PERFECTION, IDEALITY, AND TECHNOLOGY ROAD MAP AS MEASURED BY A SLIDING SCALE
(TECHNOLOGY CREATIVITY METRICS)

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ABSTRACT

This paper presents an approach to quantify and measure technology evolution levels as forecasted by a technology development road map. The concept of technology perfection performance and ideal performance are defined and contrasted in order to clarify such notions as: current state-of-the-art technology, old proximity to ideal performance, new proximity to ideal, perfection improvement, and technology creativity level. Perfection is defined as a practical and obtainable performance of a technology at a forecasted state-of-the-art development level, where ideal performance is the ultimate imaginary state of unreachable perfection. The creativity levels of technologies displayed on a road map are quantified by the use of a "creativity measurement sliding scale", also here-by called the "JJ Sliding Scale". These forecasted technology levels are displayed on this road map including the current-state-of-the-art as well as the imaginary ideal performance of selected technology. Such parameters as: functional performance, required energy or power, weight, volume, resources including cost, time to manufacture, and lack or presence of harmful effects are the key parameters used to establish the different forecasted technology levels of perfection vis-a-vis the current state-of-the-art technology. The measurement of creativity at each of the levels of technology displayed on the road map is performed by applying to the above mentioned key parameters a relative weighted factor grading. A quantified total point value for each forecasted technology development level is obtained. The ranking of technology levels by the total earned calculated point value relative to the ideal performance is presented as a metric of technology creativity levels distributed on a technology road map. The proposed methodology is applied to the development and quantification of a technology development road map for the NASA space rechargeable batteries. This paper is also using the Darwinian biological evolution concept, as an analogy, to help better understand the engineering technology forecasting and evolution.

PERFECTION AND IDEAL PERFORMANCE

During the quest for a perpetual product and process invention and innovation, managers, engineers, biologists, and technologists alike are continuously striving for an ideal system design as the most desirable solution for a given technology implementation and performance. The continuous incremental product and process improvement, as applied in technology development, is in fact that specific desire for the materialization of the endless strive for perfection of individual stages of technology development on a road map that will continuously strive towards an ideal performance. The notion of "perfection" and the notion of "ideal" have in fact a similar but different connotation. "Perfection" is defined as the state of performance of being entirely without fault or defect as per initially specified functional requirements, and where all predetermined performance requirements are being satisfied. "Ideal" is defined as an ultimate objective or aim of performance endeavor that is reaching an ultimate goal of a mental image that exists only in fantasy or imagination. All engineering systems have the natural development tendency of approaching the imaginary ideal system [1]. For that reason, perfection is a practical and obtainable performance characteristic of a technology at a given state-of-the-art level, where the ideal is the ultimate imaginary state of the unreachable perfection. In the real world of creative technology development and improvement, there is a continuos tendency towards proximity to perfection, as well as, a perfection proximity towards ideal. Using an analogy comparison with an optimization function, the technology level perfection is similar to obtaining a local maximum, where the ideal performance could be compared to a global maximum.

SURVIVAL OF THE FITTEST – THE BIOLOGICAL PERFECTION

Understanding how biological organisms have evolved can be used as a guiding model in the evolution prediction of engineering systems. Darwinian evolution based on biological organisms striving to adapt to current environmental conditions leads to temporal perfection in adaptation, insures optimum development, and cultivates reproductive success. As the environmental conditions change, the time line of evolution shifts towards a temporal ideal organism based on a tendency of the organisms to achieve a temporal perfection performance insuring optimum reproductive success and survival of the fittest biological species. As soon as the environmental parameters changed, so the value of perfection changed. As the values of the parameters became more conceptualized, so the system evolves towards an increased ideality.

