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THE TECHNOLOGY/TACTICS (TEC/TAC) PLOT: EXPLICIT REPRESENTATION OF USER ACTIONS IN THE PRODUCT DESIGN SPACE

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ABSTRACT

The initial phases of the design process including interactions with stakeholders, ideation of concept candidates, and the selection of the best candidates have a large impact on the success of a project as a whole. They also tend to be the most unstructured portion of the project, and are often marginalized by teams who assume they already understand stakeholder needs and the best solution paths to pursue. Design researchers have developed methods shown to increase the creativity and divergent thinking of the design team during these initial phases of design. Nevertheless, these methods often rely on only a vague or amorphous representation of the design space (the set of all possible concepts the design team could feasibly select to meet the objective of the project). In this paper, we introduce a particular design-space structure that can help teams ideate and evaluate their ideation, thus improving the early phases of the design process. The design space presented here is a vector space with a basis of technology (the physical product people will use) and tactics (the procedure for using the product). Also presented are definitions, principles, and sub-theories that facilitate the creation and use of technology-tactics plots to represent the design space. Considering the design space in this structured way, the design team can gain valuable insights that improve the effectiveness of the initial stages of design, and may yield additional benefits to the design process as a whole, if further developed.

***Keywords*—** Design space exploration, Technology tactics plot, Bi-objective

INTRODUCTION

An early step in the design process is ideation. Its goal is to produce a set of candidate concepts from which a final concept will be chosen and developed into a final product. Because the selected concept will be chosen from the set of concepts generated during ideation, ideation-effectiveness is of high importance during the design process [1].

As teams seek to improve ideation-effectiveness, two significant evaluations often occur: 1) The evaluation of the concept set, and 2) the evaluation of individual concepts within the set. Metrics for evaluating the concept set generally involve examining the quantity, variety, novelty, and quality of a concept set, within a design space. A design space is defined as the set of all possible concepts that feasibly meet the objectives and constraints of the project.

It is worth noting that the concept set that results from ideation is a subset of the design space, as the design space contains all possible solutions. Also, the design space is often represented only theoretically and

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amorphously since the actual limits of the design space are not known precisely in the early phases of the design process. Further, concepts in the concept set are often represented as points in the design space. As such, the quantity of points represents the quantity of concepts in the set; the distribution of point locations within the design space represents variety within the concept set, and so on. Importantly, the notion of a design space, coupled with metrics for evaluating a concept set, can guide the design team during ideation, as teams choose to deliberately pursue greater quantity or variety in poorly represented regions of the design space, for example.

While the amorphous design space may be placed on any pertinent coordinate system (such as orthogonal axes of cost versus mass), some coordinate systems may positively influence the ideation process more than others.

In this paper, we present a particular two-dimensional coordinate system that we believe has the potential to help teams think more broadly during the ideation process, thus enhancing the early stages of the design process. The system used here encourages the design team to ideate in terms of two classes of concepts: concepts related to the actual product (termed Technology or TEC), and concepts related to how the product will be used/deployed (termed Tactics or TAC). As shown in this paper, at least 9 different design space plots involving technology and tactics can be used during the ideation process, or used to evaluate it. These different plots consider various perspectives such as technology innovation versus tactics innovation relative to current solutions, technology development cost versus tactics development cost, development team skill in creating new technology versus creating new tactics, and more.

To be clear, this paper combines two well-accepted philosophies into one approach that can enhance design space exploration. Specifically, we combine (i) the philosophy of characterizing ideation effectiveness graphically with a design space and by using metrics such as quantity, variety, novelty, and quality with (ii) the philosophy that there is innovation potential in both the product itself and in how it is used. Set in the early phases of the design process, this unique combination of philosophies encourages teams to plot the concept set on two orthogonal axes; the technology innovation axis and the tactics inovation axis. Importantly, we find that this approach helps teams explicitly ideate on user tactics at the same time they are ideating on the technology/products that will be used. Such an approach recognizes the existance of both technology and tactics, and promotes their co-development and helps prevent their conflation.

Literature Survey

Evaluation of Concept Sets. In this section, we briefly review the principles found in the literature related to evaluating the concept set as a whole. Many researchers have used or further developed these principles in order to better understand the outcome of ideation [2] [3] [4] as opposed to the process of ideation [2]. Researchers have produced many indicators that can be used to evaluate the desirability of a concept set, as well as to guide the design team as they create the set. Some of the most used evaluation metrics are quantity of concepts in the set, variety of concepts across the set, novelty within the set when comparing concepts in the set to products already in use, and quality of concepts in the set at meeting the design requirements on average. Generally, the desired state is that all of these indicators be maximized, though there currently exists no measure to determine if any of these indicators are sufficiently maximized.

The basic principles relative to concept set evaluation are:

- Design Space: There exists a set of all possible solutions to solve a problem, which is called the design space. [5]
- Coverage: It is desirable to consider as many solution candidates within the design space as possible. [6]
- Exploration: It is desirable that the solutions considered be noticeably different from one another. [2]
- Expansion: It is desirable to consider a portion of concepts that are perceived to be impossible or infeasible. These points lay outside the (feasible) design space. [2]
- Quality: It is desirable to identify/generate multiple candidates that are considered good at meeting/balancing design objectives collectively and individually. [7]

Evaluation of Individual Concepts. When considering how individual concepts can be evaluated, some of the metrics used to evaluate the concept set no longer apply, and other metrics are needed. For example, many researchers proposed evaluating the creativity of individual candidates with dimensions of creativity including workability and relevance to distinguish candidates [8] [9]. Others described creativity in terms of usefulness and rarity [10] [11] [12] [13].

While concept creativity is not the focus of this paper, it is considered by many researchers and practitioners to be a characteristic of optimal solutions. Therefore, the presence of innovative solutions in the candidate set is one indication that ideation has been effective.

The graphical representation of the design space used to evaluate concept sets has a parallel when considering individual concepts - a *concept performance space.* Mahdavi, for instance, proposed an n-dimensional concept-performance space, where the size of the space is $n = d + p$, and d is the number of design variables that define a concept, while p is the number of performance objectives that concept is designed to meet [14]. Romer proposed a number of performance objectives for use in the field of wireless sensor design including mobility and deployment [15]. Such performance objectives can be considered sub-dimensions of the quality metric for the concept set, and while they are frequently used for convergent purposes, they are also useful for determining if further ideation might be necessary.

THEORETICAL DEVELOPMENTS

In this section, the core contribution of this paper is presented, which centers on the creation and use of technology-tactics plots.

