ESTABLISHING EVALUATION CRITERIA FOR AN OPPORTUNE LANDING SITE (OLS) SYSTEM

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Abstract

If one does not know where one wants to go, it is difficult to choose the best path or to recognize the destination when one reaches it. Developing a clearly defined set of evaluation criteria helps program management set the course, measure progress, and improve the likelihood for success. On the OLS System Validation and Demonstration Program, performed 2004–2007, the product was software capable of locating smooth, flat, firm, obstruction-free OLSs. The government-industry team applied a process that provides a structured approach and consistent framework for defining success, achieving consensus in decision making, and maximizing probability of success. The process begins with capturing quantified evaluation criteria that define what the product must do, as well as the nice-to-have aspects. The term desirements is used to describe the set of evaluation criteria, defined in appropriate units of measure and mapped to the desirability scale. The mandatory aspects comprise the subset called exit criteria. The evaluation criteria form the multi-dimensional solution space that characterizes the optimal system. Applying the process early in the OLS System Validation and Demonstration Program clarified objectives, supported program decisions, and diminished the effort expended on unimportant features. The result was a set of clearly defined desirements for three critical points in OLS System evolution that removed ambiguity and supported the integrated program plan for the realization of a tool to give the war-fighter access anywhere in the battlespace by 2030, despite the absence of prepared landing strips.

Introduction

The war-fighter needs to have full access to the battlespace, regardless of the presence of prepared landing zones (LZs). A capability to enable austere-area operations is the ability to rapidly locate suitable areas for landing aircraft. An unprepared area without standing water that is large enough, flat enough, firm, and free of vegetation and other obstructions is called an *Opportune Landing Site* (OLS). The OLS must be firm enough to support aircraft operations, not only for a single landing and takeoff, but also for the number of passes necessary to accomplish air operations as well as associated ground-force movement. Austere-area operations are a fact of life for the war-fighter of the twenty-first century. The capability to open an austere operating location is crucial to the success of our combat forces in the future.[1]

For a decade, research had been conducted on the problem of processing satellite imagery using spectral analysis to identify large, flat, smooth, obstruction-free land areas as candidate OLSs. (Subsequent use of the adjective "suitable" implies having these characteristics; it implies nothing about firmness or bearing strength.) At the start of the program, algorithms existed because of internal research and development efforts of The Boeing Company, in collaboration with Dr. Robert Vincent of Bowling Green State University.[2]The ability to assess soil strength with reasonable accuracy inspired less confidence.[3]

The OLS system is a software application intended to be used as a military mission planning tool. In its current form, the application is three separate modules: (1) OLS-MS performs multispectral analysis of satellite imagery to identify suitable candidate landing areas, (2) OLS-EVM implements the extended-vector method of multispectral analysis of multiple seasonal images combined with Digital Terrain Elevation Database (DTED) data to infer soil type; and (3) the Fast All-season Soil Strength (FASST) model utilizes outputs from the other two modules and weather data to calculate soil strength.

Many concepts of operations could exploit this application. It could be used by Intelligence Officers at headquarter-level facilities, Special Tactics Team (STT) members in the field as an evaluation tool, or the National Geospatial-Intelligence Agency. Its installation and use will be determined by the Air Mobility Command (AMC) when the application is demonstrated to be accurate, repeatable, and formatted in its production state.

The OLS algorithms are based on some specific assumptions about the physics of reflected electromagnetic radiation, from which assumptions derives the capability to find suitable landing sites. Appreciating these assumptions is important in understanding the capabilities and limitations of the application. Multispectral and hyperspectral satellite imagers measure the electromagnetic radiation emitted from the sun and reflected by a given area (pixel) of the Earth's surface. The reflected component also includes atmospheric scattering of solar radiation, and, as the spectrum approaches the infrared (IR) region, the radiation at the sensor includes earth- and atmospheric-emitted radiation. This radiation is formatted by the imager into separate images based on the wavelength of the radiation.

The application exploits the assumption that variations of the Earth's surface reflectance are caused by physical (spatial) and material (spectral) characteristics, which can be used to discriminate the spatial and spectral properties of the terrain for a given area (pixel). These variations are used to identify standing water, areas containing heavy vegetation (high chlorophyll), and uneven terrain (combined spatial/spectral inhomogeneity).

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1 Ryerson, C.C. and McDowell, J. (2007). "Anywhere – anytime: enhancing battlespace vertical mobility." 45th AIAA Aerospace Sciences Meeting and Exhibit, AIAA-2007-1103, Reno, NV.

2 Vincent, R.K. and Jennings, D.L. (2004). "A four-state field evaluation of the Boeing Landing Suitability Index (BLSI) for automatically mapping candidate aircraft operating sites in natural terrain from LandsatTM data." Journal of Terramechanics 41: 151–16**2.**

3 Manley, D., ND. (2007). "Identifying Unprepared Landing Sites for Advanced Theater Transport Aircraft (and Terrain Trafficability for Military Vehicles)". The Boeing Company, Advanced Theater Transport Program Manager, 2401 E. Wardlow Road, Long Beach, CA 90807-5308.

