u>Narrow the list of candidate solutions and place them in an options framework. An options framework allows the risk and ideality of a solution to be balanced with spending.</u> 3.3.1 Group solutions to candidate problems together. 3.3.2 Discard obviously inferior solutions using risk and ideality as criteria. 3.3.3 Rank order and generate possible hybrids of solutions. 3.3.4 Use group consensus, guided by ideality and risk, to choose final candidate solutions. 3.3.5 Identify technology dependencies and logical sequencing of technologies. (These can be used to inform and improve a conventional road-mapping process.) 3.3.6 Place solutions chosen in options framework. Use strategy framework consistent with Table 7: Strategy Grid for Options Framework.	 Fey, TRIZ, IMC IMC/ Altshuller TRIZ TRIZ TRIZ Hartmann (Xerox) Nichols (Merck)

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APPENDIX:

A.1 ACTIVATION PROCESS FOR USING LAWS OF EVOLUTION

It is unlikely that there is a substitute for experience when working with the Laws of Evolution. Effectiveness in using the laws can be accelerated by extensive reading of the literature associated with these laws and recognizing their existence in many of the technologies innovators work with every day. However, recognizing that these laws are new to many, two tools are proposed to assist in activating use of these tools.[12]

The first of these tools is use of morphological techniques. However, the product constructs generated should be mapped to the Laws. Altshuller discusses the strengths and weaknesses of this and several other techniques. (Altshuller, 1999, pp.63) He cites morphological techniques, "This method is most effective used when solving general design problems, like designing new machinery, or searching for new conceptual solutions ...". This is similar to the task typically before the innovator during the technology identification process. They are trying to envision alternative system level concept implementations that rely on alternative manifestations of technology. To improve the process, as suited to TRIZ, the parameter descriptions should be generalized to allow for a greater range of high level solutions to be considered. The concepts should then be mapped to the Laws to see if candidate constructs are consistent with the Laws.

One concern associated with this technique is the magnitude of the number of concepts that can be generated. Therefore, it is proposed that morphological techniques only be used to help new user's of the laws initially envision alternative states that may satisfy them. An additional concern is that while it may help envision alternative states that can "fit" into several of the Laws it does not allow for creative extensions of the functionality that many of the Laws suggest. In particular, it does not appear that this technique will work well with "Transition to a Higher-Level System". Morphological techniques are anchored in an initial functional description. This precludes comprehensive study of extensions of this function by incorporating the function in alternative system constructs.

The second of these tools is review of several questions to prompt thinking associated with the Laws. This process, called Pilot Questions (Altshuller, 1999, pp. 64), is more effective when the questions are developed to stimulate thinking along the Laws intent. Alsthulter expresses concern that use of Pilot Questions, just to stimulate creativity without any real direction on what a good answer is results in the creation of concepts anchored only in prior knowledge and insight.

Therefore, these questions are not intended to constrain thinking but to stimulate initial thinking along the Law under consideration. The questions are intended to force the innovator to envision states suggested by the Laws. These states may initially be considered illogical by the innovator and discarded as possibilities. They should not be

[12] Invention Machine Corporation (IMC) software, Techoptimizer™, Version 3.01, Professional Edition, attempts to codify much of this process, and is an additional candidate process to activate thinking.

discarded. This is typically difficult, because as with Brainstorming, the individual tends to criticize their idea because they consider it illogical. Many truly inventive solutions are initially perceived as unsolvable or illogical. This is why proper formulation of the problem, as incorporated in the balance of TRIZ and utilization of knowledge assets via CoBrain™ are so important. They work help the innovator see the possibility associated with their illogical concept.