The Technology-Tactics Plot (TEC/TAC)

The technology-tactics plot (or TEC/TAC plot) is shown in1. The plot shows two orthogonal axes; TEC (representing technology the products developed as a result of the design process) and TAC (representing tactics the way the products will be used or deployed). These axes characterize the two dimensions of the feasible design space considered in this paper. The red points on the plot represent individual concepts for a design problem. The blue point, labeled (S_0), represents the existing solution (if there is one) to a design problem. It is the solution that will be pursued if the design team does no development. With the brief introduction given above, we can now be more specific about the nature of the TEC/TAC plot axes. The horizontal axis is specifically the change in technology beyond the existing solution (S_0). Likewise, the vertical axis is the change in tactics beyond the tactics of the existing solution (S_0). Qualitatively speaking, if a concept employs similar technology/hardware as the existing solution and is used with the same tactics as the existing solution, the concept is plotted near S_0. If it employs different technology/hardware and/or different tactics, it is plotted far from S_0. In this way, the concepts emerging from ideation may be plotted in this space according to how much they differ from the existing solution in terms of both technology and tactics. In this graphical representation, S_0 is the origin and change in technology/tactics are only plotted in the positive region of the coordinate system.

Once the concept set has been represented in the TEC/TAC plot (each concept illustrated as a point within the design space), the TEC/TAC plot will show where in the design space sufficient ideation has occurred and where it has not. This guides the team to where in the design space they need to explore in more detail.

Considering the cloud of points in the TEC/TAC plot, it becomes natural for the team to discover and impose upper and lower limits on the space (these are represented as light-weight lines in 1). For example, limits can be established through critical interactions with stakeholders where these limits can be discussed and explored. Teams might ask: how different does the final product need to be (from the existing solution) to motivate customers to invest in the upgrade? How different can the final product be and still appeal to the market; would the market accept a dramatically different kind of product? To what degree can we expect users to learn a new tactic in order to use a new product? These limits may also be derived from other development information such as the development resources available. There may simply not be enough resources to pursue concepts that differ too much from existing products. Setting these limits gives the team a better understanding of the full size of the feasible design space, allowing them to evaluate how well their concept set is expanding to fill the feasible space.

The TEC/TAC plot offers design teams the opportunity to think beyond the physical product by explicitly considering how those products would be used or deployed. Without considering the TEC/TAC plot, or the principles it represents, it is common for teams to conflate technology and tactics and thereby ideate without knowing to what degree the concepts generated differ in terms of product tactics or technology. In short, when ideation results in great concept diversity along the TEC axis with minimal diversity along the TAC axis the team has missed an essential dimension of ideation and the opportunity to co-develop the product and how it will be used.

The TEC/TAC Plot as the Full Design Space.

The TEC/TAC plot can represent the full feasible design space, when it is modeled as a vector space with the following characteristic: each unique concept has a unique location in the design space, which is located by a vector beginning at the origin. When modeled in this way, it follows that a vector basis would exist for this design space, requiring one or more measurable qualities that can be attributed to each of the concepts in the set. The number of unique qualities chosen for the basis establishes the geometric dimension of the design space.

For this paper, change in technology and change in tactics are suitable qualities for a vector basis, as they can be reasonably established

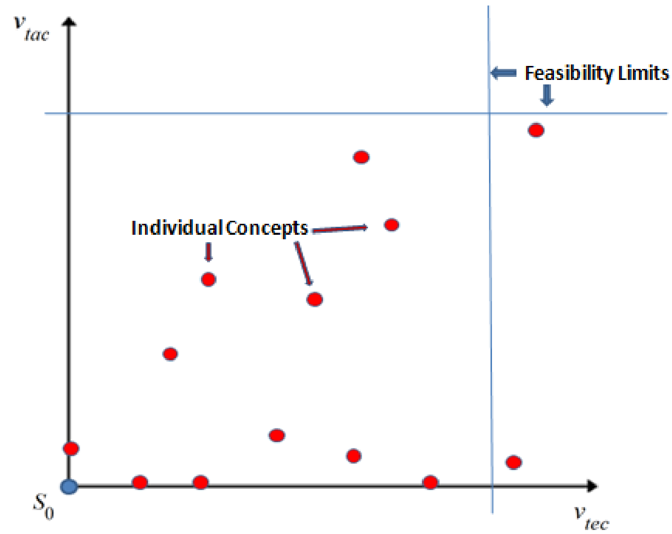

FIGURE 1. The Technology-Tactics (TEC/TAC) Plot, in which horizontal distance from the origin represents differences in technology of a given idea, while vertical distance represents difference in usage or tactics

for each of the concepts in the set, and are meaningful during ideation. In fact, we believe that these two vectors span the entire design space. To justify this, we adopt the philosophy of jobs to be done [16]. Under this philosophy, the design process starts with a problem to solve (termed: job to be done). To improve the job to be done, there are two areas of potential focus: (i) improve the tools/product/hardware to do the job (technology), and (ii) improve the way people use the technology to do the job (tactics). No third option is immediately apparent. We can summarize the proposition in this way:

- Principle 1: Any change in the actions of the user with regard to the job to be done constitutes a tactics change.
- Principle 2: Any change in the equipment utilized by the user with regard to the job to be done constitutes a technology change.
- Principle 3: If the actions of the user with regard to the job to be done are held perfectly constant, the only option for change with regard to the job to be done must be a technology change, and vice-versa

When these three principles are true, any change with regard to the job to be done will be a tactics change, a technology change, or a combination of both.

Therefore a vector measuring changes in technology (vtec) and a vector measuring changes in tactics (vtac), forms a basis of a vector space and the axes of the design space if they share an origin. This two-vector basis constrains the vector space in R2, creating a simple and useful 2D graphical representation of the space with the existing solution at the origin (S_0).

Generalization of the Origin.

The TEC/TAC plot requires the establishment of an origin. Up to this point, we have considered the origin to be the existing solution (S_0), located at (0,0). But this can be staged more generally as being located at (x0,y0), which may or may not be at x0= 0 and y0= 0.

Whether stated generally or not, the origin establishes a baseline for characterizing the change in technology and change in tactics that define the TEC/TAC plot. As such, any point on the TEC/TAC plot is defined by the vector Vi, where

$$V_i = (x_i - x_0) + (y_i - y_0)\ \forall\ x_0 \le x_i \le x_{up}, y_0 \le y_i \le y_{up} \qquad (1)$$

where i represents the i-th concept, and xupand yup are the upper limits of x and y, respectively.

Distinguishing Between Technology and Tactics

During the ideation process, at intervals deemed appropriate by the team, concepts can be plotted on a TEC/TAC plot. To do so effectively, the team must be able to distinguish between a concepts technology and its tactics. To assist teams with this we propose the use ofcontrol volumes, which are generally used in thermodynamics and elsewhere to simplify the evaluation of complex systems. Here, control volumes are useful because they allow for a definitive definition of the control volume boundary and an analysis of what crosses that boundary.

