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A Research and Development Investment Portfolio for Diminishing Manufacturing Sources and Material Shortages

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Executive Summary

The objective of this effort was to develop a diminishing manufacturing sources and material shortages (DMSMS) research and development (R&D) portfolio for potential investment. The work was sponsored by the Defense Logistics Agency (DLA) Research and Development Office in conjunction with the Office of the Secretary of Defense's Obsolescence/DMSMS Program Manager in the Defense Standardization Program Office.

This document uses the term *fields of study* to designate the DMSMS investment areas. Fields of study do not equate to individual R&D projects. Fields of study represent areas where individual DMSMS R&D projects could be developed as a result of a future Request for Information (RFI), Broad Area Announcement (BAA), or other similar mechanisms. To avoid difficulties with prioritization, however, fields of study should not be too broad. Consequently, this effort identified fields of study that are just one level above individual R&D projects. A key defining characteristic is that a field of study should encompass a small number of technology areas where R&D efforts are needed to advance the state of the art in a way that will enhance the DMSMS community's ability to do its job.

In fact, two different portfolios were developed. The management operations portfolio includes research on identifying what areas should be monitored for DMSMS and then on determining cost-effective resolutions. The resolutions portfolio consists of research on specific solutions to DMSMS technical issues in contrast with the process focus of management operations.

The IDA team facilitated the participation of subject matter experts from all of the Military Departments and from outside DoD to help develop the portfolios. Two teams were formed—one for management operations and one for resolutions. The teams used a five-step approach: generating initial field of study lists, preparing factual descriptions of each field of study, peer reviewing the descriptions, finalizing the descriptions, and prioritizing the fields of study. Tables 1 and 2 below show the resulting prioritized fields of study for DMSMS management operations and resolutions respectively.

Table 1. Prioritized DMSMS Management Operations Fields of Study

Field of Study	Priority
Forecasting hardware end-of-life	High
Forecasting supportability impacts of DMSMS	Medium-high
Technology refresh planning	Medium-high
Estimating resolution costs	Medium
Prioritization of DMSMS issues	Medium
Development and validation of parts lists needed to manage DMSMS issues	Medium
Forecasting software end-of-life	Medium-low
DMSMS data visualization	Low
Technical data package (TDP) modernization	Low
DMSMS parts statusing process improvement	Low

Table 2. Prioritized DMSMS Resolutions Fields of Study

Field of Study	Priority
Reverse engineering – electronic assemblies and printed circuit boards	High
Additive repair	High
Application specific integrated circuits (ASICs)	Medium-high
Reverse engineering – mechanical and other	Medium-high
Field programmable gate arrays (FPGAs)	Medium
Resolution cost reduction based on identification and exploitation of common technology	Low
Better use of reclaimed or salvaged items	Low

These tables use the words "low," "medium," and "high" to reflect priority. It is important to understand that a low priority does not imply that a field of study should not be pursued. All fields of study were developed because subject matter experts agreed on their importance to the DMSMS community. Viewed another way, all these fields of study will benefit DMSMS prevention and mitigation, though some are assessed to have greater and more immediate payback.

For this reason, all these fields of study should be investigated further. They should be integrated into the appropriate portfolios in DLA's R&D Office corresponding to their subject matter, specific projects should be formulated, and ultimately the projects should executed by the DLA R&D Office, or perhaps by other organizations as funding opportunities materialize, taking into account the other priorities of the executing organization. While efforts should be made to formulate and fund DMSMS R&D projects along the lines of the priorities established in this document, it may be the case that funding will become available in an R&D portfolio that does not correspond to the highest priority field of study. In such a circumstance, DLA should pursue projects corresponding to the funding opportunities.

Additional due diligence is required for further development of specific projects. While a variety of subject matter experts were involved in the formulation, review, and prioritization of the fields of study, a more comprehensive review should be conducted. Before creating specific projects, DLA should thoroughly research how these fields of study complement other existing research. Such efforts should be performed first on those fields of study where funding opportunities are more likely.