Let us take as an example: the Darwinian evolution of a Finch. Some Finch species peck out of sand; thus a long beak is the perfect adaptation to the feeding environment. Other species peck seeds and nuts, therefore, a wide beak is the perfect adaptation to the available food parameters. And still some other species peck fruits and flower nectar, and for this purpose a pointy beak is the most appropriate. As the many varieties of Finches specialize in their environments, they approached a level of adaptive perfection, while as a whole the species approached an ideal level of evolution. In time, as the environment is changing, some future Finch species possibly will adapt and might be able to peck at all of the above food sources. They will be on a higher level of perfection for the combined environment. The outcome will be an even closer proximity to ideal adaptation to the ever-changing environment. Even a "perfect" species would not be able to evolve towards an ideal if it was stagnant in its developmental diversity. This can be simply observed in lineage with intermarriage histories. In such situations, there is an increase in the observance of genetic dysfunction, i.e. hemophilia in some of the old royal families of Great Britain. Thus, not only are changes good, but necessary for the development of a superior species and for that species to be able to adapt to its changing environment; not only keeping up with change, but thriving to do better. The concept is: "too much perfection leads to developmental stagnation, where as imperfection is necessary for growth toward ideality, because of possibilities."

TECHNOLOGY EVOLUTION

As a parallel to the biological adaptation to the medium, let us take as an example the history of computer technology evolution. The main function of a computer is to perform mathematical computation. Thus the first computers on the market were doing just that. Some of us still remember the huge, bulky and awkward punch card reader used as among the first data processing computer equipment technology. As demand for smaller and faster computers grew, along with the demand for more and more information storage capacity, the newer computers technology such as the main IBM 360's were themselves rapidly replaced with the current modern age desk top computers. More recently, the newest computing technology trend is now the laptop and the palm size computers. During all this computing technology evolution, the functional performance of information processing speed and reliability has tremendously increased, where as size, weight, manufacturing cost, time to manufacture, and power consumption have drastically decreased. For the computer manufacturing companies to stay in business, at each of the different computer technology development levels, perfection was always the main characteristic to strive for [11]. In the process, many of the competing computer manufacturers could not adapt to the market needs, and perished in the process. Perhaps, the next computer technology will be a human brain-like biological computer with autonomous reasoning power, in addition to an even faster processing time and memory capability. These new computers will have the tendency to further evolve from the current serial to heavy parallel processors. These future nano-technology based computers will be so small and will require such little power to operate that they will be able to be biologically attached to the human brain or even to replace it. Again, in time as the computing demand environment changes, the value of the computer perfection performance will be continuously upgraded, having as a final goal to reach the tendency of the ideal imaginary computing system. This will be accomplished by performing biological mimicry in the performance of the future artificial human brain. Thus, perfection is a contemporary assessed value of ideality. As time and environment change, the value of perfection is re-assessed. Eventually, perfection approaches an ideal. Nevertheless as discussed earlier, ideal systems may never be conceptualized, one reason being among many others, because it may become no longer time or environment dependent.

ENGINEERING IDEALITY

According to Genrich Altshuller [1], all engineering systems evolve in the direction of improved ideality. Altshuller defines an ideal system (*I*) as "an engineering entity that performs the desired function(s) (*F*), while requiring no energy to perform its functions (*E*), has no weight (*W*), has no volume (*V*), requires no resources to produce (R), takes no time for its implementation (*T*), and has no harmful side effects (*H*)". The degree of approaching the imaginary ideal system, also called the degree of ideality *(DI)*, is a function that can be described by the following formula:

$$DI(f) = \Sigma F / (\Sigma E + \Sigma W + \Sigma V + \Sigma R + \Sigma T + \Sigma H) \quad (1)$$

Where,

$DI(f)$ - is the degree of approaching the imaginary ideal system

ΣF - is the sum of all useful functions

ΣE - is the sum of all energies or power required to perform the functions

ΣW - is the sum of all component weight

ΣR - is the sum of all required resources including incurred cost

ΣV - is the sum of all component volume

ΣT - is the sum of all implementation time

ΣH - is the sum of all harmful effects

From this equation, the larger the sum of the useful functions is, the larger the value of the ideality degree becomes. Also, when the compounded sum of the denominator is approaching zero, the degree of the imaginary ideal system is approaching infinity,

Or, when, $(\Sigma E + \Sigma W + \Sigma R + \Sigma V + \Sigma T + \Sigma H) \rightarrow 0$

then, $DI(f) \rightarrow \infty$.