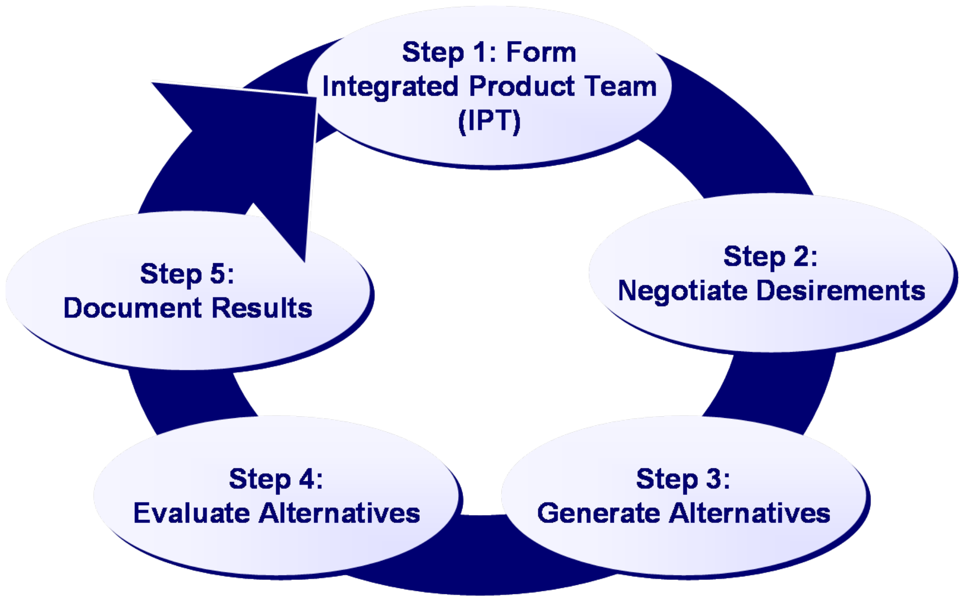

Figure 1: Systems Engineering Tailored for Science and Technology (SETFST)

Conversely, areas with highly uniform reflectance (spatial and spectral homogeneity) are assumed to be flat areas of like material substance (dirt, grass, rock, etc.). The algorithms reject areas with large variations in reflectance, such as those caused by sharp contrast between the asphalt of a road or runway and the surrounding soil or vegetation. Hence, the OLS application selects areas of homogeneous natural terrain as suitable candidate OLSs.

Approach

The Control System Development and Applications Branch (RBCC) of the Control Sciences Division (RBC) of the Air Vehicles Directorate (RB) of the Air Force Research Laboratory (AFRL) formed a team comprising The Boeing Company, the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (ERDC-CRREL), and SynGenics Corporation, as well as needed subject-matter experts (SMEs) from other directorates within AFRL.

In June 2004, ERDC-CRREL established the OLS field evaluation and soils analysis team for this program. The Boeing Company brought its team, which had been working on this problem for several years under internal research and development funding. At the start of the program, some subject-matter experts (SMEs) understood the focus of the program to be hyperspectral image analysis and soil characterization. Others were certain that the OLS program's primary purpose was to evaluate the software's capability to find runway-sized locations that are smooth, flat, and free of obstructions (i.e., suitable OLSs). There was lively discussion concerning whether the software is capable of discriminating soft but otherwise suitable sites from sufficiently firm OLSs.

A kickoff meeting was held in September 2004. One afternoon of this meeting's agenda was devoted to capturing customer requirements and desired features (desirements) for an OLS system. Customers identified included the U.S. Transportation Command (USTC), AMC, the Special Operations Command (SOCOM), and the U.S. Army. All team participants agreed at the kickoff meeting that they would support the application of Systems Engineering Tailored for Science and Technology (SETFST) to the OLS System Validation and Demonstration. Figure 1 illustrates the steps in the process. This paper describes the establishment of evaluation criteria (Step 2, Negotiate Desirements), the results of having performed this work, and the lessons learned in this part of the process during this program. Other papers presented in this session[4] describe technical accomplishments with respect to identifying OLSs using image analysis.

SETFST is a structured approach to identifying optimal solutions to complex problems. Applied to research and development, SETFST contributes to sound systems engineering over the life cycle of products that emerge from early portions of the effort. Further, it ensures that requirements/desirements are understood and supports good decision-making in the absence of complete information at each stage from conceptual design to critical design review.

The strengths of the SETFST process include its conceptual simplicity and its analytical rigor. At its simplest, desirements are identified and alternatives that might satisfy those desirements are evaluated, rated, and compared. It is a robust process with multiple benefits. SETFST

- Is recursive (step-by-step), flexible, and scalable.
- Provides a consistent framework for SMEs and managers to
  - ◊ Capture, discuss, negotiate, and evolve alternatives toward consensus
  - ◊ Realize the highest probability of "system" success
  - ◊ Explore the range of acceptable values expressed in desirement definitions and achieve outcomes superior to those that result from settling for minimally acceptable levels of performance with respect to requirements.
- Reveals sensitivities and quantifies risk.
- Is easily updated as desirements and knowledge evolve.

An objective function is generated that incorporates all desirements. The evaluation and analysis activities enable prediction of where, within the multidimensional solution space, desirements are met, thus providing pointers to the best solutions. This approach may be used to guide investment of program resources to the candidate technologies most likely to provide an affordable[5] solution that is, overall, the best possible value—meeting customers' needs at a price those customers are willing to pay.

4 Ryerson, C., McDowell, J., Almassy , R., Eizenga, K., and Ventresca, C. (2008). "The Opportune Landing Site Program." Presentation at the Transportation Systems Workshop, Phoenix, AZ.

5 Ventresca, C. and Quaglieri, R. (2002). "An analysis process for affordability and the relationship to cost". 43rd AIAA/ASME/ASCE/AHS/ASC Conference Special Session on Affordability 33-SDM-22, AIAA-2002-1767, Denver, CO.

The Practice of SETFST

Team Development

SETFST is a collaborative effort. Project teams work best when they contain a relatively small number of SMEs appropriate to the problem—e.g., engineers, scientists, regulators, logisticians, financial analysts—and customers and users. The process creates systematic and traceable inputs that encourage "what if" scenarios as the team works through the definition of desirements and performs Value Analysis.