In the context of the design process, imagine that a control volume contains everything the design team controls that is sent to the user at the end of the design process, regardless of how it is actually sent. Generally speaking, the control volume for engineered products will contain a product and whether explicit or not, instructions on how to use the product. Relative to the control volume, this means that the design team works to transition information and physical goods across the control volume boundary, while the user crosses the boundary to acquire or access what the team delivered. This idea is illustrated in 2, where the dashed line represents the control volume boundary. One reason why control volumes are meaningful to TEC/TAC plots, is that they clarify whether a concept has just a technology change, just a tactics change, or whether it has both associated with it. When a team wishes to place a concept on the TEC/TAC plot, the team should ask: i. Does new technology need to be delivered to theuser for them to implement this concept? In other words, does this concept require the user to have technology they dont currently have? If so, new technology crosses the control volume boundary, and the concept is plotted to the right of the existing solution (S_0) in the x dimension. How far it is plotted to the right of S_0 depends on how different the new technology is from the existing technology. ii. Do new tactics (instructions) need to be delivered to theuser for them to implement this solution? In other words, does the user have to behave differently with respect to existing or new technology to accomplish the desired task? If so, new tactics cross the control volume boundary, and the concept is plotted above the existing solution (S_0) in the y dimension. How far above depends on how different it is from existing tactics.

It is important to notethat, in this paper, the control volume is defined by what is delivered to the end user not what is delivered to the manufacturer. This is helpful in clearing up confusion about what information or physical goods are crossing the boundary.

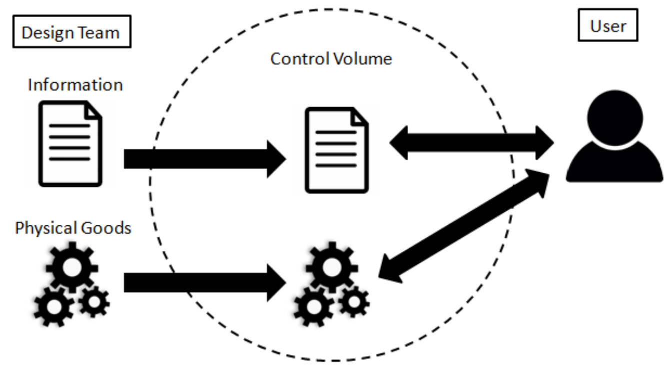

FIGURE 2. Control Volumes in Solution Delivery: all aspects of a given solution must be passed through the boundary by the design team (at a cost) to become accessible by the user (also at a cost)

Three Different Perspectives on TEC/TAC Plots

Up to this point in the paper, we have simply considered the TEC/TAC plot from the perspective of change in technology and change in tactics beyond an existing solution. We have considered that perspective to be the general interpretation of the TEC/TAC plot.

There are, however, at least two other ways to use TEC/TAC plots in a meaningful way during the design process; using them (i) to characterize the anticipated development costs for each concept, and (ii) to characterize the anticipated costs for users to acquire and learn to use the concept under consideration. In brief, three different TEC/TAC plot types are considered in this paper:

1. Relative Difference Plots
2. Design Team Centric Plots
3. User Centric Plots

The first of these types has been the focus of the paper up to this point. The second type aims to illustrate the feasibility of concepts from the design teams perspective in terms of actually being able to develop the concept, and the third type considers feasibility of each concept from theusersperspective in terms of a user being able to acquire and learn to use the technology efficiently.

Importantly, each of these perspectives benefits from using the principle of control volumes. For design team centric plots, teams consider how much it will cost to develop each concept, which in the context of control volumes means how much will it cost (in terms of time, money, and skill) to transition technology across the control volume boundary. And for the user centric plots, how much will it cost (in terms of time, money, and skill) to acquire and learn to use the new technology within the control volume.

By considering team- and user-centric TEC/TAC plots, the design team can benefit in two ways. First, the team can evaluate the quantity and variety of the concepts in the set. Second, the team can impose meaningful upper limits on the space in terms of maximum development costs or maximum development times, for example. Such limits capture what the design team can accomplish based on the resources they and/or the user are willing to invest. Anysolution candidatesthat fall beyond this upper resource limit can be discarded.

A total of 7 specific TEC/TAC plots have now been introduced. They are:

- The general (relative difference) TEC/TAC plot
- The financial cost to develop TEC/TAC plot
- The time to develop TEC/TAC plot
- The skill required to develop TEC/TAC plot
- The financial cost for users to acquire or learn to use the new technology TEC/TAC plot
- The time for users to acquire or learn to use the new technology TEC/TAC plot
- The skill for users to acquire or learn to use the new technology tEC/TAC plot

It is not necessary that all of these plot types be considered to evaluate the effectiveness of the ideation process, but these and others may be considered if the team deems it valuable to do so. The plots will now be described in more detail to help teams better understand the relative value of each.

Relative Difference Plot (General TEC/TAC Plot). The value of the general TEC/TAC plot is its simplicity. The plot can be used generically and relatively, without defining a specific measure for change in technology and change in tactics. This lends itself to divergent thinking early in the design process, because very little needs to be known about a concept in order to plot it on a TEC/TAC plot. Concepts can be added to the plot easily, and the meaning of each concepts location within the plot grows as more concepts are added. This simple plot helps teams identify where in the design space additional exploration is needed.

Challenges associated with the general TEC/TAC plot are that the upper and lower limits are more difficult to define than the limits of TEC/TAC plots characterizing cost and time. Additionally, when considered alone, the general TEC/TAC plot does not capture all relevant information. For example, concept feasibility due to team or user-centric factors is not specified, so some concepts may be infeasible, even those very close to S_0, due to factors represented in the team or user centric TEC/TAC plots.In this case, a simple demarcation cannot be drawn to separate feasible and infeasible concepts as it relates to important team and user considerations. However, when used in conjunction with team and user centric plots, infeasible concepts relative to all perspectives can be removed from the general TEC/TAC plot, leaving it a useful summary of all plots, as shown in 3. Note that S_0 is plotted at the origin.

When establishing upper limits on change in technology and change in tactics, it is possible to define a limit where the market will no longer accept a solution because it is too different from what they are used to. The exact shape of this upper budget will vary based on how independently the team can work on tactics and technology development. Establishing this limit requires significant understanding of the market preferences and trends.

When establishing lower limits on change in technology and change in tactics, the client who commissions or funds the development is likely to have expectations regarding a minimum level of development (change or differentiation) beyond existing solutions. Establishing these lower limits helps the team avoid spending too much time on concepts containing only marginally incremental improvements. A recent study by Goodson et al. discusses recent attempts by students and faculty to establish and use such limits [17].