Contents

1. Introduction

A. Background

The objective of this effort was to develop a prioritized portfolio of diminishing manufacturing sources and material shortages (DMSMS) research and development (R&D) areas for potential investment. This document uses the term *fields of study* to designate the DMSMS investment areas. The work was sponsored by the Defense Logistics Agency (DLA) Research and Development Office in conjunction with the Office of the Secretary of Defense's Obsolescence/DMSMS Program Manager in the Defense Standardization Program Office.

Fields of study, as used in this document, do not equate to individual R&D projects. Fields of study represent areas where individual DMSMS R&D projects could be developed as a result of a future Request for Information (RFI), Broad Area Announcement (BAA), or other similar mechanisms. To avoid difficulties with prioritization, however, fields of study should not be too broad. Consequently, this effort identified fields of study that are just one level above individual R&D projects. A key defining characteristic is that a field of study should encompass a small number of technology areas where R&D efforts are needed to advance the state of the art in a way that will enhance the DMSMS community's ability to do its job.

R&D is a necessary and important component of overall DMSMS-related activity. According to the official Department of Defense (DoD) DMSMS guidance[1], "a DMSMS issue is the loss, or impending loss, of manufacturers or suppliers of items, raw materials, or software." Furthermore, "DMSMS management is a multidisciplinary process to identify issues resulting from obsolescence, loss of manufacturing sources, or material shortages; to assess the potential for negative impacts on schedule or readiness; to analyze potential mitigation strategies; and then to implement the most cost-effective strategy."

R&D is specifically important to DMSMS management for two major reasons.

- *To improve DMSMS management operations.* DMSMS issues are inevitable. Effective DMSMS management operational processes identify potential issues as early as possible to maximize the window of opportunity for resolving them before they impact readiness or a production schedule. In addition, more low-

[1] SD-22, *Diminishing Manufacturing Sources and Material Shortages: A Guidebook of Best Practices for Implementing a Robust DMSMS Management Program*, Defense Standardization Program Office, January 2016.

cost resolutions are generally available the earlier an issue is identified. Early detection of issues and associated mitigation activities are enabled by efficient management operations, accurate end-of-life and impact forecasting, improved forecasting of technological changes, better understanding of costs, convincing presentations to decision makers, and obtaining and using validated data. Consequently, R&D in these subject areas offers opportunities to minimize the ill effects of DMSMS.

- *To reduce the cost and increase the speed of implementing resolutions to DMSMS issues.* The hierarchy of resolutions to DMSMS issues ranges from the use of approved items, to repair and reclamation, to the use of substitute items, to the development of a new sources, to reverse engineering and redesign at the item level or a higher levels of assembly. Some lower-cost resolutions may not be feasible (e.g., there may be no approved items or repair or reclamation may not be economical). Higher-cost resolutions are labor intensive and may take a long time to implement. R&D in these subject areas offers opportunities to increase the feasibility of lower-cost resolutions and improve the efficiency of reverse engineering and other redesign-related activities.

Because these two principal reasons for conducting DMSMS management R&D implied two very different R&D directions, fields of study were developed separately for DMSMS management operations and for DMSMS resolutions.

B. Approach

IDA facilitated the participation of subject matter experts from all of the Military Departments and from outside DoD as well to help develop the portfolio. Two teams were formed—one for management operations and one for resolutions. Team members represented one or more of the following:

- Centralized DMSMS management service provider,
- Engineering activity,
- Prototyping facility,
- Supply chain organization,
- Technology center,
- University.

The teams used a five-step approach: generating initial field of study lists, preparing factual descriptions of each field of study, peer reviewing the descriptions, finalizing the descriptions, and prioritizing the fields of study. Each of these steps is summarized below.

