

# Survey of the Army's Technology Base for ESOH Applications

A White Paper

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## INTRODUCTION

The Army, Department of Defense, and other federal agencies spend significant amounts of public funding to develop new technologies to meet a variety of needs, ranging from environmental cleanup, to energy production, to advanced sensing for defense applications. Despite these efforts, however, there are never sufficient resources to solve all possible problems with which public agencies are faced. The purpose of this white paper is to explore one possible strategy for increasing the problem-solving return on investment for one agency (the U.S. Army) and one subset of problems with which they are faced (Environment, Safety, and Occupational Health (ESOH) problems). The following sections describe the drivers behind the challenge of finding viable solutions for ESOH problems, and the constraints faced by federal agencies in their quest.

### **Drivers**

Given the potential economic return and savings of effort resulting from finding new applications for technologies that have already been developed at federal expense, this white paper proposes to develop a semi-automated system that can monitor the development of new technologies and articulation of new needs to identify new applications for technologies in the area of Environment, Safety, and Occupational Health. The following sections describe the drivers that motivate a need for improvement to be addressed in this research.

### ***ESOH Needs***

As the number of regulations and standards grow that restrict permissible levels of negative impacts on humans and the natural environment, the Army and other organizations are faced with an increasingly large number of ESOH problems that they must address to comply with regulations and ensure the health and safety of the humans

and ecosystems they impact. Examples of ESOH problems faced by Army installations and operations include:

- Range clearing of unexploded ordnance (UXO)
- Clean-up of fuel spills and other soil/groundwater contamination from liquid waste
- Mitigation of noise impacts to surrounding communities and sensitive ecosystems resulting from aircraft training and operations

These and other ESOH problems represent an increasingly significant share of the concerns that must be addressed as part of the ongoing training and readiness missions of the Army.

### ***Resource Constraints***

In seeking to solve the problems with which they are faced, the Army and other federal agencies must work with a set of available resources that is typically far less than would be required to solve all problems that have been identified. These resources may include:

- Funding, both for internal problem solving and sponsorship of external research, development, and execution of solution
- Equipment and materials technology
- Time for the use of internal human resources

All of these resources can be expressed in terms of cost to solve a particular problem. The resource allocation process used by the Army involves distributing these resources across the set of problems to be solved, based on their impact to mission readiness, regulatory compliance, and other prioritization criteria.

### ***Traditional Organizational Barriers***

The problem of allocating resources to solve problems can be complicated by organizational standard operating procedures (SOPs). In particular, the way in which problems are identified, articulated, and passed through the chain of command to enter a queue for funding can have significant impact on the amount of resources they are assigned and the kind of solution that is developed to address them. In general, boundaries both between functional groups within an organization and between organizations themselves can prevent the transfer of solutions to similar problems. In some cases, resources are allocated to “reinvent the wheel” in finding solutions to problems that have already been solved elsewhere, usually due to lack of awareness of those other solutions or lack of time or resources to conduct a thorough search for applicable existing solutions. In other cases, solutions developed for other purposes may be able to be easily adapted to solve the problem at hand, but no systematic mechanism presently exists to identify opportunities for technology transfer within or across organizations.