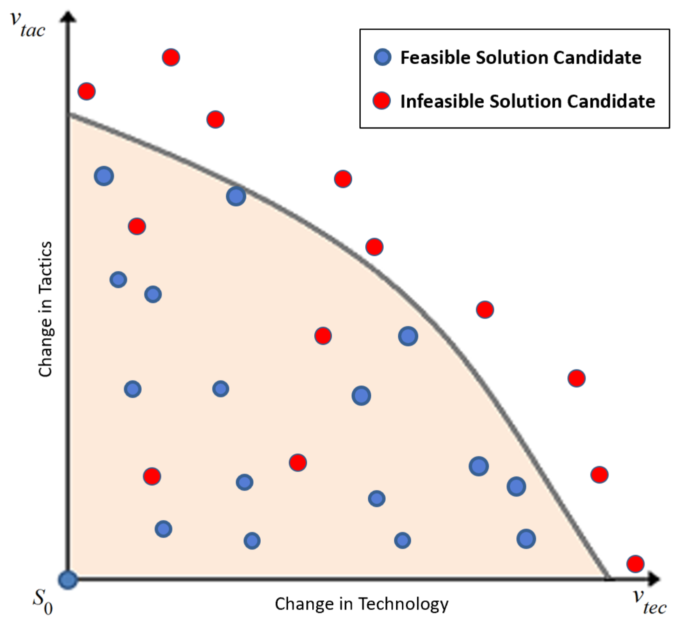

FIGURE 3. The Relative Difference Plot, with an outer boundary marking the point where changes in the concepts become too extreme, though some infeasible concepts still exist inside the boundary based on other criteria

The Design Team Centric TEC/TAC Plots. Design team centric plots illustrate which concepts are feasible for the team to develop given limited development resources. Three resources that commonly restrict feasibility are development time, money, and skill required.

A generic design team centric financial cost plot is shown in 4. This plot evaluates concepts with respect to the financial cost to develop them. This cost plot focuses exclusively on the design team and their budget for the project.

While upper limits can be added on this plot at the maximum technology development budget and maximum tactics development budget for the project. In some special cases, the limit curve will be a line defined by $(Tacticsspend) + ($ Technology spend) = Max budget, as shown in 5 below.

Additional team centric plots include time to develop and skill to develop each concept. The time plot is analogous to the financial plot in its structure and use substituting time to develop for financial cost to develop.

The skill plot focuses on plotting concepts relative to the abilities of the team in terms of development skill. This TEC/TAC plot allows the team to explicitly evaluate how well the concept set is evolving relative to what the team actually has skills to further develop. This plot can be used to encourage the team to both push the limits of their skills and pull wild ideas into the realm of feasibility.

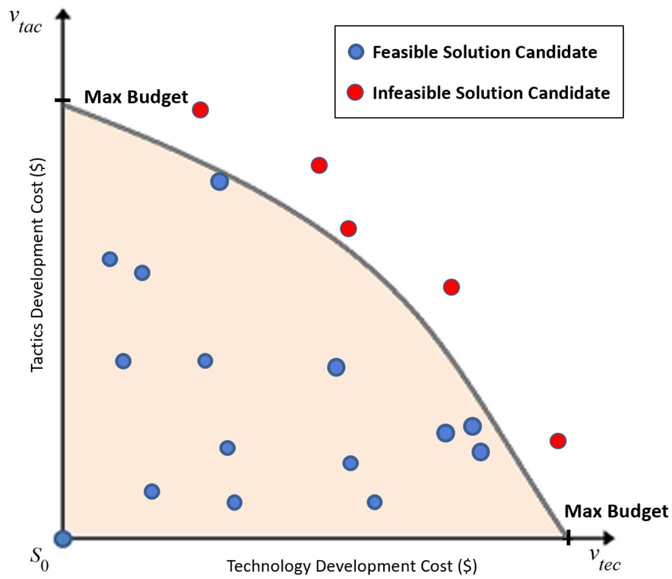

FIGURE 4. The Design Team Centric-Financial Cost Plot. Upper limits based on point where concepts become too costly for the design team to pursue

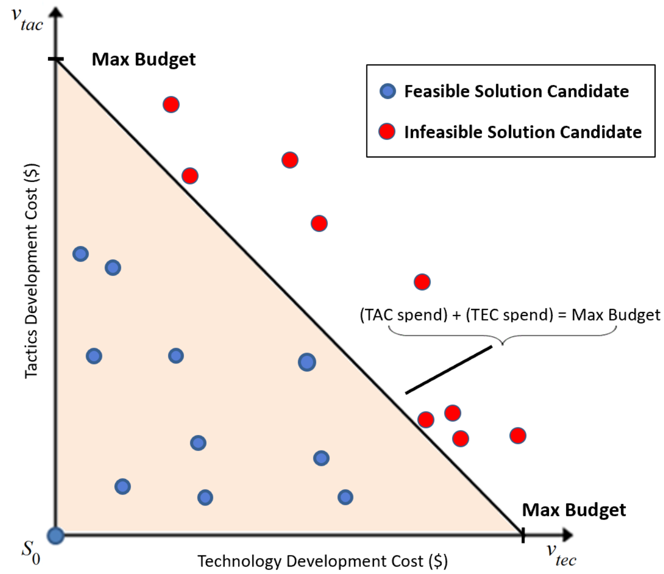

FIGURE 5. The Linear Limit Case. High cost of developing more complex Tactics means less money available for Technology development

We recognize that it is more difficult to establish the limits of skill as it relates to a TEC/TAC plot, than it is to establish limits for quantities such as financial cost and time. Nevertheless we believe it is valuable for a team to consider their skills when evaluating concept sets that result from ideation, even if that evaluation is more qualitative or anecdotal than the evaluation of financial cost and time.

The User Centric TEC/TAC Plots. As concepts emerge during the ideation process, each one places a burden on the user in some way. These are the costs associated with the user accessing the control volume. We include a set of user centric plots on the following basis:

- Principle 1: Time, money and skill to cross the control volume boundary is likely different for users and development teams
- Principle 2: The costs imposed by a solution on a user in terms of time, money and skill influences the desirability of a solution
- Principle 3: Design decisions influence a solution's imposed costs to the users time, money and skill
- Principle 4: It is essential for development teams to consider the design space from the consumer's perspective [18] [19] [20]

When evaluating concepts relative to the user's burden, the team can ask: what costs will be incurred by the user to acquire, access, or learn how to use the final product resulting from this concept? Analogous to the design team perspective, these costscan also be broken down into financial cost, time, and skill.