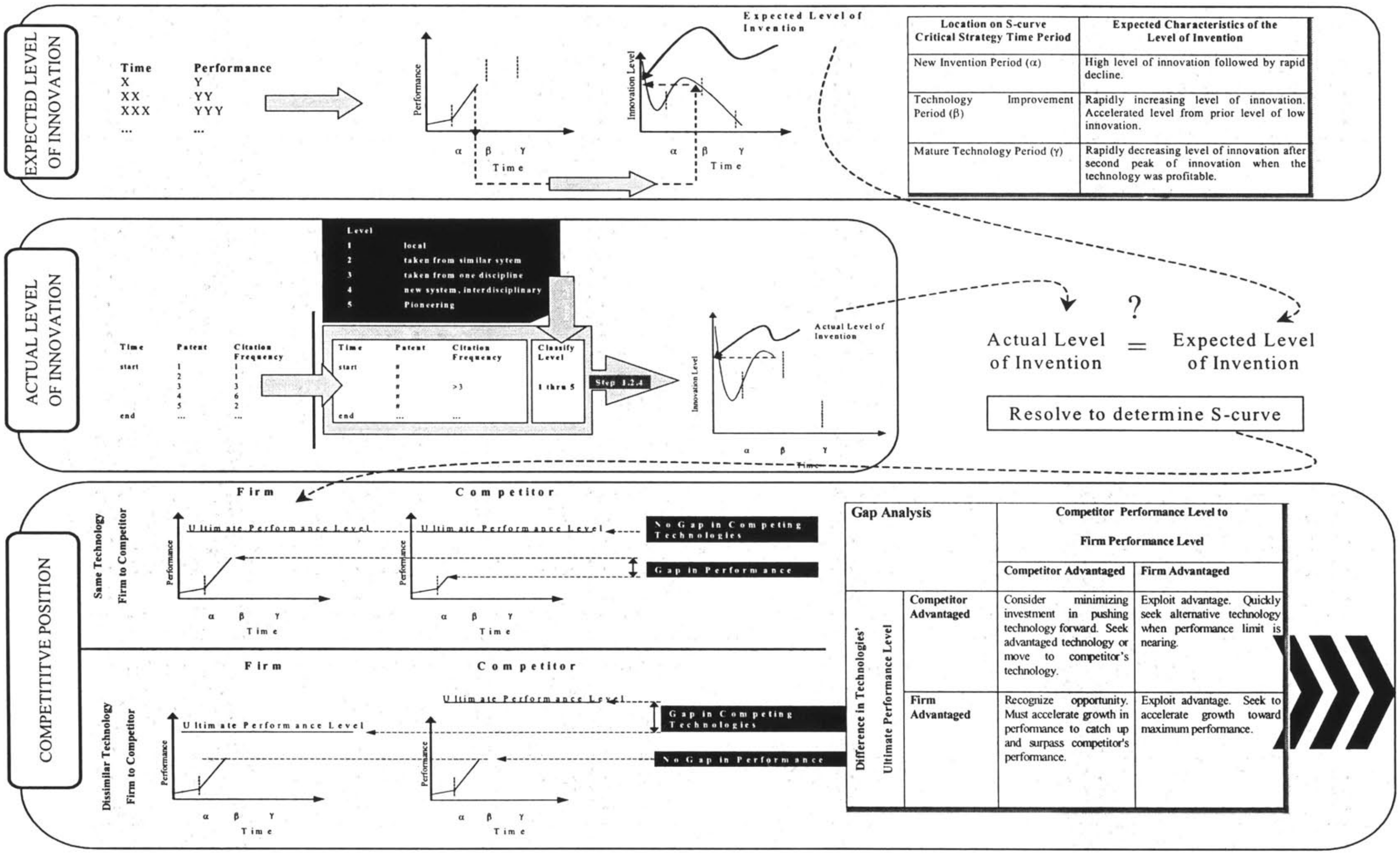
Candidate questions, mapped to the given laws, are shown below in Table 13.