## Problem Definition

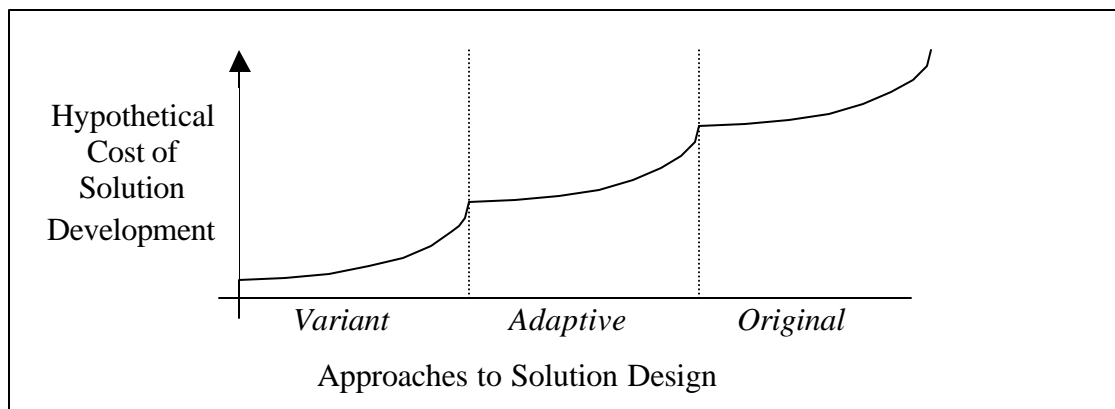
All of the drivers described in the previous section have contributed to a sub-optimal problem solving system for ESOH problems in the Army and other federal agencies. In this context, sub-optimal means that more dollars are spent than necessary in finding solutions for ESOH problems, which is significant due to the fact that there are fewer resources available to solve problems than there are problems to solve. The following sections describe the resource requirements and caveats of solving problems in different ways, followed by a discussion of specific research needs that exist to solve the problem of doing more with fewer resources to address the Army's ESOH needs.

### *The Cost of Finding Solutions*

The development of technological solutions to problems has been classified into three primary categories (Pahl & Beitz 1984; Brown & Chanrasekaran 1986):

- 1) Original Design – design “from scratch” in which solution principles are unknown
- 2) Adaptive Design – modification of a known solution to solve problems for which it was not originally designed
- 3) Variant Design – adaptation (often “resizing”) of a known solution to solve a problem of the same nature as that for which it was originally designed

Figure 1 shows a hypothesized relationship between the cost of solving a given problem and the approach selected to solve that problem. In general, developing an original design solution for a given problem is significantly more expensive than adaptive or variant design. In contrast, using an adaptive or variant design strategy means that significant resources have *already* been expended for the development of solution principles, and the efficacy of the solution has *already* been demonstrated in its application to a problem, either similar to or different from the problem being posed. The costs of developing solution principles and/or debugging the solution have been borne by the entity who initially undertook original design of the solution, and these costs thus do not have to be absorbed by the agency wishing to adapt or vary that solution for application to another problem.



**Figure 1:** Hypothetical Relative Costs of Alternative Solution Methods

Given the resource constraints inherent in ESOH problem solving situations described in the previous section, minimizing the cost of developing a viable solution is a desirable objective. In other words, the priority of solution strategies should favor variant design over adaptive design, both of which are superior to original design in terms of probable development cost. Thus, to optimize use of limited resources to find viable solutions for the greatest number of problems, variant and adaptive designs should be used wherever possible instead of original designs (hereafter denoted the Principle of Design Reuse).

The Army's interest in finding ESOH applications for existing technologies falls into the category of adaptive design, since it intends to find new uses for already developed technologies or solutions to solve ESOH problems. Variant design is not of interest in this white paper, since it is assumed that if an appropriate solution were already known, it would as a matter of course be varied and applied directly to the problem of interest. Instead, the problem is one of determining mechanisms for reducing the need for designing original solutions to problems for which potential adaptive solutions already exist. As will be described further in later sections of this white paper, this challenge involves problems of ineffective information exchange, lack of a mechanism for identifying potential new applications for non-ESOH technology, and lack of a framework for understanding and classifying ESOH problems that could facilitate finding a match between non-ESOH technologies and ESOH problems.

### ***Caveats of Design Approach Selection***

While the Principle of Design Reuse is a logical and effective guideline for improving the efficiency of resource allocation for problem solving, several key assumptions must be articulated and verified in order to ensure its applicability to a given problem solving situation.

Assumption #1: First, the principle assumes that the resources required to search for an appropriate solution to be varied or adapted are significantly less than the margin of resources required to perform original design. Developing efficient search mechanisms to support this assumption is one of the primary goals of the research proposed in this white paper.