From the users perspective, financial costs can include cost to purchase the technology, costs to train people on using the new technology, or other financial costs related to implementing a new technical system. The burden associated with time, can include the learning curve for users to become proficient at using the new technology. And the skills required by the user can simply be an assessment of what the design team expects the users to do; is the user expected to adjust or fine tune the system to their environment; is the user expected to have skill in a particular field of knowledge such as machine maintenance or deploying a missile? When a team plots concepts on a TEC/TAC plot relative to the skill required of the users, it helps the team understand if they are asking too much of users. Setting the limits of user centric plots requires knowing the user, including their skills and resources.

There is one additional TEC/TAC plot that will be mentioned here but not developed or discussed deeply, as it is the focus of a different work by the authors. It is a benefit added plot, as illustrated in 6.

The benefit added plot illustrates the perceived benefit of technology innovation, and the perceived benefit of tactics innovation to the user. As concepts are placed on the benefit plot, the team can evaluate if the concept set is appropriately focusing on what users would find beneficial. We mention this plot here to emphasize that by only examining the costs to the user and not the benefit it is impossible to estimate which concepts will be valued by the user and which will not . In evaluating the concept set, the team should determine if it has created a sufficient number of concepts, of sufficient variety.

PLACING CONCEPTS ON TEC/TAC PLOTS AND USING THEM FOR EXPLORATION

To plot individual concepts and explore the design space:

1. Generate a set of concepts for the design problem at hand. No specific ideation process is recommended here.
2. Begin the evaluation process, by choosing which perspective will

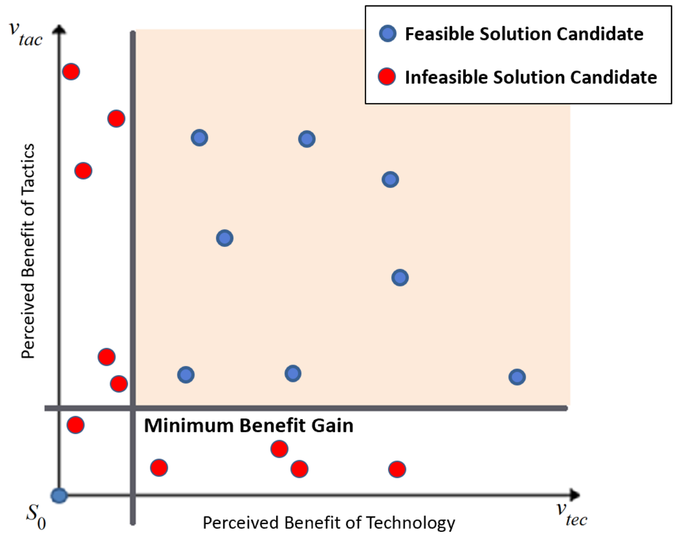

FIGURE 6. Design Team Centric Benefit-Added Plot. Projects that provide low benefits to the design team are marked as infeasible (note these are lower bounds). No upper bound has been found

be used for the evaluation. The options are (i) relative difference perspective, (ii) design team perspective, and (iii) user perspective.

3. Establish S_0, which is the existing solution (or the solution that will be pursued if no development is done). It is useful to articulate what technology is associated with S_0, and what tactics are associated with S_0.
4. Choose whether S_0 will be located at the origin (0,0) or another point in the design space.
5. Establish TEC/TAC plot limits, if there are any. These limits are likely to be discovered through interactions with project stakeholders.
6. Evaluate each concept relative to S_0 and the TEC/TAC plot limits using the evaluation perspective chosen in (2), above. For example, if the relative difference perspective is chosen in (2), then explicitly evaluate how different the concept is from S_0 in terms of technology and tactics. If it is similar, place it near S_0 on the TEC/TAC plot. If it is dissimilar, place it far from S_0. If concepts are deemed to be infeasible relative to the perspective chosen in (2), place them beyond the limits established in (5). Repeat this process for all perspectives chosen in (2). This could result in as few as 1 or as many as 7 TEC/TAC plots.
7. If desired, transfer feasibility information from the development team perspective and/or the user perspective to the relative difference plot by indicating which points in the relative difference plot are feasible across all perspectives and which are not.
8. Choose ideation metrics to use in the evaluation of the concept set, and evaluate it. A common choice is to consider the quantity, variety, novelty, and quality of the concept set.
9. Use the evaluation results of (8) to decide if additional ideation is needed, and where in the design space improved quantity, variety, novelty, or quality are needed.

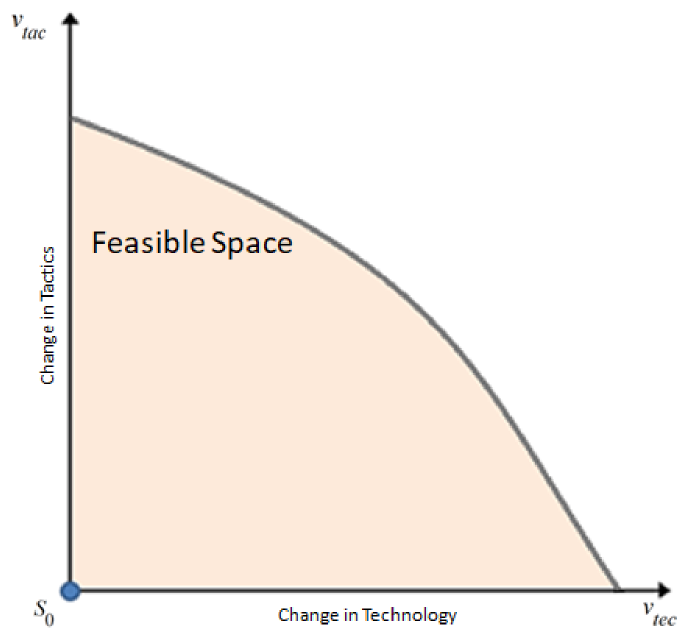

FIGURE 7. The Feasible Design Space on a TEC/TAC Plot. The actual placement and shape of the upper bound will depend on the basis of the plot

10. Repeat steps 1-9 until the results of the ideation process are satisfactory.

In using the process described above, the team explores the design space, in that it discovers the size and content of the feasible design space.

During the exploration process, it is valuable to keep in mind two truths. The first is that there are boundaries to concept feasibility, and the full set of concepts within those boundaries constitute the feasible design space. The second truth is that there are boundaries to the explored space. One goal of the exploration process is to expand the explored space until it meets or exceeds the feasible space. Often it is necessary to exceed the feasible boundaries in order to identify where those boundaries are.

When the exploration process begins, the team is likely to have only a vague understanding of the feasible boundaries. As the exploration process proceeds, a more clear understanding of the feasible boundaries begin to emerge.

To illustrate this, consider the feasible design space shown in 7.