Definition of Desirements and Determination of Exit Criteria

Once the team has coalesced, it begins capturing desirements—definition and documentation of what the final product, technology, or system must do. The customer provides the team with criteria related to performance, reliability, portability, schedule to completion, life cycle cost, maintainability, etc. Each criterion is documented with a description, a unit of measure, one or more customers or applications to which it pertains, and assumptions made. The following details are specified for each criterion for each customer: priority, objective, desirability limit, desirability function (***d***-curve), and a weighting factor. Each criterion is assigned a numerical weighting factor reflecting its importance relative to other desirements of the same type. Types are weighted for relative importance with respect to each other. Again, these weighting factors are customer-specific. Once the ***d***-curve, with its objective and desirability limit(s) is set for a desirement, one measure of "goodness" is established for a particular customer. Individual desirements are documented for every application or customer. A composite set of desirements is identified comprising desirements for all customers—i.e., for the "Constructed Customer". The set of exit criteria is the subset of the constructed set of desirements that defines successful completion;

it includes Key Performance Parameters (KPPs), if any, and all other criteria that must be met.

Generation of Alternatives

The team identifies possible solutions (called *alternatives*) to satisfy the desirements. These may be new technologies; combinations of existing materials, technologies, or components; novel approaches; or other systems with potential to satisfy the set of desirements. Sometimes, a Request for Information (RFI) is issued to industry. Often at this stage, additional SMEs and vendors are called upon to work with the core team.

Value Analysis

Value Analysis is evaluation of the alternatives against the desirements. The measures of merit are desirability and risk. Desirability is a measure of "goodness". Risk is the probability of failure to exceed the desirability limit. Theoretical models, simulation, expert opinion, statistically designed experiments, or other quantitative assessment methods may be employed to predict how each alternative will fare with respect to a desirement. A worksheet is compiled for each alternative evaluated against every criterion of a given type. Tabulated in the worksheet for each desirement are the predicted mean response value of the desirement's unit of measure and some measure of spread of the prediction interval for that alternative. The predicted mean value is translated into a desirability value, $\boldsymbol{d_i}$, using the desirability function for desirement $\boldsymbol{i}$. The $\boldsymbol{d_i}$ values are aggregated into a composite desirability ($\boldsymbol{D_{type}}$) for the alternative with respect to all desirements of the given type. A measure of risk is calculated for each alternative for each desirement and aggregated to produce a risk measure for the alternative against all desirements of a given type. Similarly, top-level desirability is calculated using $\boldsymbol{D_{type}}$ values and weighting factors, while the overall risk measure is generated from the lower-level probabilities of failure to meet desirability limits.

From the worksheets, a Value Scorecard is compiled for each customer comprising one scorecard for each type of desirement and one Affordability Scorecard presenting top-level results. Scorecard metrics include expected value, the desirability value to which it maps, and risk. The Value Scorecard presents desirability and risk for multiple alternatives for all desirements for a single customer. Thus, desirability and risk are displayed at three levels: individual desirement, desirement type, and overall. The scorecard assists in identifying risk drivers and technical challenges in meeting the desirements. The Value Scorecard for a single customer is used to communicate with that customer when reporting progress or raising issues. The scorecard for the Constructed Customer is used to support program decisions, such as the selection of a single technology alternative for further development.

Optimizing Solutions

Once the team has focused on a particular technology alternative, the process moves to refining it to best meet the program objectives and exit criteria. Levels of design variables are evaluated in different combinations to produce response-value predictions using statistically designed experiments and response-surface methodology. Regression analysis or other quantitative methods are performed to generate predictive functional relationships. The Multiattribute Desirability Optimization Methodology[6] applies an optimization formula to establish values of design variables that relate to the best-value, most robust solution.

Establishing Desirements for an OLS System

This paper focuses on that part of the SETFST process involving establishment of evaluation criteria (Step 2, Negotiate Desirements) during the OLS program. This section describes attributes of desirements, which are used to quantify the expected benefit and potential of technologies under development to satisfy customer wants and needs. Assessment of technology alternatives produces two measures of merit: *Desirability* and *Risk*. Some fields—the class attributes—specify

6 Ventresca, C. (1991). "Continuous process improvement through designed experiments and multiattribute desirability optimization". ***ISA/91 Advances in Instrumentation and Control***, 46:2. Instrument Society of America, pp. 1685-1700.

the desirement while other fields relate to benchmarks that characterize suitability for specific applications or customers. The definition of a single desirement for one customer includes specification of the class attributes and the customer-specific attributes associated with that desirement. The two types of fields are further defined below.

Desirement Field Definitions—Class attributes

Class attributes are fields whose content is entered only once and remains constant across customers or applications. They include the following:

- Desirement Number (Des #): An alphanumeric code in accordance with a convention agreed upon by the team; e.g., format *Xn,* where *X* is a prefix signifying the type of desirement and *n* is number of the desirement within that type. For example, P01 may be used to denote the first performance desirement. (See Type, below.)
- Desirement Name: A short verbal description of the desirement.
- Unit of Measure: The specific engineering unit or measurement scale used to quantify the level of achievement of the criterion and to determine if the desirement has been met.
- Desirement Description: A statement providing explanation of what the desirement means; a "What" of the Product; a desired function or characteristic of this thing.
- Assumption, How Tested, or Other Clarification: Explanatory remarks or clarification of how compliance with the criterion will be measured and validated. Assumptions that apply across customer or application may be included here; e.g., "Validation of OLS predictions through sampling on LZ and comparison of DCP-measured CBR7[*] values."
- **Type:** Optional group name. Desirements are sometimes organized into groupings of similar desirements to facilitate analysis. Example types are *Performance*, *Logistics*, *Cost*, *Other*.

Desirement Field Definitions—Customer-Specific Attributes

Application attributes are those fields whose values must be considered separately for each customer or application. While there is only one set of class attributes, a set of customer-specific attributes should be defined for each customer, including the Constructed Customer.