Assumption #2: Second, the principle assumes that the solution identified for potential reuse will actually be variable or adaptable to successfully solve the problem being addressed. This assumption is key, since if a solution is identified and resources are invested for variation or adaptation only to find that an original design was needed, the cost of pursuing this dead-end path must then be *added* to the additional significant costs of original design. The cost of pursuing a dead-end path must also include the difficult-to-quantify costs of the time and effort it takes to realign both the sponsoring agent and the design team to the new strategy. Organizational vestedness in dead-end solutions is a significant cost of incorrect design approach selection, and it is particularly significant in the kind of political solution development environment typical of government-sponsored research and development (Allison 1971; Birnbaum & Murray 1987; Meyer & Miller 1984; also could insert anecdote about the development of the Bradley personnel carrier in here somewhere).

### ***Research Need***

Given the Principle of Design Reuse and the two assumptions that support its effective application, a need exists to assess its applicability to the problem of technology transfer for solving ESOH problems, and to assess the economic significance of being able to identify feasible adaptive solutions in terms of cost/resource savings and/or enhanced effectiveness in solving ESOH problems.

If a significant potential savings in resources or increase in developing effective solutions to ESOH problems is predicted, there is a follow-on need to develop a robust mechanism for identifying both:

- candidate ESOH problems to which a given non-ESOH technology could be applied via adaptive design
- candidate technologies that could be adapted to solve a given ESOH problem

via a resource-efficient search/matching algorithm that, together with the follow-on cost of adaptive design, requires less resources than would the development of an original design solution to the relevant problem.

Finally, given that a mechanism for searching for matches between technologies and potential problems to which they could be applied, there is a need to be able to predict the likelihood that adapting the design of the technology will result in an effective solution to the ESOH problem. This predicted likelihood is the inverse of the probability that pursuing adaptive design of the technology will result in a dead-end path that must be followed by an original design process to solve the problem. This error statistic is necessary to assess the risk of violating Assumption #2, i.e., the risk (and associated likely costs) of being wrong in planning a design approach to solve the problem.

## **PROBLEM STATEMENT AND RESEARCH OBJECTIVES**

The problem to be addressed by the research proposed in this white paper has three primary parts, expressed in the following research questions:

- 1) Is there a significant potential for either a) realizing cost savings in solving ESOH problems, or b) the ability to solve more ESOH problems for the same cost by maximizing the use of adaptive design in solving those problems?
- 2) If so, what is an effective mechanism for identifying matches between non-ESOH technologies and ESOH problems to which they could be adapted?
- 3) Can the Army realize additional benefits by expanding this mechanism to include non-Army technologies or to address non-Army ESOH problems?

The objectives of the proposed research parallel these three research questions as follows:

- 1) to assess and compare the potential costs and benefits to the Army of the use of adaptive design strategies for solution of ESOH problems, in order to determine whether or not a formal mechanism to facilitate the identification of adaptive design opportunities would result in net benefits to the Army

- 2) pending affirmation of potential benefits to the Army, to develop a prototype mechanism for identifying adaptive design opportunities to solve Army ESOH problems
- 3) to assess potential benefits to the Army of generalizing the mechanism to non-Army technology bases and/or non-Army ESOH problems and make recommendations for further development of the mechanism accordingly

The following section describes the proposed research approach for achieving these objectives.

## **SOLUTION: PROPOSED RESEARCH APPROACH**

To achieve the research objectives described in the previous section, a two-phase approach is proposed. Phase I addresses the first two research questions and approaches and involves developing and pilot testing a problem-technology matching mechanism applied to Army ESOH needs and technologies. Phase II of the research entails expanding the pilot test to non-Army technology bases and assessing needs, opportunities, and expected returns to the Army resulting from the sharing of technology bases with non-Army entities. The following sections describe proposed research methodology for each of these phases in turn.