FASTER, BETTER, CHEAPER AS A CREATIVITY MOTIVATOR

From the description above applied to an actual practical situations, systems move toward ideality when there is an improvement in functional performance, while there is a decrease in needed resources, as well as a decrease in harmful side effects or an increase in reliability. In fact, the NASA coined FASTER, BETTER, CHEAPER edict is a major driving force in stimulating the pace of space technology programs towards perfection. In time, NASA missions will have a tendency to be implemented and perform in the direction of perfection and ideality. The question is how much of an ideal performance is ideal? It all starts with how much "better" are we considering the performance of a given flight technology designed system. The word "better", from the NASA edict point of view, definitely does not mean at all the word "the best", or the ideal situation. The edict is more related to specified levels of desired "better" performance, in the context of "faster" and "cheaper" implementation mode, where "better" is associated with level of perfection, as in the context of the accepted risks. A continuous improvement of the "better" will push in time the performance envelop towards the ideal situation, "the best". The ideal best performance considers time as an element of developmental reference during which best/perfection performance can be obtained through inventions and innovations [4],[6],[9]. Now the edict can be modified to read Faster, Cheaper, and Accepted Perfection for a given technology of a space mission with the final goal of a continuous technology development improvement towards an ideal system performance. Being able to measure the perfection performance relative to the ideal situation becomes an important quantification metrics tool of quantifying perfection performance as a proximity to ideal. What we propose here is the concept of a sliding scale that enables creativity measurement embodied by the term perfection vis-a-vis the proximity to ideal.

CREATIVITY SLIDING SCALE

Let us consider the value **C** as the imaginary ideal situation. As defined earlier, the desired degree of ideality $DI(f)$ could take many desired perfection performance values. In the case of technology development, these values can be also interpreted as technology creativity levels, or the technology development components of a technology road map [2],[8]. These creativity levels will be materialized in design options, design decisions, and the selection of the most appropriate design to implement the desired function [13,14]; a well known concept by which form follows function [3]. Knowing the numerical values of the design parameters described in formula (1) above, and substituting them, we can compute the magnitude of $DI(f)$. For a given technology proximity to perfection on the technology road map, we would calculate $DI(f)$=**B**. Based on the imposed functional and performance requirements established by the technology driven program or project, the value of B can thus be calculated and could take values or "slide" from 0 to the imaginary value of infinity, ∞.

Or, $0 \leq \mathbf{B} \leq \infty$ (2)

Since technology development is always evaluated against an existing "old" technology such as the current state-of-the-art, the value zero of formula (2) above is seldom zero. Thus, the actual magnitude can be represented by a numerical value **A**. On the other hand, the infinity element of the equation (2) is the degree of approaching the imaginary ideal situation, or **C**, as defined earlier. Thus, practically speaking the following relation can be obtained

$$\mathbf{A} \leq \mathbf{B} \leq \mathbf{C} \quad (3)$$

Where, *A* is the old technology, or the current state-of-the-art, which is used as the term of reference. **B** is the new technology that is intended to be developed as a result of a new creative thinking. Finally, **C** is the ideal technology that we eventually would like to reach for a given new technology development in the future. The farther the new **B** technology is from the current state-of-the-art technology **A**, the higher the creativity improvement of the new technology is. The closer the **B** value is to **C**, the higher the creativity of the new technology is. Graphically, the scale is described as per diagram below:

Old New Ideal

A.........................**B**....................**C**

The relationships between **A, B**, and **C** adopt the following meanings:

C – A = the old proximity to ideal
C – B = the new proximity to ideal
B – A = creativity improvement

If we can quantify the magnitude of **A** and **B** and by computing the value of **B - A**, we are able to perform in fact a "creativity improvement " measurement from the old existing technology to the new proposed technology. Also, knowing the value of **B** and what are the boundaries of improving the technology at level **B** we can determine and measure the degree of perfection improvement at that level. The "perfection" performance of value **B** is approaching temporal perfection in response to an existing functional and performance specification and environmental requirement conditions. As the environment is continuously changing, even when at a certain moment when system perfection at value **B** is approaching **C** the ideal, the value of **B** has already changed on the measuring sliding scale. Relation **C – B,** on the other hand, will become an actual measurement of the degree of invention and innovation as represented by the "sliding scale" of approaching the imaginary ideal system. The smaller the difference **C – B** is, the higher the level of creativity of the new technology becomes. Also, the value of **C-B** is an indication of how much room for improvement towards an ideal system a technology has.