7 The Dynamic Cone Penetrometer (DCP) is a device used in field determination of soil strength. DCP measurements for a candidate LZ are converted to and reported as a California Bearing Ratio (CBR) for the site.

- Objective: Desired response value. Assumption: d_i = 1.00 at objective, unless stated otherwise.
- Lower / Upper Desirability Limit (***d***-Limit): The limit of the range of acceptable response values. There is one ***d***-Limit (lower) if more is better or (upper) if less is better. There are two ***d***-Limits if a particular value is best, and desirability falls off as one strays in either direction from the objective. The ***d***-Limit(s) must be exceeded for an alternative to be deemed satisfactory.
- Objective Rationale: Explanation of why the particular value was chosen as the Objective; (optional) assumptions or clarifying comments.
- ***d***-Limit Rationale: Explanation of choice of particular value(s) for the ***d***-Limit(s); (optional) assumptions or clarifying comments.
- Comments: Additional clarification or customer/application-specific details, often provided by prospective customers.
- Priority: Relative importance of achieving the desirement. May be characters (e.g., *High, Med., Low*) or a numerical (real or integer) weighting factor to signify relative importance. If numbers are used, a higher number signifies greater importance.

For the outcome to be declared a success, the process demands that all exit criteria, including KPPs, must be met. In addition, the process enables exploitation of the trade space defined by the minimally acceptable level and the ideal level on any criterion. The process of defining this trade space is sometimes painful and often involves changing the way team participants have done business; however, it has been found repeatedly to increase the probability of success by highlighting potential risk areas and aiding in the reduction of the probability of failure to meet the exit criteria. The desirements defined in accordance with the Multiattribute Desirability Optimization Methodology form the multi-dimensional solution space, leaving the team to do what engineers do best—develop systems that meet the defined criteria.

Results and Conclusions

Initially, the team focused on the product of the current effort, beginning with guidance from AMC provided in the form of a Concept of Operations for the demonstration.[8]7 This document

8 McCarty, R.E.; Ventresca, C.; Ryerson, C.; and Almassy, R (2007). "Transitioning the opportune landing site system to initial operating capability". Presentation at the Technology Maturation Conference, Virginia Beach, VA.

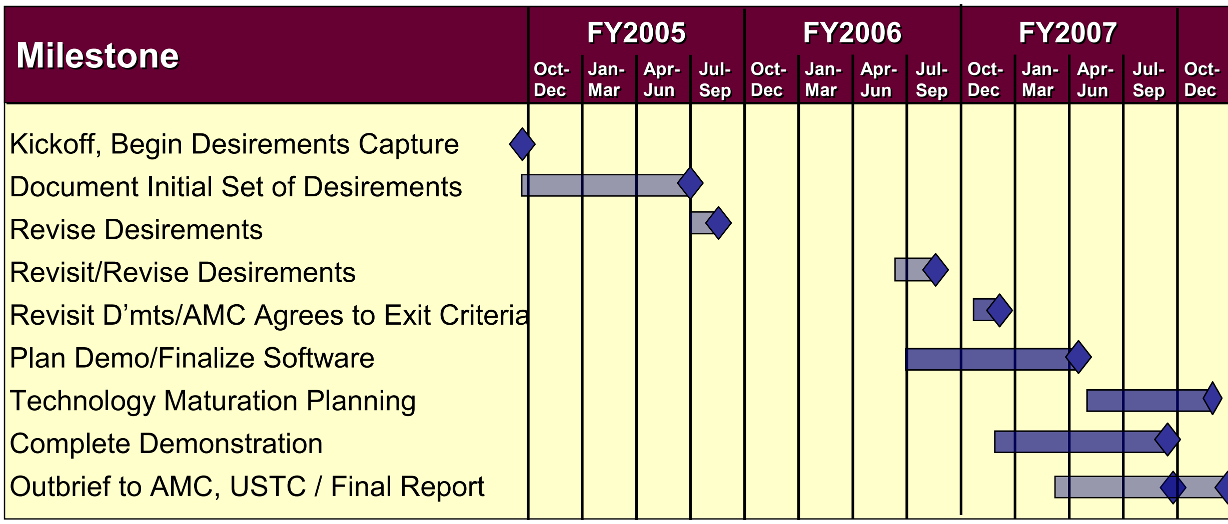

Figure 2. Timeline for negotiation of desirements and outcomes

serves as an excellent starting point for documenting the definition of success. Nevertheless, controversy remained. The ability to assess soil strength with reasonable accuracy caused concern as a risk area. It was always an important interest of the Army's, but how it would be implemented was not so straightforward. A major issue with regard to soil-strength assessment was how to express it—as California Bearing Ratio (CBR) or number of passes. There was discussion about whether the software should identify runways or sets of contiguous pixels suitable for aircraft operations, given that there were enough of them to stitch together a site of the desired size.

Figure 2 shows a time line of key events related to the documentation and negotiation of desirements on the program. The bars indicate activity leading up to the accomplishment of the milestone described in text and whose timing is illustrated with a diamond. It was nine months after the kickoff meeting that the first reasonably complete set of desirements was documented by the team. Refinement and enhancement occurred over the next three months so that, one year after the kickoff meeting, there was an actionable set of desirements to guide development. At this point, the team leader from one of the participating organizations expressed how valuable this guidance will be in making resource-investment decisions during the remainder of the work to be done and added that this should have been done much earlier in the program.

One year later, the desirements were revisited and fine-tuned. Again in the fall of 2006, customer guidance was sought and received. Ultimately, the team defined three sets of desirements—one for the end of the current program (2007), one for a product ready for a system design decision (~2010 or three years following the start of the next OLS system program), and one for the system that would provide the ultimate capability (~2030). Figure 3 at the end of this paper presents the desirements for the OLS software at the end of the current program. The set of desirements for the ultimate OLS system is shown in Figures 4 and 5.