- *Generating initial field of study lists.* The teams were asked to nominate field of study ideas. Some of the ideas were quite broad, whereas other ideas seemed to represent single projects. All of the ideas were discussed in facilitated telephone calls that resulted in some ideas being eliminated and other ideas being combined. Ultimately, a consensus initial list was formed.
- *Preparing factual descriptions of each field of study.* The factual descriptions were designed to answer a set of questions[2] that were intended to provide sufficient information for the fields of study to be reviewed and prioritized. The target length was two pages. Team members were not asked to research any field of study; they recruited subject matter experts[3] to prepare the descriptions, using a prescribed format, based on their proficiency with the subject. For some fields of study, more than one team member volunteered to recruit a subject matter expert. In those cases, every subject matter expert prepared a description. A lead for that field of study was identified to consolidate all of the inputs.
- *Peer reviewing the descriptions.* Team members were also asked to identify peer reviewers. The only constraint was that a peer reviewer should not have been a participant in the original drafting of the description. Peer reviewers were asked to comment on the accuracy and completeness, as well as raise additional questions that should be asked or points that should be clarified. There was no constraint on the length of the peer review. Hard-hitting, constructive comments were encouraged. In many instances, there were multiple peer reviews for a single field of study.
- *Finalizing the descriptions.* The IDA team revised the descriptions based on its own independent peer review and the comments of the other peer reviewers. The revised descriptions were then discussed with the original authors to finalize them.
- *Prioritizing the fields of study.* Each team developed a set of ranking criteria and associated weights. Team members rated the final field of study descriptions according to the criteria and generated overall prioritized field of study lists.

Sections 2 and 3 of this document provide more information on the last two steps of the approach. Section 4 presents conclusions.

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[2] The questions are shown in Section 2.

[3] An alphabetical list of all contributors to the descriptions and their peer reviews is shown in Appendix C without mention of their organizations.

2. Field of Study Descriptions

R&D for DMSMS management implied two very different fields of study. These were developed separately for DMSMS management operations and for DMSMS resolutions. The management operations portfolio includes research on identifying what areas should be monitored for DMSMS and then on determining cost-effective resolutions. The resolutions portfolios consists of research on specific solutions to DMSMS technical issues in contrast with the process focus of management operations.

The field of study descriptions are organized to answer the same set of questions for both management operations and resolutions. The questions were structured to identify the role and importance of a field of study to DMMS practitioners both currently and in the future after technological advancements had been made.

Several questions delved into the technological advancements themselves to identify the technologies involved, current R&D activities, potential future projects, and risks. One question dealt with the expected cost using the following scale:

- Minimal cost (<$100,000)
- Some cost ($100,000 to <$500,000)
- Moderate cost ($500,000 to <$1 million)
- Substantial cost ($1 million to <$2.5 million)
- Significant cost (>$2.5 million)

Another question inquired about the technological maturity using technology readiness levels[4] (TRLs) to designate when advancements might be achievable as follows:

- Short-term (tactical) <5 years, starting TRL 7–9
- Mid-term (strategic) 5-10 years, starting TRL 4–6
- Long-term (next generation) >10 years, starting TRL 1–3

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[4] Per Assistant Secretary of Defense for Research and Engineering, Department of Defense. *Technology Readiness Assessment (TRA) Guidance.* April 2011, http://bbp.dau.mil/doc/TRA%20Guidance%2013May11.pdf, TRL definitions are as follows: 1. Basic principles observed and reported; 2. Technology concept and/or application formulated; 3. Analytical and experimental critical function and/or characteristic proof of concept; 4. Component and/or breadboard validation in laboratory environment; 5. Component and/or breadboard validation in relevant environment; 6. System/subsystem model or prototype demonstration in a relevant environment; 7. System prototype demonstration in an operational environment; 8. Actual system completed and qualified through test and demonstration; 9. Actual system proven through successful mission operations.

A. Management Operations Fields of Study

Table 2-1 shows the final fields of study for management operations along with a short summary of each one's technological focus. Full descriptions are included in Appendix A.