CREATIVITY, ROAD MAPS AND MEASURING SLIDING SCALES

In measuring creativity in technology development, we propose to link the "sliding scale" terminology to the technology road map concept. "Fix scale" is meant for a single given creative technological design. The use of the fix scale concept implies that there is no alternative creative thinking and no design decision [13], since there are no other design options to be considered. On the other hand by using the sliding scale concept, it implies that many design options are considered to perform a given main function. The proximity to the ideal of the design options considered is another element that can be discussed in support of the technology road map sliding scale concept. This representation leads to the well-known concept of the "technology development road map." As any good planning, a technological road map draws a plot for the course of how to get from where we are on a given current technology and to where we would like to be in a give time in the future. If properly documented, the road map will also tell us what actions and supporting procedures we need to take [5]. A plan with a list of "what to do" will invigorate the motivation for action, such that as we celebrate the technology achievements of the past, we will keep our eyes on the future road ahead of us [10]. The road map will identify different design technologies that will implement a desired main function, and the associated schedule of implementation. As a short summary, the road map should identify the following: 1) The current technology level **A;** (2) The next higher level technology level **B** on the road map; (3) The degree of technology development **(B - A)** that is desired for each of the next technology milestones to be foreseen on the road map; (4) The proximity of a given next technology level **B** on the road map reaching the imaginary ideal situation **C**, as **(C-B)**. A good technology road map should contain more than one next technology development level $\mathbf{B}_{(i)}$, where the value **i=1,2,...,n.** With this new view, the sliding scale of technology development road map will have a slightly different look, as follows:

Old tech. New tech. 1 New tech. 2..New tech. n Ideal

$$\mathbf{A}.........\mathbf{B}_{(1)}...........\mathbf{B}_{(2)}...........\mathbf{B}_{(n)}.........\mathbf{C} \quad (4)$$

In order to quantify technology development levels $B_{(i)}$ on the road map, it is proposed that for each of the parameters of equation (1) above, a "weighted factor" value from 1 to 10 is to be assigned, and a total value to be summed up for each of the $B_{(i)}$ values. The concept of weighted factor is similar to the one used in the Quality Function Deployment (QFD) technique [15], where the prioritization and selection of actions to be considered are selected in a similar manner [7]. For an exemplification, Table 1 illustrates how technology road map quantification can be generated. This representation we named it the "JJ Sliding Scale"

Technology Development Sliding Scale

Param.	Level **A**	Level $B_{(1)}$	Level $B_{(2)}$...	Level $B_{(n)}$	Level **C**
(ΣF)	7	7	8	9	10
(ΣE)	4	5	4	8	10
(ΣW)	5	5	7	8	10
(ΣR)	3	5	7	8	10
(ΣV)	6	6	3	2	10
(ΣT)	7	5	7	8	10
(ΣH)	6	7	9	9	10
TOTAL	38	40	45	52	70

Table 1. Quantification of technology road map using weighted factors from 1 to 10 for the individual parameters of Equation (1) and calculated for each of the technology development levels of the road map.

By assigning a weighting factor to the parameters of equation (1) and using Table 1 above, the imaginary ideal technology at Level **C** is totaling 70 points. Similarly, the current state-of-the-art technology at Level **A** is quantified at 38 points, out of the total maximum 70 points. The identified Level **B** technologies at level **1**, **2**, and **n** are quantified at 40, 45, and 52 points respectively. These next three levels of the technology development are in fact the components of the technology road map that are considered and planned to be developed in the future. With quantified values attributed to each technology development on this sliding scale, we now can also better understand the perfection improvement at each technology development level.