### **Phase I: Development of a Prototype System for Matching Technologies with Army ESOH Needs**

Phase I of the proposed research has as its primary goal finding an answer to the following research questions:

- What procedures are used by the Army to identify ESOH needs, and can those procedures be improved? Do the procedures effectively identify the set of all ESOH needs likely to be faced by the Army?
- What is the set of ESOH needs recognized at present by the Army, and how can those needs be expressed in a way that enables their requirements to be compared to the capabilities of available technologies?
- What is the set of technologies presently available to the Army for addressing non-ESOH needs, and how can the capabilities of those technologies be expressed in a way that enables them to be compared to the requirements of unmet ESOH needs?
- Is there a systematic and efficient matching mechanism for predicting the goodness of fit between unmet ESOH needs and the capabilities of Army technologies? If so, what steps need to be taken to develop and institutionalize that mechanism?

The specific problem formulation used in this white paper is as follows: given a technology, identify potential applications for using it to solve ESOH problems. The problem can also be articulated in inverse form: given an ESOH problem, identify potential technologies that may be able to solve it. As articulated, this problem can be abstracted as a pattern matching problem, in which technologies and ESOH problems

each represent patterns between which there is some correlational linkage that represents the degree of "fit" between problem and technology. In the case of a good fit, the technology has a high likelihood of representing a potential solution for the problem. A bad fit correspondingly means that the technology is not likely to be able to be applied to solve the problem. The goal of Phase I of the research is to develop a prototype system for identifying problems that have a good fit for a given technology, or conversely, technologies that have a good fit for a given ESOH problem. Specific objectives are:

- 1) to identify data structures that can adequately represent the features of technologies and problems such that degree of fit can be established
- 2) to identify a pattern matching method that can calculate a value for degree of fit between technology and problem
- 3) to locate or create databases of ESOH problems and supplement the records in these databases with fields that describe the features of those applications necessary for applying the pattern matching method
- 4) to locate databases describing technologies developed with Army funding and supplement the records in these databases with fields that describe the features of those technologies necessary for applying the pattern matching method
- 5) to develop an automated algorithm to peruse both databases (items 3 and 4) and recommend new matches between technologies and problems according to a goodness of fit statistic

The following sections describe two primary research tasks proposed to achieve these objectives: assessment of Army ESOH needs, and review of the Army technology base. The expected outcome of this phase of the research is a prototype algorithm for matching available technological solutions to the Army's ESOH problems and predicting the goodness of fit for each identified match. This goodness of fit statistic is a predictor of the likelihood that the solution will be able to be adapted to successfully address the identified problem.

### ***Task I-1: Army ESOH Needs Assessment***

The first task of Phase I involves assessing the ESOH needs of the Army via articulation and review of the processes presently used for needs identification. The scope of the proposed research is limited only to ESOH needs presently identified by the Army; prediction of likely future ESOH needs is outside the scope of the work, although it may be addressed in follow-ons to the proposed work. Likewise, identification of the ESOH needs of other federal agencies, the public, or the private sector is not part of this task, but instead will be addressed in Phase II of the research as part of the generalization of the outcome of Phase I.

Specific questions to be answered in this task include:

- How do ESOH needs get identified within the Army organizational structure? Who typically recognizes that a need exists? Who is responsible for articulating that need, and in what form is it articulated?

- How do ESOH needs get passed up through the chain of command and brought to the attention of decision makers who allocate resources for their solution? How, if at all, is the articulation and scope of the needs changed as it passes through the organization?
- At what point, if any, is a search performed for existing solutions or strategies to address the identified need? If such a search is performed, how is it executed? What is its typical scope, and how is it limited by organizational and resource constraints?
- How are ESOH needs prioritized for the purposes of allocating resources for their solution? What are the explicit and implicit criteria used to prioritize problems?
- What is the set of ESOH needs that are presently unmet within the Army's needs identification organizational structure?
- What is the proportion and nature of ESOH problems that are routinely solved via variant design without the need for adaptive or original solutions? How are these problems different from those that require adaptive or original solutions? What is the proportion and nature of ESOH problems requiring adaptive or original solutions that are presently queued within the resource allocation process and remain unmet? What proportion of ESOH needs are presently unmet but for which solution development is actively in progress?