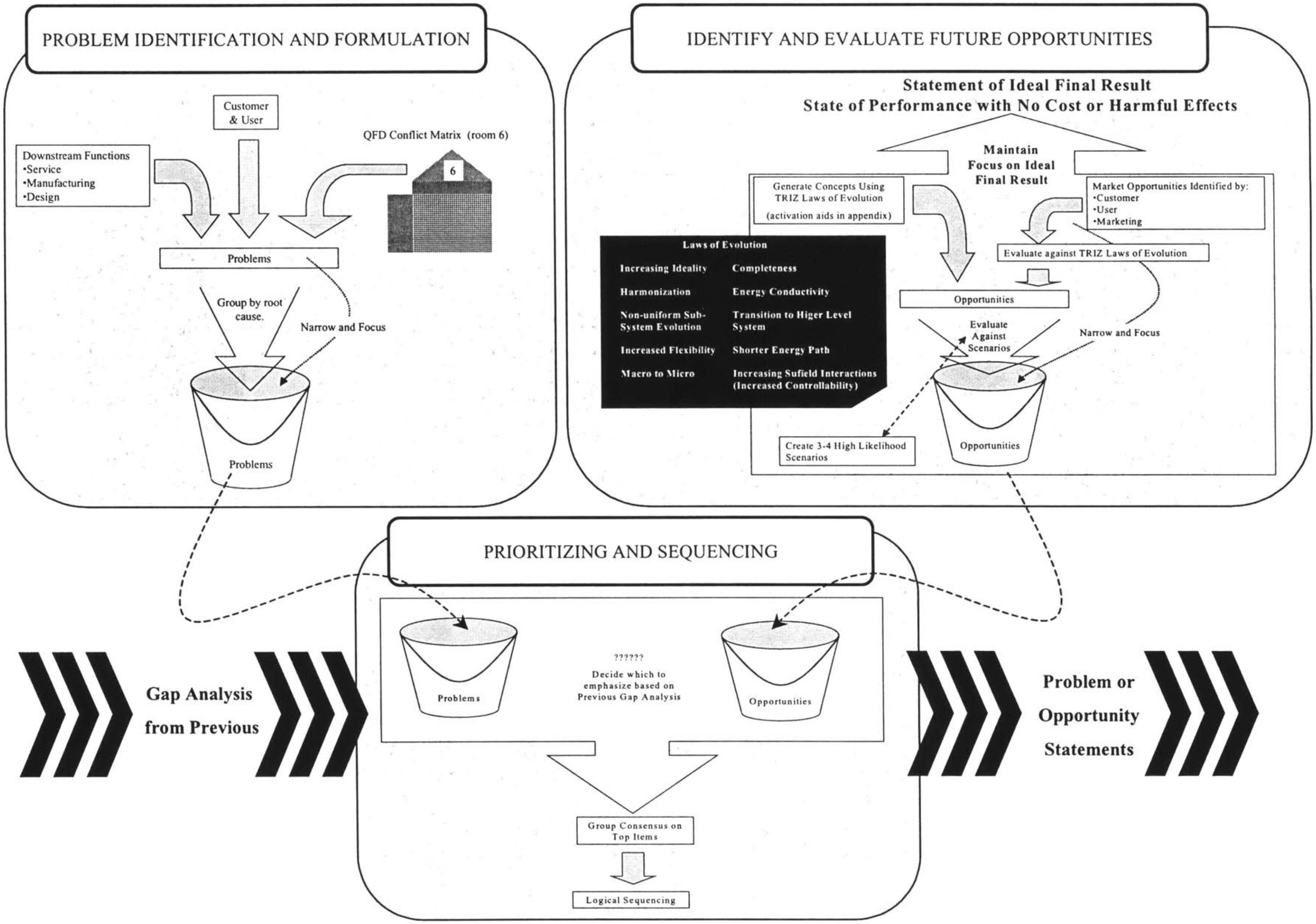
Table 13: Candidate Questions to Activate Thinking