It was agreed that the objective of the OLS Software Demonstration and Validation Program would be shown to have been met if the team were to demonstrate that the exit criteria previously negotiated and finalized at the 29 November 2006 meeting with AMC were met. All desirements of interest were of the performance type; hence the prefix "P" on every desirement number. At this meeting, three KPPs and one additional desirement were identified as exit criteria for the demonstration. Following is a summary of the definition of success for the demonstration. More detail may be found in Figure 3.

- KPP P01: Capability to identify suitable landing sites in a specified area, given that suitable landing sites exist. Suitable is defined as having an area of the specified dimensions that is flat and free of obstacles, standing water, and heavy vegetation. Bearing strength is not a consideration for suitability in this context. Exit criterion: at least 50% of suitable OLSs found. Objective: 100%.

- KPP P02: Capability to determine bearing strength of identified landing sites. The measurand was defined as a dimensionless ratio of predicted CBR divided by actual CBR, from field sample collection and analysis. Exit criterion: 1.05 or less. Objective: 1.00.
- KPP P04: Repeatability, defined as the percentage of time OLS software returns the same results using the same entry parameters while evaluating the same Landsat image. Exit criterion: at least 90%. Objective: 100%.
- P11: Ability to accept user-defined parameters. The capability of OLS software to process inputs provided by users, including parameters like length, width, ratio requirement, CBR, glideslope, etc. was considered mandatory. Assessment using a 6-point satisfaction scale was to be performed by an AMC-designated evaluator based on information provided by Boeing, and the result would serve to guide future development. Exit criterion: 4 (marginally satisfactory). Objective: 6 (very satisfactory).

The following desirements were not exit criteria for the program, but they were desirements against which the performance of the OLS software was to be assessed during the demonstration. Interestingly, it was the technical team who augered for evaluating the software against P03 because the incidence of false positives was considered too crucial to the utility of a fielded OLS system to be deferred to the next phase of effort without some sense of the magnitude of the challenge ahead.

- P03: Low incidence of false positives. Probability of designating an unsuitable landing site as a suitable OLS—a measure of accuracy, expressed as the percentage of OLSs identified by the software that were unsuitable. Suitability as defined for this criterion excludes bearing strength. The value with respect to this desirement was to be assessed through comparison of the software analysis results with field inspection and observation results for St. Clair County, Illinois. The goal was 0%. No upper bound was set at this stage.
- P07: Flexibility and longevity, a measure of the ability of the OLS software to function if Landsat or other asset relied upon as a data source were no longer available. Assessment against the 6-point satisfaction scale was to be performed by an AMC-designated evaluator based on information provided by Boeing.
- P09: Capability of the OLS system to operate in all weather in which flight operations would be conducted. This desirement dealt with the ability of the OLS system to function effectively in all weather conditions, regardless of cloud cover, precipitation, or other obscurants. Assessment against the 6-point satisfaction scale was to be performed by an AMC-designated evaluator based on information provided by Boeing.
- P12: Flexibility in finding more than LZs. Ability of the OLS software to perform other functions; e.g., assessing overland mobility, finding areas for base camps and drop zones (DZs), etc., so long as the criteria are similar to those for LZs. Evaluated as a ranking based on what the system can find and the difficulty of finding it. (A higher ranking is better.) Scale definition is based on the OLS system's ability to find the following: 1 = LZs only; 2 = LZs and drop zones; 3 = LZs, drop zones, and base camps; 4 = LZs, drop zones, base camps and marshalling areas; 5 = LZs, drop zones, base camps and marshalling areas, as well as routes and communication lines.

The importance of evaluating the system against these last four desirements, even though they are not exit criteria, is that the results guide the technology maturation planning and risk management strategy for continued development of an OLS system.[1]

Alternatives identified included multispectral image analysis, hyperspectral analysis, and the extended-vector approach. Evaluation of alternatives indicated that the hyperspectral approach had high risk and lacked a sufficiently high overall desirability to make it worth pursuing. This knowledge enabled the team to choose to invest their efforts in refining OLS-MS, OLS-EVM, and FASST—choices that led further enhancements to these software modules and to a successful demonstration of their capabilities. Results are highlighted below:

(Endnotes)

1 McCarty, R.E.; Ventresca, C.; Ryerson, C.; and Almassy, R (2007). "Transitioning the opportune landing site system to initial operating capability". Presentation at the Technology Maturation Conference, Virginia Beach, VA.

- KPP P01: Capability to identify suitable landing sites proved difficult to quantify because it was unknown how many suitable sites exist in the region chosen for the demonstration of this desirement. OLS-MS identified 40 sites, whereas an individual using the standard manual method identified only 17 sites in the region. It could be argued that the software scored 235%. While the exact score is unknown, there is agreement that the exit criterion of at least 50% was certainly exceeded, and it could be argued that the objective of 100% was met. The lesson learned is that properly defining the measurand and the method of collecting the data to support quantification against that measurand is important.

- KPP P02: Capability to determine bearing strength of identified landing sites was confirmed by blind testing. The ratio of predicted CBR to measured CBR averaged 0.85, exceeding the exit criterion of 1.05 or less and engendering confidence that the OLS software does not over-estimate soil strength.
- KPP P04: Repeatability of the OLS-MS software was tested by AFRL. Ten runs on each of two different types of input image data produced identical results. The objective of 100% was met.
- P11: Ability to accept user-defined parameters was judged very satisfactory (6) by AMC. Runway size and orientation parameters offer the user the desired capability.

All exit criteria were exceeded. The aggregated desirability for the exit criteria was 0.999 with a risk of 0.23. The largest contributor to risk was P02, the capability to determine bearing strength.