As part of answering these questions, a hypothetical classification of ESOH needs is proposed:

- Needs for which a solution exists (variant design), and that are similar to the original need that initiated design of the solution
- Needs for which an existing solution can be adapted (adaptive design), although that need is not the original reason for which the solution was designed
- Needs for which a solution is presently unknown (original design) and which will require research for the development of a viable solution

In the first two cases, the agent identifying the need may or may not be aware of the existence of the solution. An additional hypothesis to be tested in this research task is that the awareness of potential solutions by the agent who identifies an ESOH need is inversely proportional to the likelihood of a request by that agent for development of an original solution. In parallel, this research task will also involve testing the hypothesis that the likelihood of identifying an applicable variant or adaptive design opportunity decreases as a need is passed up through the chain of command to receive allocation of resources.

Three subtasks are proposed to achieve the goals of Army ESOH needs assessment:

Subtask I.1a: Review the set of Broad Area Announcements (BAAs), Requests for Proposals (RFPs), and other formal solicitation of solutions generated by the Army for the past year to identify ESOH-related problems that require solution. In addition, review selected strategic planning and policy documents recommended by the Army

Environmental Policy Institute to identify other ESOH needs that may supplement the identified set. The expected outcome of this subtask is a list of ESOH needs presently identified by the Army.

Subtask I.1b: Conduct semi-structured interviews and protocol analysis at all levels of command between the agent who identifies an ESOH need and the agent who is responsible for allocating resources for the solution of that problem. Establish a representation of the needs identification and resource allocation processes that identifies any information or resource bottlenecks, task responsibilities, and areas of potential improvement. The expected outcome of this subtask is a procedural map of the process of needs identification and resource allocation for the solution of ESOH problems in the Army. An additional outcome of this task is an estimate of the direct cost and resource impacts of the present Army process for generating solutions to ESOH needs.

Subtask I.1c: Via consultation with ESOH domain experts, establish a functional or topical classification of the list of ESOH needs of the Army. Via facilitated discussion and protocol analysis of domain experts, extract a set of features that can be used to characterize and classify the set of ESOH problems with the intent of matching them to potential solutions. The expected outcome of this subtask is a feature-based description of Army ESOH needs that can be mapped into a functional classification.

The ultimate outcome of Task I.1 is a feature-based characterization of Army ESOH needs that can be used as a pattern for matching with potentially viable non-ESOH technologies. The process of establishing a feature-based characterization for technologies is described in the next section.

### ***Task I-2: Army Technology Base Review***

The second task of Phase I involves reviewing the Army's technology base to develop a feature-based representation of Army technologies that can be used for pattern matching with Army ESOH needs. Review of the technology base of other federal agencies, the public, or the private sector is not part of this task, but instead will be addressed in Phase II of the research as part of the generalization of the outcome of Phase I.

Specific questions to be answered in this task include:

- How is a technology development project initiated by the Army organizational structure? Who articulates the scope of work for technology development? Who authorizes a request for proposals?
- How is a technology development project executed by a typical Army laboratory or contractor? What proportion of technology development is original design? What proportions are adaptive or variant design?
- To what degree, if any, does a technology developer for the Army execute a search for potential solutions to the problem in question that could be varied or adapted to meet the need?
- To what degree does the technology development process rely on research proposals from the original developer of candidate technologies? How is this reliance limited by the technology developer's knowledge of the Army's

ESOH needs? If it exists, how might this informational bottleneck be ameliorated?

- What is the set of Army-sponsored technologies that presently exist? What is the set of technologies that are presently under development or over the horizon? What, if any, databases exist that describe these technologies? What are the strengths and weaknesses of these databases?
- How can Army-sponsored technologies be expressed in terms of features that permit pattern matching with the characterization of ESOH problems faced by the Army? What features should be used to characterize those technologies?
- How might an algorithm be developed to assess goodness of fit between technologies and ESOH needs that can serve as a basis for recommending opportunities for the adaptive design of solutions to ESOH problems?