Table 2-1. DMSMS Management Operations R&D Fields of Study

Title	Focus
Forecasting hardware end-of-life	• Focus is on technologies and techniques that could be used to make improved estimates of the end-of-life of hardware items.
Forecasting software end-of-life	• Focus is on technologies and techniques that could be used to improve estimates of end of support for commercial-off-the-shelf (COTS), custom, or any combination thereof of firmware, middleware, wrappers, gateways, firewalls, application programs, or operating systems.
Estimating resolution costs	• Focus is on technologies and techniques that could be used to improve specific or average resolution cost estimates over the life cycle.
Forecasting supportability impacts of DMSMS	• Focus is on technologies and techniques to improve the determination of the timing, duration, and magnitude of the impact of DMSMS issues on subsystem and systems supportability, and mission success.
Technology refresh planning	• Focus is on technologies and techniques that can (1) improve estimates of when replacement technologies will be available and what those technologies are, and (2) identify optimal refresh strategies.
DMSMS data visualization	• Focus is on technologies and techniques to improve the collection, collation and communication of data or information associated with DMSMS issues, resolutions, and impact thresholds for weapon system supportability and mission capability.
Prioritization of DMSMS issues	• Focus is on technologies and techniques that improve decision making to determine which issue to address next; considerations include cost, mission criticality, impact date, etc.
Technical data package (TDP) modernization	• Focus is on technologies that can be used to convert between formats to produce a more readily usable TDP.
DMSMS parts statusing process improvement	• Focus is on technologies and techniques that reduce the manual effort required to status a part and make that effort as efficient and seamless as possible.
Development and validation of parts lists needed to manage DMSMS issues	• Focus is on technologies and techniques to enable proactive monitoring processes by improving (1) the development of parts lists, in cases where no bills of material are available and (2) the validation of bills of material (BOMs) to detect errors within BOM scrubbing processes.

DMSMS management operations begin with identifying the items to be monitored. In some cases, no parts list may be available, the parts lists may be incomplete, or there may be inconsistencies or other errors. The field of study for the "development and validation of parts lists needed to manage DMSMS issues" is aimed at these issues. Once the parts lists are developed, a predictive tool is used to identify the current status of parts (i.e., whether they are obsolete or not, and to forecast when parts may become obsolete). Three of the fields of study, "DMSMS parts statusing process improvement," "forecasting hardware end-of-life," and "forecasting software end-of-life" are applicable here.

The remainder of the management operations fields of study are all involved with determining the most cost-effective resolution to current and potentially future DMSMS issues.

- "Forecasting supportability impacts of DMSMS" can help determine whether a resolution is even necessary, and if it is, this field of study provides information about when the resolution must be implemented.
- "Technology refresh planning" provides complementary information. Knowing what technological changes are on the horizon, is a key consideration for determining when a resolution must be in place. Technology refresh planning also is a factor in the use of multi-step resolutions since there may be an interim resolution that must be in place until a technology refresh can be initiated.
- "Prioritization of DMSMS issues" addresses what issue should be resolved first.
- "Technical data package (TDP) modernization" provides technical information on what the resolution needs to be.
- "Estimating resolution costs" is a key element of cost-effectiveness.
- "DMSMS data visualization" can support all of the above by effectively portraying the information in a way that improves decision making.

B. Resolutions Fields of Study

Table 2-2 shows the final resolutions fields of study. It provides a short title and a brief synopsis of their technological focus. Appendix B contains the full descriptions.