Notice the presence of S_0 and the feasible boundary (shown as a curve) in the plot. As the ideation process begins, the design team generates concepts without a certain knowledge of the feasible boundary, resulting in concepts that may be inside or outside the feasible space. Imagine that the ideation process results in 8.

As the team evaluates each concept in this set, relative to feasibility, three scenarios occur. (i) all concepts are infeasible (this is unlikely), (ii) all concepts are feasible, or preferably (iii) a portion of the concepts are feasible and a portion are infeasible.

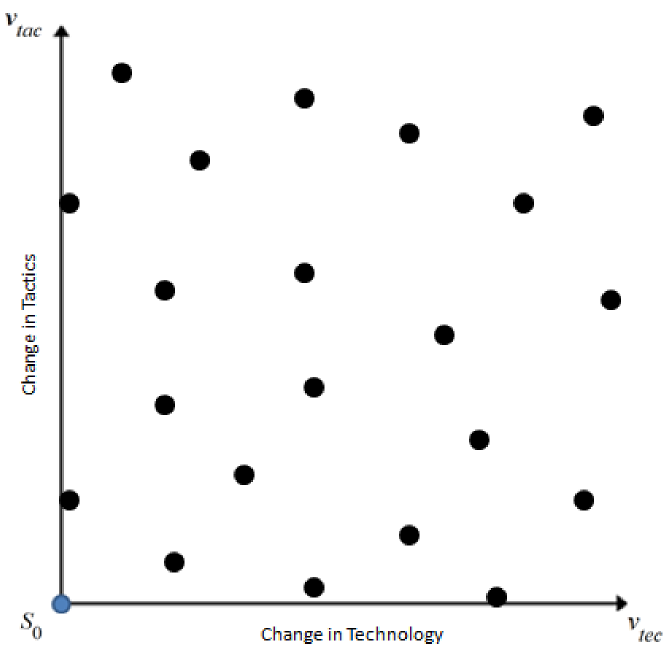

FIGURE 8. A Sample Candidate Set. Note that in this representation, the set appears to fill the entire design space

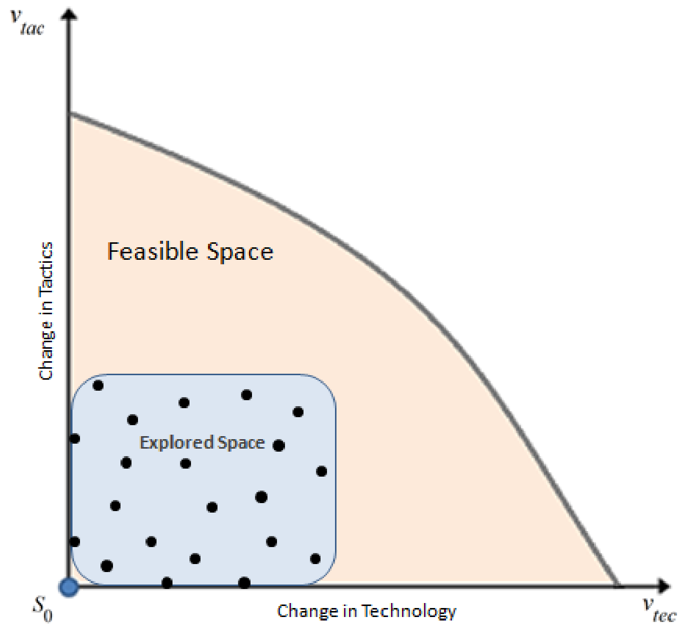

FIGURE 9. The Explored Design Space, which in this case only fills a portion of the entire design space. Discovery of the actual upper bound on the space reveals empty space we can explore

Under the preferred scenario (iii), the exploration process begins to define the feasible boundaries. Under scenarios (i) and (ii), the teams understanding of the feasible boundary is not improving. For scenario (i), the team should generate solutions that are more similar to S_0. For scenario (ii), depicted in 9, the team needs to expand the explored space by generating additional concepts that are more distinct from S_0.

While the feasible design space is generally fixed by the constraints of the project, and therefore unchanging during the design process, the explored design space is generally growing as the team adds to the concept set. If the design team develops a good understanding of the feasible design space boundaries, it will be able to declare with greater confidence that the quantity, variety, novelty, and quality of the concept set is sufficient.

EMPIRICAL FINDINGS

To test the implications of the TEC/TAC plot, the basic principles of the plot were presented to capstone students at the United States Air Force Academy, and the teams were encouraged to incorporate the concept into their design ideation processes. 10 shows the results of an ideation session by one of the teams. This design team was challenged to develop technologies for detecting the presence of certain sensors and prevent the sensor from detecting the user.

With the TEC/TAC plot as a guide, the team effectively filled less concentrated areas of the plot to cover the available space. 10 illustrates the potential for this plot to alter the lens through which the design team sees their concepts. Take, for example, the concept Shoot it (in the upper left-hand corner). Despite its obvious simplicity, this concept was plotted very high on the tactics axis. Perhaps the design team considered the impact of this concept on established movement patterns of the end-user. They may have considered the high level of skill an end-user would need to acquire in order to successfully locate and shoot a small sensor in a (potentially) hostile situation. In short, the design team is deliberately considering their users and the desirability and feasibility of the tactics they would be expected to adopt.

After reaching the candidate set in Figure 10, the team began to consider their concept set. Earlier it was noted that bounds are difficult to establish on the general plot because of the challenge of defining the amount of change that is acceptable to the user. In this early test, the team had the freedom to determine the upper limits. In this case, the upper limit (designated by a green dotted line in figure 10) does not denote upper limits on the change, but rather an elimination of several high-change concepts which all were determined infeasible for various reasons.

Having completed an initial elimination, the team then arrived at the concept set illustrated in figure 11 (note the scope of the plot has been narrowed to below the upper bounds, and that several of the points within those bounds were also determined infeasible for separate reasons. They then took the examination a step into convergent examination, restricting the set to the most promising concepts, which further reduced the set to 12.