As part of answering these questions, a hypothetical classification of technologies is proposed:

- Mature technologies that have been tried and successfully applied in multiple domains
- Existing but immature technologies that have not been applied in any domains besides the one for which they were originally designed
- Emerging technologies that are still in the development and refinement process; may not have been successfully applied yet in the domain for which they were originally designed
- Over the horizon technologies that are still in the research and development stage, for which a problem domain has been identified and articulated
- Conceptual technologies that have been proposed by technology developers in response to RFPs or BAAs but are not presently funded for research and development

Each of these classes of technologies hold potential for solving ESOH problems, particularly the second and third classes of immature and emerging technologies. These technologies are ripe for efficient adaptive application to ESOH problems, since the costs of their original design have already been borne by some other funding source. The fourth and fifth categories, over the horizon and conceptual technologies, can also serve as promising sources of ideas for solving ESOH problems, although they may require higher levels of funding to be successfully applied. Mature technologies, while still holding some potential for addressing ESOH problems, are less likely to be transferable to new domains, since by definition they have already been explored as solutions in multiple domains.

Five subtasks are proposed to achieve the goals of Army technology base review:

Subtask I.2a: Identify and review both internal Army databases and external databases (such as the Radius database developed by Rand) to identify: 1) a set of Army-sponsored technologies in all domains of application; and 2) the fields used to characterize and describe those technologies in their respective databases. The expected outcomes of this

subtask are a list of Army-sponsored technologies and a set of fields used in existing databases to characterize those technologies.

Subtask I.2b: Conduct semi-structured interviews and protocol analysis with Army-sponsored technology developers to assess the explicit and implicit processes they use to develop and characterize their technologies. Establish a representation of the Army-sponsored technology development and reporting processes that identifies any information or resource bottlenecks, task responsibilities, and areas of potential improvement. The expected outcome of this subtask is a procedural map of the process of technology development and reporting used by Army-sponsored technology developers. An additional outcome of this subtask is a representation of the features of technologies used by their developers in reporting and describing those technologies.

Subtask I.2c: Via consultation with ESOH domain experts, establish a functional or topical classification of the list of Army-sponsored technologies. Via facilitated discussion and protocol analysis of domain experts or review of historical cases of successful technology transfer, extract a set of features that can be used to characterize and classify the set of technologies with the intent of matching them to Army ESOH needs. The expected outcome of this subtask is a feature-based description of Army technologies that can be mapped into a functional classification.

Subtask I.2d: According to the specific nature of features identified for characterizing technologies and ESOH problems, select a pattern matching strategy that can be used to calculate a goodness of fit statistic between technology patterns and problem patterns. Pattern matching strategies can be identified in at least two possible ways: 1) via the use of robust, fuzzy regression techniques (such as an artificial neural network), to identify and articulate correlations from historical cases of successful matches; and 2) via protocol analysis or monitored facilitated discussion with domain experts from both ESOH and non-ESOH domains. The expected outcome of this subtask is a flowchart or other algorithmic representation of a pattern matching strategy that can calculate goodness of fit between problem and technology feature characterizations.

Subtask I.2e: Adapt existing technology and problem databases as necessary to add fields for representing features. Develop an executable algorithm that can search both databases in parallel, identify goodness of fit for each problem-technology combination, and highlight combinations with fit that exceeds a selected threshold. The expected outcome of this subtask is an automated or semi-automated system for identifying candidate technologies for adaptive application to matching ESOH problems. An additional outcome of this subtask is an assessment of the expected costs and benefits due to reduced technology development requirements of the pattern matching approach for identifying potentially viable adaptable technologies for solving ESOH problems.

The ultimate outcome of Task I.2 is a prototype system for matching Army-sponsored technologies with ESOH problems or needs that they could be adapted to address. Note that the Subtasks identified for Task 2 can and should be conducted in parallel with the subtasks for Task 1, particularly Subtasks 1c and 2c, since they involve the same set of ESOH domain experts that should be convened only one time if possible.