Table 2-2. DMSMS Resolutions R&D Fields of Study

Title	Focus
Field programmable gate arrays (FPGAs)	• Focus is on hardware-, software-, and firmware-related technologies to improve bit stream analysis to deduce the functionality of the electronic item and other means of FPGA obsolescence mitigation.
Application specific integrated circuits (ASICs)	• Focus is on hardware-, software-, and firmware-related technologies to improve delayering and imaging techniques to deduce functionality of the electronic item.
Reverse engineering – electronic assemblies and printed circuit boards	• Focus is on technologies to improve function analysis and characterization to enable faster and lower cost reverse engineering of electronics items.
Reverse engineering – mechanical and other	• Focus is on technologies to improve function analysis and characterization to enable to enable faster and lower cost reverse engineering of non-electronics items including materials.
Additive repair	• Focus is on improving additive technologies for repairing items that are currently not economically repairable, as well as technologies to qualify and approve the results.
Resolution cost reduction based on identification and exploitation of common technology	• Focus is on data science and analysis technologies that enable identification and consolidation of existing obsolete and at-risk components by technology variant, or other identifying factor, leading to cost reduction through economy of scale manufacturing.
Better use of reclaimed or salvaged items	• Focus is on technologies to estimate remaining life, extract the desired items, or increase shelf life.

These fields of study are best understood in the context of the DMSMS resolution options as identified in the SD-22 as follows, roughly ordered from low cost to high cost.

- No solution required
- Approved item
- Life-of-need buy
- Repair, refurbishment, or reclamation
- Extension of production or support
- Simple substitute
- Complex substitute
- Development of a new item or source
- Redesign – next higher level of assembly
- Redesign – complex or system replacement

"Better use of reclaimed or salvaged items" and the "additive repair" fields of study are concerned with finding acceptable ways to use or repair existing assets to deal with the obsolescence. "Resolution cost reduction based on identification and exploitation of common technology" explores an approach for making a business case for a commercial company to keep production lines open longer in the context of the "extension of production or support" resolution in the SD-22. The remaining four fields of study are all concerned with reverse engineering, either for FPGAs, ASICs, electronic assemblies and boards, or mechanical and other items. Reverse engineering is often needed in the development of a new item or source if no technical data is available.

Team members discussed another resolutions field of study in microcircuit emulation. It was not included in this document because team members felt that the DLA R&D Office's efforts in that area were quite thorough.

3. Field of Study Prioritization

A. Prioritization Criteria

Table 3-1 and Table 3-2 contain the prioritization criteria for DMSMS management operations and resolutions fields of study, respectively. Subject matter experts were asked to score every field of study on each criterion using a scale of 1–10 where 10 is best and 1 is worst. The score was based on the descriptions given in Appendices A and B and on the subject matter experts' individual knowledge. Although the words are slightly different, the intent of the two sets of criteria is the same as are the relative weights among the criteria.

Table 3-1. Prioritization Criteria and Relative Weights for DMSMS Management Operations Fields of Study

Prioritization Criteria	Relative Weight
Magnitude of the potential impact to DMSMS management in terms of improving proactivity and ultimately reducing the cost of resolutions	30%
Likelihood of achieving the desired technical result (including both demonstration of value and readiness to implement)	20%
Extent to which the technical results would be integrated into multiple mainstream DMSMS management operations (i.e., this is the probability that there would be widespread adoption of the technical results in that most of the mainstream DMSMS management providers would spend the money to modify their processes and implement the changes)	20%
Likelihood that the technical results would be integrated into a mainstream DMSMS management operation (i.e., this is getting at the probability of there being a first adopter who will spend the money necessary to modify its processes and incorporate the technical results)	10%
Expected cost of the technical effort (the technical effort is completed when both the value has been demonstrated and implementation can begin)	10%
Magnitude of the potential reduction of DMSMS management operations cost	3.33%
Expected timeframe for achieving the desired technical result	3.33%
Expected timeframe when technical results would be integrated into mainstream DMSMS management operations	3.33%

The most important criterion is the magnitude of the potential impact, with a relative weight of 30%. The next criterion, at a relative weight of 20%, represents the likelihood that the expected technical result would be achieved. At weights of 20% and 10%, the third and fourth criteria pertain to the likelihood that the results would be used by multiple, or any, DMSMS management providers, respectively.

The remaining criteria are given a weight of 10% in total. For the resolutions fields of study, the criteria deal exclusively with time—one being the timeframe when the technical result would be achieved, and the second being the timeframe of widespread adoption. One additional criterion, the potential decrease in DMSMS management operations costs, is included for management operations fields of study.