Results of the evaluation against desirements that were not exit criteria follow:

- P03: Incidence of false positives was 0, meeting the objective.
- P07: Flexibility and longevity was rated marginally satisfactory (4).
- P09: Capability of the OLS system to operate in all weather was rated unsatisfactory (2) because of the difficulty of obtaining images when atmospheric obscurants are present.
- P12: AMC judged the software capability of finding LZs and drop zones and rated it 2 on flexibility in finding more than LZs. The ability to accept user-defined parameters enables this additional capability.

When these last four desirements were figured into the overall assessment, composite desirability was 0.526 and risk was 0.54. All-weather operating capability (P09) was the biggest contributor to the lower composite desirability and to the increase in risk.

Observations and Recommendations

Developing a clear, well documented, consensus-based definition of success facilitates the building of relationships among team members. Applying a structured approach to technology maturation as soon as possible within a program increases the probability of success by providing information to help guide resource investment. In the OLS System Demonstration and Validation Program, not only did this process influence the choice of the multi-spectral approach to image analysis, but also, it helped the team decide what to demonstrate to provide the highest level of customer satisfaction. Because the customer was present throughout the process, the program team obtained buy-in that, if certain specific things were accomplished, the program goals were met.

Among the lessons learned was the mutual influence of desirements captured and technological solutions considered. In the absence of a well defined set of desirements that the customer has agreed to, the development team lacked confidence that they were pursuing the right objectives. Moreover, the customer expanded his/her view of the realm of the possible through interaction with the technical team, and the result was a well considered set of desirements. Together, the customer representatives and the development team generated a shared definition of an evolving OLS system and the observable characteristics constitute success at three stages in this evolution. Developing such a set of criteria early in a program facilitates communication within the development team and between the developers and customers. It leads to more refined ideas, a more efficient development process, and a better product.

The program manager was very impressed with the outstanding demonstration results and the technological achievements on the program, especially in light of the seemingly insurmountable obstacles (e.g., that soil-strength inference is beyond the capability of multispectral image analysis without modification of the laws of physics) perceived early in the program. It has been shown repeatedly that desirements and evaluation criteria are well defined using this process and that that definition facilitates the achievement of a good result. The process provides a structure and a frame of reference for outcomes, for communication, and for decisions concerning resource investment.

At the outset of any development program whose success depends upon the maturation of evolving technologies, there is uncertainty concerning the eventual outcome. Involving the customer early and at appropriate points throughout the development program serves to properly guide development-team efforts and expectations on both the developer and customer sides of the team. The SETFST process provides a means of communication understood by both sides that facilitates commitment of resources to activities that are most effective in providing the customers with what they want. This communication tool enables the adjustment of customer expectations based on scientific (physical), funding, and time constraints, while, at the same time, reducing "wheel spinning" and pursuit of unfruitful paths by the development team. It also helps generate the roadmap for future maturation of the product.

Without a clear concept of what constitutes success from the perspectives of the customers, SMEs are sometimes inclined to pursue avenues of scientific interest, independent of whether they have a bearing on meeting the customers' needs with acceptable levels of risk. Other times, technologists, in the absence of an understanding of customer needs and wants, will perform well directed efforts toward perceived but incorrectly defined customer needs. The process applied on this program, through its programmed periodic prescribed communication, channeled efforts in the appropriate direction to result in a successful outcome for this demonstration and validation program.

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#	Desirement Name	Units of Meas.	Objec-tive	d-Limit	Desirement Description	Assumption, How Demonstrated or Other Clarification	Objective Rationale	Threshold Rationale	Prior-ity
Type:	Performance								
P01	Capability to ID Landing Sites	% of Suitable LZs Correctly Identified	100	50	Probability of designating a suitable landing zone (LZ) in a geographical region, given that a suitable LZ exists in the region—a measure of accuracy without consideration of bearing strength.	Percentage of Correct LZ IDs [Pr(CrIDs)]. Pr CrIDs = (Area in Correct LZ ID'd) ÷ (Total Area of LZs in region analyzed). Comparison of software analysis results with inspection and observation results for St. Clair County, IL (Task 1)	Ideally, the OLS would correctly identify all areas suitable for LZs in a region under study.	The OLS shall demo the capability to correctly designate the existence and location of landing sites at least 50% of the time.	High
P02	Capability to Determine Bearing Strength of ID'd LZs	Predicted/ Actual CBR	1	1.05	FASST-predicted CBR ÷ Actual LZ CBR. Predictions made at 85% confidence level.	Validation of OLS predictions through field sampling and comparison of software predictions with DCP-measured CBRs. (Task 2)	Until there is very high confidence in the OLS soil-strength predictions, it is unlikely that aircraft will be authorized to land without a site survey.	Overestimate of bearing strength is a serious problem; underestimation is less serious, though it may preclude finding suitable LZs. Must have 85% confidence that the actual CBR is greater than or equal to that provided by the system.	High
P03	Low Incidence of False Positives	Pr(Incor-rect ID)	0	0.2	Probability of designating an unsuitable landing site as a suitable LZ--a measure of accuracy.	Comparison of software analysis results with inspection and observation results for St. Clair County, IL (Task 1)	Ideally, there would be no false positives.	The OLS software should not incorrectly report suitable sites; however, no threshold must be met for the demo.	High
P04	Repeatability	Pr(Same Answer)	100	90	Percentage of time OLS returns the same results using the same entry parameters (given area at a particular time).	Software validation based on acceptance testing. (Task 3)	Given the same entry parameters for the same area at the same time, the system provides the same answers.	Demo the capability (may report results of lab testing used to reach demo threshold, but should demo at least one example of repeatability).	High
P07	Flexibility and Longevity	Scale: 1 to 6	6	2	Ability of OLS to function even if Landsat or other asset relied upon as a data source is no longer available.	Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfactory; 3 = marginally unsatisfactory; 2 = unsatisfactory; 1 = very unsatisfactory Assessment by AMC-designated evaluator based on information provided by Boeing. (Task 4)	A capability is desired, regardless of available data source.	Address impact to OLS performance if one or more sensors are no longer available (e.g., LANDSAT satellite is decommissioned).	Low
P09	Capability to Operate in All Weather	Scale: 1 to 6	6	2	Ability of OLS to function in all weather conditions, regardless of cloud cover or precipitation, obscuration by terrain, etc.	6-Point Satisfaction Scale; see P07 for definition. Assessment by AMC-designated evaluator based on information provided by Boeing. (Task 4)	Demo the capability, if possible; if not, address weather/atmospheric limitations.	Currently not feasible because of sensor limitations. Need to know how weather and atmospheric conditions will affect OLS performance. Can be handled by report for demonstration.	High
P11	Ability to Accept User-Defined Parameters	Scale: 1 to 6	6	4	Ability of OLS to process inputs provided by users, including parameters like length, width, ratio requirement, CBR, glideslope, MOG, etc.	6-Point Satisfaction Scale; see P07 for definition. Assessment by AMC-designated evaluator based on information provided by Boeing. (Task 5)	Ability to change parameters based on operations, changes in mission in flight, etc. that might require changed input parameters is desired.	The mission should dictate the parameters for the OLS search. Operators need this flexibility. Assume no GUI in place for demo; operator specifies parameters, which are entered by s/w driver.	Med
P12	Flexibility in Finding More than LZs	Scale: 1 to 5	2	1	Ability of OLS to perform other functions; e.g., assessing overland mobility, finding areas for base camps and drop zones (DZs), etc., so long as the criteria are similar to those for LZs.	Rank based on what it can find and the difficulty of finding it. Scale definition based on ability to find the following: 5=4+routes/comm lines; 4=3+marshalling areas; 3=2+base camps; 2=1+drop zones; 1=LZs only Assessment by AMC-designated evaluator based on information provided by Boeing. (Task 5)	Would like to find LZs and drop zones.	At a minimum, must find LZs. The capability for OLS to find more than LZs (marshalling areas, lines of communication, etc.) should be addressed.	Low