## **Phase II: Evaluation of the Benefits to the Army of Generalizing the Prototype System to the ESOH Needs and Technology Bases of Other Agencies**

Phase II of the proposed research involves attempting to generalize the pattern matching mechanism generated in Phase I to other technology bases developed by federal agencies and private sector organizations, and assessing the needs, opportunities, and expected returns of full scale generalization to the Army.

### ***Task II-1: Expansion of Approach to Other Technology Bases***

The first task of Phase II involves the steps necessary to generalize the pattern matching system previously limited in scope to Army ESOH problems and technologies. The scope of Phase II needs and technology bases includes a minimum of at least two other Federal agencies, and may include private sector needs and technology bases as well. The goal of this task is to attempt to generalize the outcome of Phase I to other ESOH need and technology bases, and to identify the challenges and investment requirements of full scale generalization.

Specific questions to be answered in this task include:

- What is the set of federal agencies that face ESOH needs and/or sponsor the development of technologies that could be applied to ESOH problems? What are the two (or more) agencies to whom generalization of the pattern matching system would return maximal benefits to the Army?
- How do the ESOH need sets and technology bases of these agencies compare to the ESOH needs and technology bases of the Army?
- What changes, if any, need to be made to the data representation used by other agencies in order to apply the pattern matching system developed for the Army? What, if any, changes need to be made to the pattern matching system itself?

An initial set of candidate federal agencies is proposed to include the Air Force, Navy/Marine Corps, Department of Energy, National Institute of Standards and Technology, National Science Foundation, and the Environmental Protection Agency. Each of these agencies is involved to some degree in the development of technologies, and most agencies in this set are directly affected by ESOH problems.

Three subtasks are proposed to achieve the goals of expanding the pattern matching approach to other federal agencies:

Subtask II.1a: Based on criteria of maximum anticipated return to the Army and maximum multiplier effects, identify two federal agencies from the set of candidate agencies to which the pattern matching system will be generalized. Review RFPs, BAAs, and other solicitations and documents of these agencies to identify a set of ESOH needs using the methods from Phase I. Likewise, review databases of technologies used by these agencies and identify a set of technologies that is representative of all technology development sponsored by these agencies. Compare both the set of ESOH needs and representative technologies with the set developed for the Army case. Identify and

characterize any differences. The expected outcomes of this subtask are a list of ESOH needs and technologies for the two additional federal agencies, and an assessment of the differences between these data sets and the Army data set from Phase I.

**Subtask II.1b:** Based on the differences in initial data sets identified in Subtask II.1a, identify modifications to the problem and technology feature representations and pattern matching algorithm used in the prototype system, and articulate the specific tasks necessary to complete the modifications. Evaluate the costs of system modification vs. the anticipated benefit to the Army of having a larger available data set of ESOH needs and technological solutions. The expected outcome of this subtask is a set of specific research tasks necessary for generalizing the pattern matching system from Phase I to other federal agencies via adaptation of the system itself. An additional outcome of this task is an estimate of the costs and benefits to the Army of generalizing the system via adaptation of the system to the format of existing databases.

**Subtask II.1c:** In parallel with Subtask II.1b, identify the requirements that would be necessary to adapt the databases of needs and technologies presently used by other federal agencies to use the prototype pattern matching system developed in Phase I in its present state. Evaluate the costs of database modification vs. the anticipated benefit to the Army of having a more applicable data set of ESOH needs and technological solutions. The expected outcome of this subtask is a set of specific research tasks necessary for generalizing the pattern matching system from Phase I to other federal agencies via modification of the databases of those agencies. An additional outcome of this task is an estimate of the costs and benefits to the Army of generalizing the system via agency database modification.

The ultimate outcome of Task II.1 is an analysis of the requirements, costs, and benefits of generalizing the pattern matching system from Phase I to apply to other federal agencies. The process of evaluating system needs, opportunities, costs, and benefits and developing recommendations for technology base sharing is described next.