Though this paper is focused on the uses of TEC/TAC in divergent thinking and ideation, this experiment also shows the promising applications of the plot to convergent methods as well. In fact, in a survey of 21 of the students involved in this investigation, 17 of those students cited aiding in down-selecting their concepts as a primary benefit of the

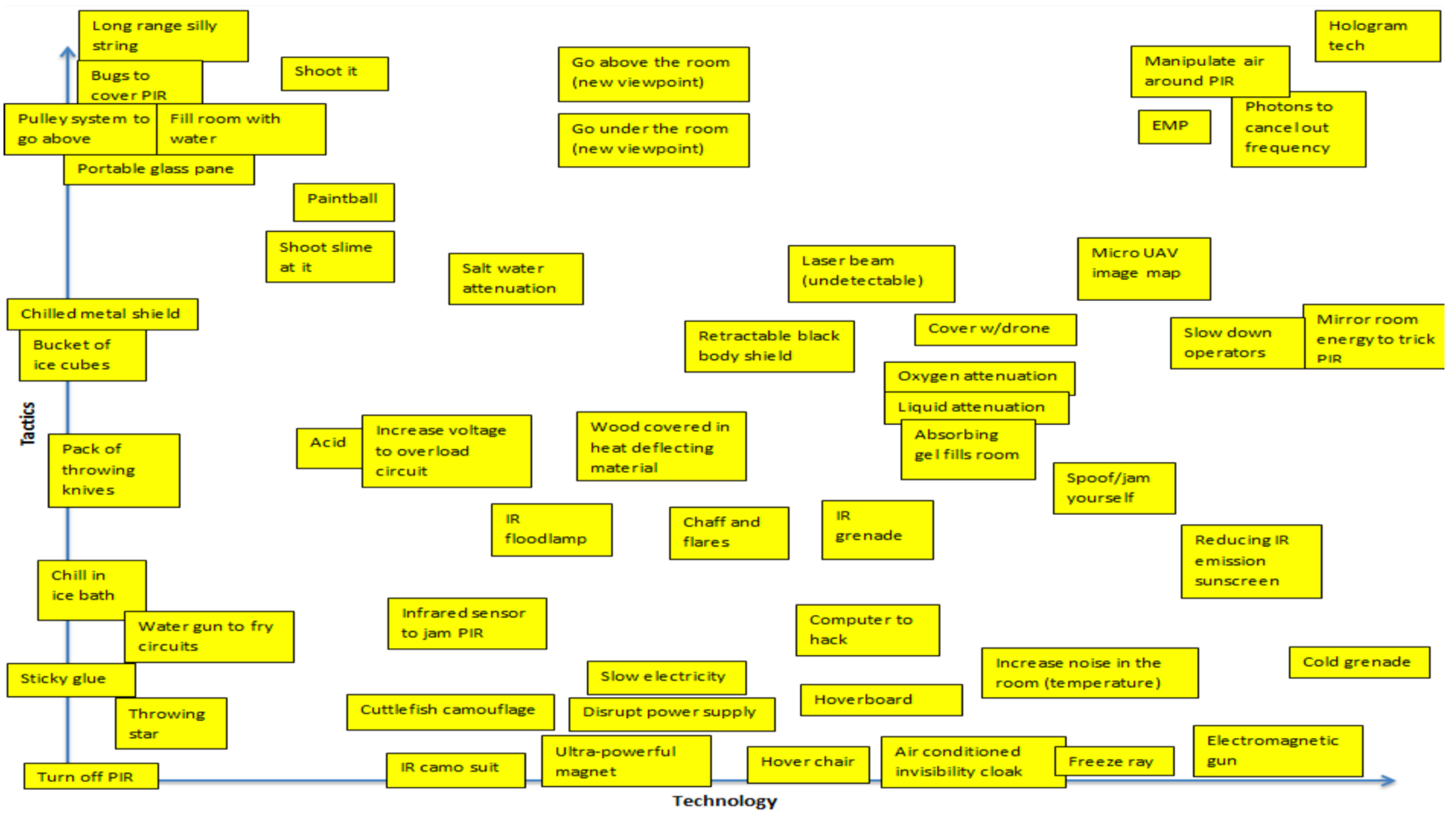

FIGURE 10. Filled TEC/TAC Plot. The team has attempted to fill the blank areas on the plot, and has included many infeasible concepts to push limits on the explored design space

plot.

Further research is exploring the applications of TEC/TAC to convergent processes. In this case, this design team was able to utilize the plot to grow their concept set until the feasible design space was mapped, and then use the limits to assist in converging toward the best solution. This initial test drive demonstrates the potential value of the TEC/TAC plot as a design tool throughout the entire design process.

CONCLUSION

In this paper, we have explored themerits of exploring the feasible design space as a 2D vector space. We introduced the concepts of tactics and technology as axes for that space, and established the mapping of solution concepts within the TEC/TAC plot. A process for bounding the feasible design space with measurable constraints has been shown, and a definition for the placement of points and constraints on the space in terms of a control volume has been created. We have also investigated how the plot may be adapted to examine at least 9 major aspects of common projects and shown how both the concept set and the individual concepts within the set can be evaluated.

The TEC/TAC plot helps design teams to avoid the pitfall of under-examining the design space during ideation, especially when it comes to examining the tactics dimension. Likewise, viewing the sequence of plots, as we have done, provides a straight-forward means for the design teams client(s) to evaluate the thoroughness of the teams ideation. It provides a means whereby both ideation-effectiveness evaluations can occur, namely: 1) It requires teams to spread their concepts across the design space, examining the set from multiple reference points to increase the quantity, variety, quality, and novelty of the set, and 2) it provides a simple means for comparing concepts against each other in terms of differentiation, cost on limiting resources, and benefits to the design team, their client, and the user, including finding the limits on feasibility to quickly identify the most promising concepts.

The plot is a map by which the design space can be explored. When the team has successfully expanded their concept set to span the feasible design space, they are left with a concept set that is far more likely to find and produce a superior final result. The merits of TEC/TAC when applied just to this initial portion of the design process are encouraging and point to opportunities for research into the applications of this theory tootherportions of the design process as well.