Figure 3. Desirements for the current OLS demonstration program

#	Desirement Name	Units of Meas.	Objec-tive	Thres-hold(s)	d at Thresh	Where d=0.00	Desirement Description	Assumption, How Tested or Other Clarification	Objective Rationale	Prior-ity
Type:	**Performance**									
P01	Capability to ID Landing Sites	Pr(Correct ID)	100	95			Probability of designating a suitable landing zone (LZ) in an area, given that a suitable LZ exists in the area--a measure of accuracy without consideration of bearing strength	Percentage of Correct LZ IDs [Pr(CrIDs)]. Pr CrIDs = (Area in Correct LZ ID'd) ÷ (Total Area of LZs in region analyzed)	The OLS should provide the best five candidate LZs within a specified geographic area, including relative strength	High
P02	Capability to Determine Bearing Strength of ID'd LZs	Predicted/ Actual CBR	1	0.5 and 1.05	0.2 and 0.5	0.2 and 1.1	FASST-predicted CBR ÷ Actual LZ CBR. Predictions made at 85% confidence level.	Validation of OLS predictions through sampling on LZ and comparison of DCP-measured CBRs by skilled combat control teams (CCTs).	Until there is very high confidence in the OLS soil-strength predictions, it is unlikely that aircraft will be authorized to land without a site survey.	High
P03	Low Incidence of False Positives	Pr(Incor-rect ID)	0	0.0001	0.98	0.005	Probability of designating an unsuitable landing site as a suitable LZ. Suitability as defined for this criterion excludes bearing strength.	Removed soil strength 11/29/06.Together with P01, measures accuracy.	Ideally, there would be no false positives.	High
P04	Repeatability	Pr(Identifying Same Site)	100	100			Percentage of time OLS returns the same results using the same entry parameters (given area at a particular time).	Software validation based on acceptance testing.	Given the same entry parameters for the same area at the same time, the system provides the same answers.	High
P05	Fidelity	Scale: 1 to 6	6	4			Level of detail available from OLS; ability to have the same level of detail as we have today from a site-survey team, not just a go / no-go decision.	6-Pt Satisfaction Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfac.; 3 = marginally unsat.; 2 = unsatisfactory; 1 = very unsatisfactory	It is important to know the surface: existence/location of undulations; crowns and drop-offs are great concern. Ability to assess an area for different aircraft, tire pressures, number of uses, etc. would be a valuable added capability.	Med
P06	Durability and Upgradability	Scale: 1 to 6	6	4			An assessment of the degree of flexibility; compatibility with future OLS-related technologies (upgradability / resistance to obsolescence), compatibility with air vehicles of the future.	6-Pt Satisfaction Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfac.; 3 = marginally unsat.; 2 = unsatisfactory; 1 = very unsatisfactory	Opens up the Battle Space; fully compatible with joint systems, AMC-X.	Med
P07	Flexibility and Longevity	Scale: 1 to 6	6	4			Ability of OLS to function even if Landsat or other asset relied upon as a data source is no longer available.	6-Pt Satisfaction Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfac.; 3 = marginally unsat.; 2 = unsatisfactory; 1 = very unsatisfactory	Data-source agnostic; system can grow through the years to accommodate any available data sources.	High
P08	Ground Survey Personnel Time Required	Manhours	0	15			Time required for support by site-survey personnel on the ground to ensure that an OLS-identified is safe.		The thought is that the sampling procedure would be changed to enable confirmation of a good site with fewer samples taken.	High
P09	Capability to Operate in All Weather	Scale: 1 to 6	6	4			Ability of OLS to function in all weather conditions, regardless of cloud cover or precipitation, obscuration by terrain, etc.	6-Pt Satisfaction Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfac.; 3 = marginally unsat.; 2 = unsatisfactory; 1 = very unsatisfactory	Change in landing suitability would be predicted by models incorporating weather.	High
P10	Worldwide Operating Capability	% Area Coverage	100	95			Percentage of global land areas that OLS is able to analyze; regions and climates.		Ideally, would like entire world coverage in all seasons.	High
P11	Ability to Accept User-Defined Parameters	Scale: 1 to 6	6	5			Ability of OLS to process inputs provided by users, including parameters like length, width, ratio requirement, CBR, glideslope, MOG, etc.	6-Pt Satisfaction Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfac.; 3 = marginally unsat.; 2 = unsatisfactory; 1 = very unsatisfactory	Ability to change parameters based on operations, changes in mission in flight, etc. might require changed input paramaters.	Med
P12	Flexibility in Finding More than LZs	Scale: 1 to 5	5	4			Ability of OLS to perform other functions; e.g., assessing overland mobility, finding areas for base camps and drop zones (DZs), etc., so long as the criteria are similar to those for LZs	Rank based on what it can find and the difficulty of finding it. Scale definition based on ability to find the following: 5=4+routes/comm lines; 4=3+marshalling areas; 3=2+base camps; 2=1+drop zones; 1=LZs only	Very important to tie mobility into an OLS capability to effect joint operations.	Low