### ***Task II-2: Assessment of Needs, Opportunities, and Expected Returns of Technology Base Sharing***

The second task of Phase II involves evaluating the potential of the pattern matching approach for improving the performance of finding solutions to ESOH problems, as compared to existing mechanisms for solving ESOH problems identified in Phase I. As described in the first part of this proposal, metrics of solution performance include minimizing cost of finding a viable solution, or increasing the number of ESOH problems that can be solved for a given cost. The scope of this task includes a separate comparative assessment of both the Army-specific and generalized systems to the traditional processes of ESOH problem solution.

Specific questions to be answered in this task include:

- What are the costs and benefits of finding solutions for ESOH problems using default solution procedures identified in Phase I?
- What are the costs and benefits of finding solutions for ESOH problems using the Army-specific pattern matching system developed in Phase I? Does this

process for solution identification perform better in terms of cost and other performance metrics than the default procedure presently in use?

- What are the costs and impacts of finding solutions for ESOH problems using the generalized pattern matching system developed in Phase II? How do these costs and benefits compare with the Army-specific system? Is the additional expense of generalization justified in terms of return to the Army?
- What are additional needs and opportunities for improvement, both in terms of organizational SOPs and with respect to the pattern matching system, that should be addressed in future research to further improve the process of finding solutions for ESOH needs?

Three subtasks are proposed to achieve the goal of assessing the needs, opportunities, and returns of technology base sharing:

Subtask II.2a: Identify a representative set of unmet ESOH needs presently faced by the Army. For each need, identify three similar installations that are facing the same problem. Obtain permission and staff buy-in to use these installations as test cases for evaluating the efficacy of the pattern matching system. The expected outcome of this subtask is a set of representative and comparable test cases for evaluating the relative performance of the three approaches to ESOH problem solution.

Subtask II.2b: Randomly select one of the three cases to be trained in the application of the Army-specific system, and another to be trained in the use of the generalized system. Develop and execute training to relevant personnel in these two cases. Monitor the direct and indirect costs and benefits of each strategy in the three cases. Repeat in other ESOH instances to increase confidence in findings until either convergence or divergence of findings is identified. The expected outcome of this subtask is a set of case studies and cost/benefit data that provide a basis for comparing the relative performance of the three approaches. An additional outcome of this subtask is a set of training materials for use of the pattern matching systems.

Subtask II.2c: Prepare a final report and briefing to describe the findings of the comparative analysis. Include specific recommendations to address needs and opportunities identified for each of the three approaches. Based on the findings of the comparative analysis, recommend the best performing of the three approaches, and identify specific tasks and requirements for full scale implementation of this approach to finding solutions for ESOH problems. The expected outcome of this subtask is a final project report and briefing containing the findings of the comparative analysis, recommendations for improving the efficiency and effectiveness of each of the three approaches, and recommendations for full scale deployment of the best performing approach.

The ultimate outcome of Task II is a recommendation to the Army of an approach to finding solutions for ESOH problems that is supported by cost-benefit analysis and documented in a final project report and briefing.

## CONCLUSIONS AND RECOMMENDED ACTIONS

The research proposed in this white paper represents a potentially significant contributor toward increasing the effectiveness and efficiency of finding solutions to ESOH problems faced by the Army and other federal agencies. Pending successful completion of the proposed research and development, testing, validation, and economic justification of the proposed pattern matching system, this project could have significant impacts in improving technology transfer for non-ESOH applications as well.

Given the documented significance of ESOH problems to the Army and other federal agencies as well as the ever-prevalent conditions of too many problems to be solved with constrained resources, we recommend executing Phase I of the proposed research to determine if a basis exists for developing a pattern matching approach for finding viable solutions to Army problems. The recommended scope of Phase I is limited to either a scope of ESOH problems in general, or to a subset of ESOH problems with significant potential for generalization. Pending successful demonstration of a Phase I system, cost benefit analysis should be performed as described in Phase II above, to support a decision of whether generalization of the pattern matching system to other agencies or problem types is justified in terms of return to the Army on its investment in the system.

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