Thus from Table 1, creativity improvement at level $B_{(1)}$ is $B_{(1)}$**-A**, or 40-38=2. The new proximity to ideal of $B_{(1)}$ can now be computed as **C-**$B_{(1)}$, or 70-40=30. This indicates that there is still a lot of room for improvement for the technology at level $B_{(1)}$. As the assigned weighting factors indicate, not all parameters of equation (1) have registered improvements; some remained the same and one (ΣT) registered a decrease from 7 to 5. Worth to be mentioned is that the current point value 7 of (ΣF) at level $B_{(1)}$ can be further improved to 8 at the next level $B_{(2)}$ of technology on the road map. In addition, the sum of harmful effects (ΣH) can be reduced, thus improving the total point value from the first predicted value of 7 to the next value of 9. Changes will take place at the other parameters as well. This will bring the total maximum value of technology level $B_{(2)}$ of Table 1 to a total value of 45 points. As an analogy, this is viewed as an optimization of a global function around a local maximum. The chosen parameters are not the only two parameters that can be taken for consideration for improvement in order to obtain the technology level perfection. This local perfection improvement now places technology on the road map at a higher level of creativity. This reinforces the sliding scale concept very appropriately. The more parameters of equation (1) are improved, the closer to the ideal performance is realized. Consequently, an optimization that is close to the ideal performance is analogous to an optimization of a global maximum.

SPACE RECHARGEABLE BATTERY AND ROAD MAP METRICS

The current NASA space rechargeable battery is NiCd based [12]. Weight, volume, operation temperature, power density, recharge cycle, and safety are desired performance parameters that need to be improved. For space applications in the next fifteen years, the Li-Ion batteries are considered to be developed and used as the secondary low temperature battery technology of the future. By applying the JJ Sliding Scale described above to the space rechargeable battery technology road map, we have generated quantified metrics for the individual battery technologies, as described in Table 2. NiCd, the current state-of-the art battery, gained a total point value of 29. Next is Li-Ion with 43 points, followed by Li-Polymer with 49 points. As it can be easily observed, the creativity improvement **B-A** for the first two batteries on the road map is 14 (43-29=14) and 29 (49-29=20) respectively. It is worth noting that Li-Polymer battery had earned 49 points which is higher than the "battery-on-a-chip" technology which had earned only 46 points, even though it is placed on a higher level on the road map. What earned the battery-on-a-chip technology a higher level on the technology development road map is the reduction of weigh and volume, the increased functional performance and reliability, and the potential of being integrated on-a-chip with other micro spacecraft-on-a-chip revolutionary technologies of the future. Again, this is a good justification for using the "JJ sliding scale" concept as a relative technology quantification metric. It is also observed that the new obtained proximity to ideal values **C-B** indicate enough room for future improvement in the continuos quest for finding the imaginary ideal battery. See table 2 below.

	Year 2000	Year 2005	Year 2010	Year 2015	Year Infinity
Param.	Tech. 0 NiCd	Tech. 1 Li-Ion	Tech. 2 Li-Polymer	Tech. 3 On-a-chip	Ideal. Ideal
(Σ F)	6	6	7	8	10
(Σ E)	5	6	7	4	10
(Σ W)	2	7	8	7	10
(Σ R)	5	6	7	6	10
(Σ V)	3	7	8	9	10
(Σ T)	6	6	7	5	10
(Σ H)	2	5	5	7	10
TOTAL	29	43	49	46	70

Table 2. JJ Sliding Scale for space rechargeable battery

CONCLUSION Quantification of technology perfection, ideality, and proposed next level of technology development can be used by technology managers and developers to better plan future technology initiatives. Each of the battery technologies listed on the road map of Table 2 can provide quantified information on such elements as: creativity improvement, proximity to old state-of-the-art technology, and proximity to the imaginary ideal battery. The latest can provide information on how much room for total battery improvement is available as to approach the ideal space rechargeable battery technology. Having means to quantify and measure planned future technology development allows other important technology development and management decisions to be performed.

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