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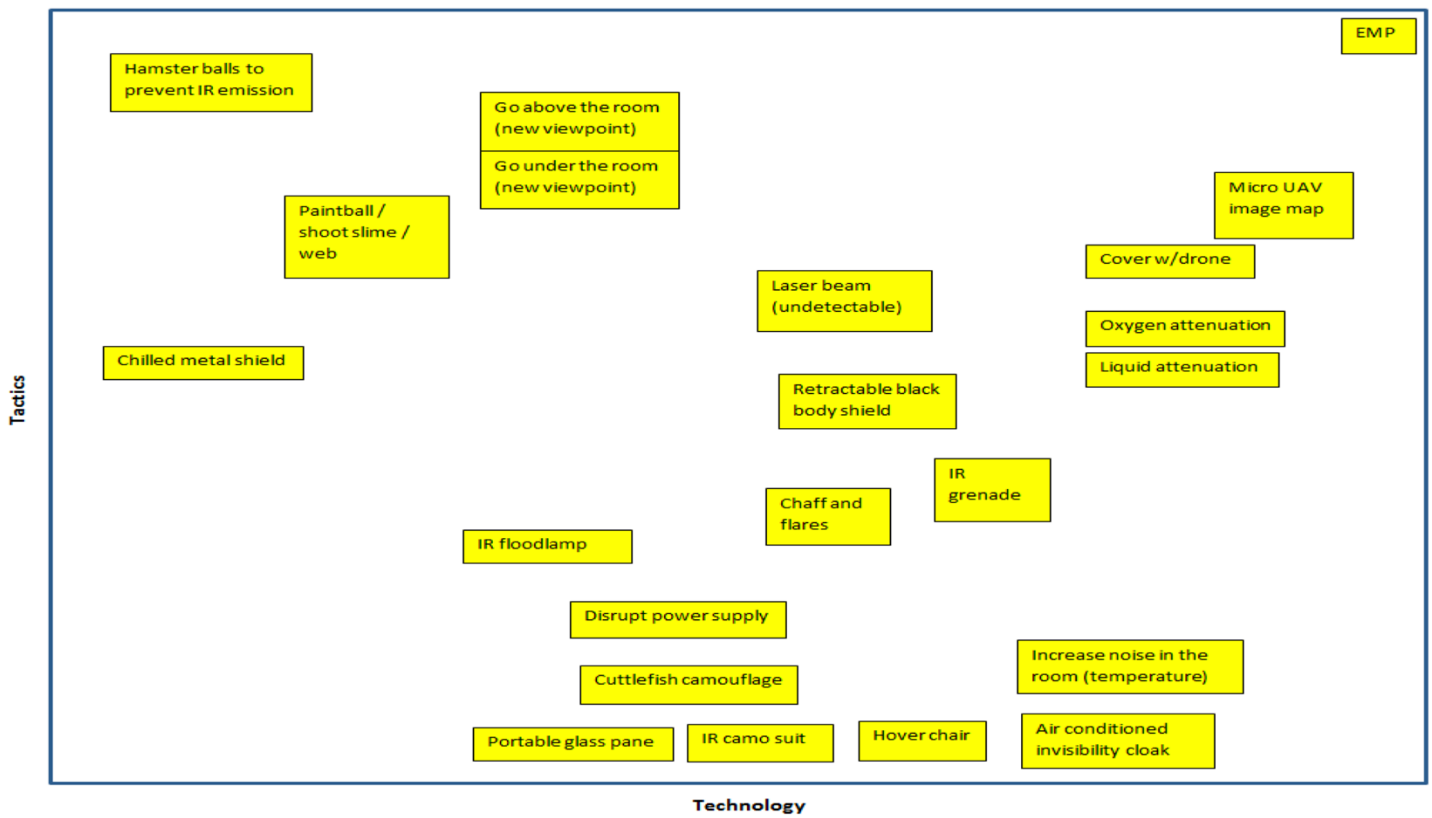

FIGURE 11. Infeasible Concepts Removed. Note that "EMP" is now the top-rightmost concept. The students were able to establish upper limits above this point

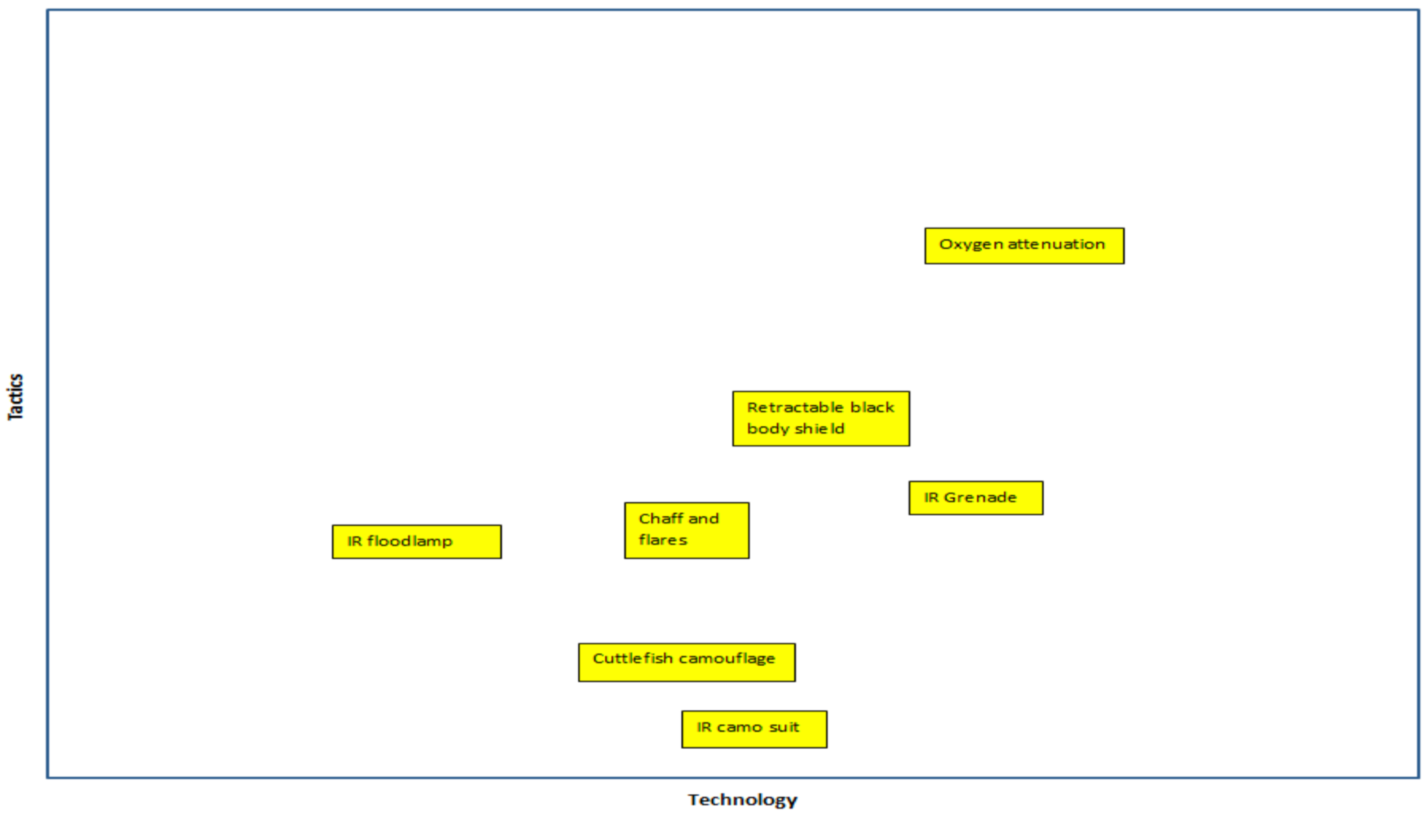

FIGURE 12. Most Promising Concepts Selected. The team's understanding of the performance of each of the concepts in accomplishing the mission allowed the top-performing concepts to be selected

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