Table 3-2. Prioritization Criteria and Relative Weights for DMSMS Resolutions Fields of Study

Prioritization Criteria	Relative Weight
Extent to which the cost of resolving an applicable DMSMS issue is likely to be reduced (due to the use of the new technology) and the extent of its applicability (i.e., the number of DMSMS cases that this field of study has the potential to affect)	30%
Likelihood of achieving the desired technical result (including both demonstration of value and readiness to implement)	20%
Likelihood that the capability would be established in a commercial company or an organic facility (i.e., this is getting at the probability of there being a first adopter who will spend the money necessary to be in a position to offer the technical capability to customers)	20%
Extent to which the capability would be established in multiple commercial companies or organic facilities (i.e., this is the probability that there would be widespread adoption of the capability in commercial industry or organic facilities who would spend the money necessary to be in a position to offer the technical capability to customers)	10%
Expected cost of the technical effort (the technical effort is completed when both the value has been demonstrated and implementation can begin)	10%
Expected timeframe for achieving the desired technical result	5%
Expected timeframe when the capability would be established in commercial industry or organic facilities	5%

B. Prioritization Results

In the discussion that follows, priority is described as “low,” “medium,” or “high.” It is important to understand that a low priority does not imply that a field of study should not be pursued. All fields of study were developed because subject matter experts agreed on their importance to the DMSMS community. Because different people implicitly apply an absolute score in a different way, the absolute scores of each subject matter expert involved in the prioritization (prioritizer) were converted to their relative rankings (from one to ten). These relative rankings were used to prioritize the fields of study.

Five organizations (albeit slightly different ones) were represented on the teams that created the descriptions for both DMSMS management operations and resolutions fields of study. Subject matter experts from these organizations were used to prioritize the fields of study. To obtain viewpoints of a wider cross section of perspectives, subject matter experts from additional organizations also participated in the prioritization process. In total, there were nine management-operations subject-matter-expert prioritizers and eight resolutions subject-matter-expert prioritizers.

Four factors were used to prioritize the fields of study.

1. The sum of the rankings from multiple reviewers.
2. The number of times that a field of study was ranked in the top four (for management operations) or three[5] (for resolutions).
3. The number of times a field of study was ranked in the top "X" where X represents a natural breakpoint in the weighted scores of the prioritizers.[6] For example, if for one prioritizer, the weighted score of the fourth highest-ranked field of study was much lower than the weighted score of the third highest-ranked field of study, then X for that prioritizer was three. If for another prioritizer, the weighted scores of the third and fourth highest-ranked fields of study were similar and much better than the weighted score of the fifth highest-ranked field of study, then X would be four for that prioritizer.
4. The average ranking for a field of study in cases where it was ranked in the top four (for management operations) or three (for resolutions).

Using the first three factors for the management operations fields of study, "forecasting hardware end-of-life" ranked far better than the others and was given high priority. Four fields of study consistently ranked lower than the others as follows:

- Forecasting software end-of-life
- DMSMS data visualization
- TDP modernization
- DMSMS parts statusing process improvement

None of them were in the top "X" more than three times, and the sum of their rankings was well below the others. Since the sum of the rankings for "forecasting software end-of-life" was six points better than the next worse one, it was given a medium-low priority and the other three were given a low priority.

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[5] Only the top three were identified because there were seven fields of study for resolutions as compared to 10 fields of study for management operations.

[6] For management operations: five prioritizers had a natural breakpoint of four, two had a natural breakpoint of five, and the remaining two had a natural breakpoint of six. For resolutions: four prioritizers had a natural breakpoint of three and four had a natural breakpoint of four.

The first three prioritization factors were not sufficient to distinguish between the remaining five fields of study. The last prioritization factor broke the tie. “Forecasting the supportability impacts of DMSMS” and “technology refresh planning” clearly dominated the other three in that regard and were given a priority of medium-high and the remainder were medium. Table 3-3 shows priorities for the management operations fields of study.