Figure 4. Performance desirements for the ultimate (~2030) OLS system

#	Desirement Name	Units of Meas.	Objec-tive	Thres-hold(s)	d at Thresh	Where d=0.00	Desirement Description	Assumption, How Tested or Other Clarification	Objective Rationale	Prior-ity
Type: **Performance (Continued)**										
P13	Ability to Replan Quickly	Minutes	3	15	0.90	60	Time required to replan by designating a different LZ even after the mission has been launched, measured in minutes from the time a request for a new LZ is submitted to the OLS until a suitable one is ID'd by the OLS.	The real issue is whether replanning is possible and whether there is a growth path defined to achieve the desired response time by 2030. Capability depends on recent weather data and soil strength assessment. Assumption is Wx/strength assessment was done pre-mission.	The OLS outputs should be quickly updatable with latest inputs (e.g., changing conditions or mission replanning).	High
P14	Timeliness of Results	Hours	1	4	0.50	40	Time required to analyze four 100 km square area for potential LZs	Assuming availability of weather data and recent imagery.	Tied to the dynamics of the planning process. Should be able to provide notional answers quickly; nonlinear battlefield concept. Gives info to aircrew member prior to takeoff, even in contingency situations.	Med
P15	Georectifiction of Image	Feet	0	10			A measure of the registration (in 3-D) of the LZ identified by the system with the actual LZ.	Some believe that this problem should be solved by system(s) on which OLLS depends, not OLS.	The goal is zero georegistration error.	High
Type: **Cost**										
C4	Government Ownership	% of OLS	100	75			Percentage of the OLS to which the Government has unlimited rights.		Ideally, the Government would like to own all software within the total OLS.	High
Type: **Human Factors**										
U1	Usability	Scale: 1 to 6	6	5	0.86	3.8	Multidimensional metric including learnability, efficiency, memorability, error rates, user satisfaction.	Users will evaluate system by completing a questionnaire following experience with the system. Questionnaire results will be translated to 6-pt satisfaction scale.	Ideal: Output would have all information that site survey teams use (hardcopy), use should be fairly intuitive, interface seamless with all systems then in use.	High
U2	Good Human-System Interface	Scale: 1 to 6	6	5			The degree to which the system provides the user what is needed when needed in a manner that conveys the right information. Should include error checking and obviate need for redundant data entry. Also relates to output presentation--e.g., location of LZ.	6-Pt Satisfaction Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfac.; 3 = marginally unsat.; 2 = unsatisfactory; 1 = very unsatisfactory	Error checking of user input is highly desired by 2030. Should be very intuitive. Preferably it is part of the MPS and requires very little additional input.	Med-High
U3	Requires Minimal User Interaction	Scale: 1 to 6	6	5			Amount of user interaction required for the OLS to function effectively. The default is that input would be provided from MPS; however, capability for user to input data should be provided.	6-Pt Satisfaction Scale: 6 = very satisfactory; 5 = satisfactory; 4 = marginally satisfac.; 3 = marginally unsat.; 2 = unsatisfactory; 1 = very unsatisfactory	Ideally, the system should require little user interaction; should be fullly automated. Weather data should be incorporated automatically for processing of LZ data and updated continually in the background without user intervention.	Med
U4	Degree of Confidence Inspired	Level of Confi-dence (%)	99.9	95			The level of confidence users have in the results provided by the OLS.	Reference: Jared M. Spool paper.	System should inspire a high degree of user confidence in the accuracy of the LZs identified to the extent that no "boots on the ground" are needed.	High
Type: **Integration**										
I1	Compatibility with Other Systems	Scale: 1 to 3	3	3			Compatibility of OLS with AF mission planning systems, with Theater Battle Management Core System (TBMCS); ability to exchange data with aircraft in real time over available data links	Scale: 3 = fully compatible; 2 = partially compatible; 1 = not compatible. Assumption: data links available	There are multiple mission planning systems. Ideally, OLS would be compatible with any MPS in use.	Med
I2	Compatibility with COP	Scale: 1 to 3	3	2			Degree to which OLS is compatible with and able to feed data into the Common Operating Picture (COP)	Scale: 3 = fully compatible; 2 = partially compatible; 1 = not compatible. Assumption: data links available		Med
Type: **Logistics**										
L1	Availability	% Uptime	100	99			The degree to which OLS is available for use when needed/wanted.		Should be as available as TBMCS.	High

Figure 5. Remaining desirements for the ultimate (~2030) OLS system