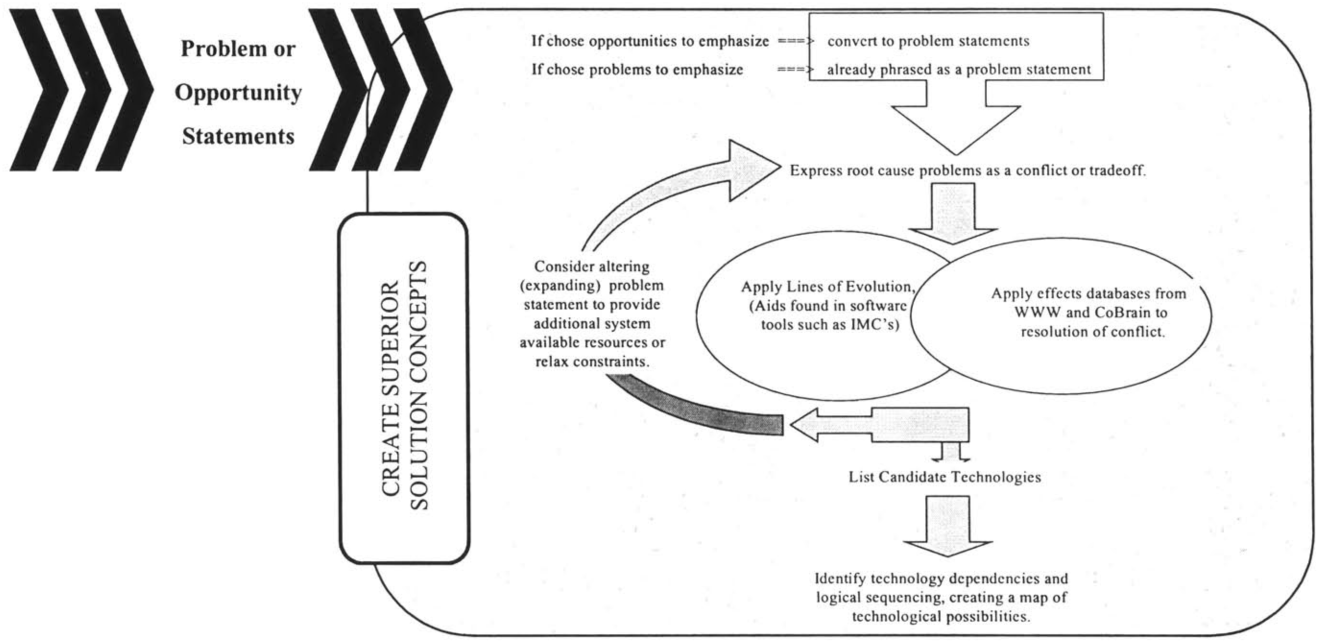
Law	Candidate Questions
Increasing Degree of Ideality	Is there anything in the system that could serve multiple functions? Can the weight, volume, or number of parts be reduced?
Completeness	Does the system have an engine, a transmission, a function and a control mechanism?
Harmonization	What are the state changes of the subsystems? Are their logical sequences and relationships between their state changes?
Energy Conductivity	Is energy applied directly to the subsystem in need? Are there alternative ways to transmit energy to the subsystem or part?
Non-Uniform Evolution of Subsystems	Are there subsystems that have not undergone improvement recently?
Transition to a Higher-Level System	What uses the system's outputs and inputs? Can the system be made part of a larger system by combining it with similar, opposite or dissimilar items?
Increasing Flexibility	Can parts be made flexible? Can parts of the design be made movable? What functionality might change with movable and flexible parts? Can the object be made subject to fewer constraints?
Shortening of the Energy Path	Can any parts be removed? Are there any parts, or subsystems in the design that are principally to reduce harmful effects?
Transition from Macro- to Micro Level	Can parts of the system be made smaller? What would it mean to make a given subsystem small?
Increasing Degree of Substance-Field Interactions	Are there parts or subsystems (substances in TRIZ) that could be used to effect change of states on different parts or subsystems? Can new or modified substances control more than one, or alternative substances?

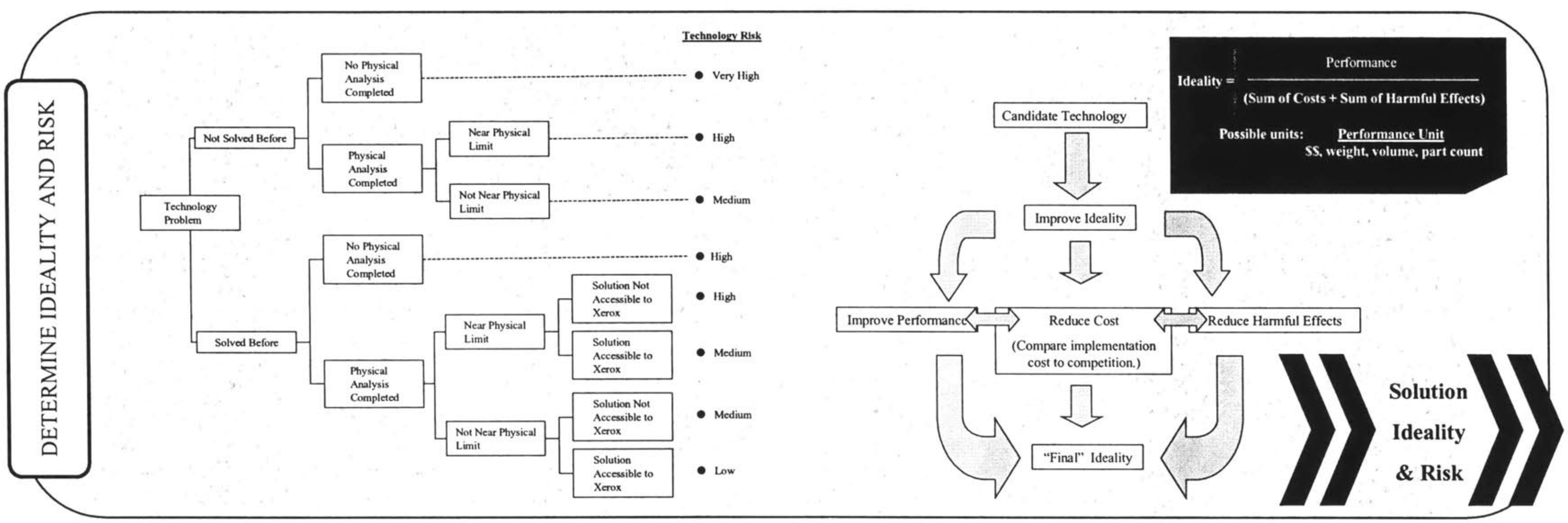
A.2 PROCESS FLOW DIAGRAMS

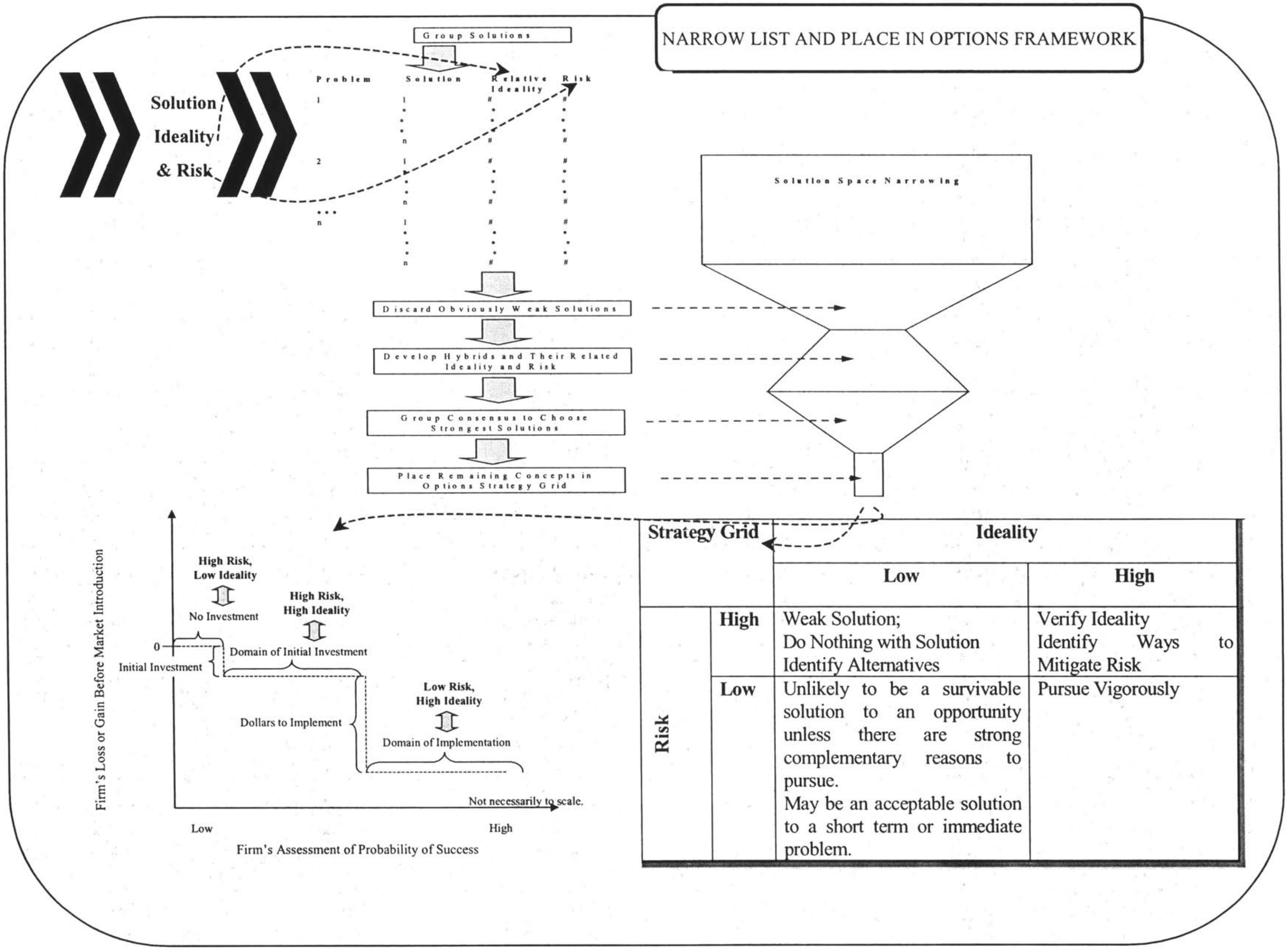
Figure 28: Integrated Process Diagram (four pages)




PROBLEM IDENTIFICATION AND FORMULATION
Customer & User
QFD Conflict Matrix (room 6)
Downstream Functions
•Service
•Manufacturing
•Design
6
Problems
Group by root cause.
Narrow and Focus
Problems
IDENTIFY AND EVALUATE FUTURE OPPORTUNITIES
Statement of Ideal Final Result
State of Performance with No Cost or Harmful Effects
Maintain Focus on Ideal Final Result
Generate Concepts Using TRIZ Laws of Evolution
(activation aids in appendix)
Market Opportunities Identified by:
•Customer
•User
•Marketing
Laws of Evolution
Increasing Ideality
Completeness
Harmonization
Energy Conductivity
Non-uniform Sub-System Evolution
Transition to Higer Level System
Increased Flexibility
Shorter Energy Path
Macro to Micro
Increasing Sufield Interactions (Increased Controllability)
Evaluate against TRIZ Laws of Evolution
Opportunities
Evaluate Against Scenarios
Narrow and Focus
Create 3-4 High Likelihood Scenarios
Opportunities
PRIORITIZING AND SEQUENCING
Gap Analysis from Previous
Problems
??????
Decide which to emphasize based on Previous Gap Analysis
Opportunities
Problem or Opportunity Statements
Group Consensus on Top Items
Logical Sequencing


Problem or
Opportunity
Statements
CREATE SUPERIOR SOLUTION CONCEPTS
If chose opportunities to emphasize ===> convert to problem statements
If chose problems to emphasize ===> already phrased as a problem statement
Express root cause problems as a conflict or tradeoff.
Consider altering (expanding) problem statement to provide additional system available resources or relax constraints.
Apply Lines of Evolution, (Aids found in software tools such as IMC's)
Apply effects databases from WWW and CoBrain to resolution of conflict.
List Candidate Technologies
Identify technology dependencies and logical sequencing, creating a map of technological possibilities.


DETERMINE IDEALITY AND RISK
Technology Risk
Technology Problem
Not Solved Before
Solved Before
No Physical Analysis Completed
Physical Analysis Completed
Near Physical Limit
Not Near Physical Limit
Solution Not Accessible to Xerox
Solution Accessible to Xerox
Very High
High
Medium
High
High
Medium
Medium
Low
Ideality = Performance / (Sum of Costs + Sum of Harmful Effects)
Possible units: Performance Unit
$$, weight, volume, part count
Candidate Technology
Improve Ideality
Improve Performance
Reduce Cost
(Compare implementation cost to competition.)
Reduce Harmful Effects
"Final" Ideality
Solution
Ideality
& Risk



Strategy Grid		Ideality	
		Low	**High**
Risk	**High**	Weak Solution; Do Nothing with Solution Identify Alternatives	Verify Ideality Identify Ways to Mitigate Risk
	Low	Unlikely to be a survivable solution to an opportunity unless there are strong complementary reasons to pursue. May be an acceptable solution to a short term or immediate problem.	Pursue Vigorously