Table 3-3. Prioritization of the Management Operations Fields of Study

Field of Study	Priority
Forecasting hardware end-of-life	High
Forecasting supportability impacts of DMSMS	Medium-high
Technology refresh planning	Medium-high
Estimating resolution costs	Medium
Prioritization of DMSMS issues	Medium
Development and validation of parts lists needed to manage DMSMS issues	Medium
Forecasting software end-of-life	Medium-low
DMSMS data visualization	Low
Technical data package (TDP) modernization	Low
DMSMS parts statusing process improvement	Low

Using just the first prioritization factor for the resolutions fields of study was sufficient to identify two fields of study with high priority—

- Reverse engineering – electronic assemblies and printed circuit boards, and
- Additive repair;

and two fields of study with low priority—

- Resolution cost reduction based on identification and exploitation of common technology, and
- Better use of reclaimed or salvaged items.

The second and third ranking criteria were used to differentiate among the three remaining fields of study. “Application specific integrated circuits (ASICs)” and “reverse engineering – mechanical and other” were ranked as medium-high and “field programmable gate arrays (FPGAs)” was ranked as medium.

Table 3-4 portrays the results. The fourth ranking criterion did not change anything further.

Table 3-4. Prioritization of the Management Operations Fields of Study

Field of Study	Priority
Reverse engineering – electronic assemblies and printed circuit boards	High
Additive repair	High
Application specific integrated circuits (ASICs)	Medium-high
Reverse engineering – mechanical and other	Medium-high
Field programmable gate arrays (FPGAs)	Medium
Resolution cost reduction based on identification and exploitation of common technology	Low
Better use of reclaimed or salvaged items	Low

4. Conclusions

All of these fields of study should be investigated further. Though some are listed as "low" priority, all represent important advancements to DMSMS management and the resolution of DMSMS issues. The fields of study should be integrated into the appropriate portfolios in DLA's R&D Office corresponding to their subject matter. Specific projects should be formulated, and ultimately the projects should be executed as funding opportunities materialize while taking into account the other priorities of the R&D Office. Some projects may be executed by other R&D organizations.

The development of specific projects requires additional due diligence. While a variety of subject matter experts were involved in the formulation, review, and prioritization of the fields of study, more comprehensive efforts should be conducted to thoroughly research how these fields of study complement other existing research. As part of such a due diligence research effort, an RFI to government, industry, academia, and other non-profit entities should be used to support a decision on next steps and ultimately project development.

While efforts should be made to perform due diligence, formulate, and fund DMSMS R&D projects in an order consistent with the priorities established in this document, it may be the case that funding will become available in an R&D portfolio that does not correspond to the highest priority field of study. In such a circumstance, projects corresponding to the funding opportunities should be pursued.

Once projects have been fully defined, a BAA, Request for Proposal (RFP), or an equivalent mechanism should be used to put projects on contract. Since any type of organization could be in a position to execute any of the projects, the mechanism used to compete projects should not put limitations on who can do the work.

Appendix A
Diminishing Manufacturing Sources and Material Shortages (DMSMS) Management Operations Fields of Study Summaries

Forecasting Hardware End-of-Life

Focus

Focus is on technologies and techniques that could be used to make improved estimates of the end-of-life of hardware items.

Why is the field of study important to DMSMS management?

Forecasting the end-of-life for hardware items is useful for guiding initial part selection, defining proactive management actions, and as a critical input to strategic DMSMS solutions. (See the technology refreshment field of study.)

What is the current status of how this field is used by the DMSMS community?

Hardware item end-of-life forecasting has been performed for over 20 years. The methods used to create the forecasts can be categorized as ordinal-scale-based scoring methods and data mining of the historical record (hybrids of the two can also exist). Various versions of both of these methods are currently incorporated into commercial databases. Commercial implementations generally do not report uncertainties or confidence levels for their forecasts and primarily focus on standard piece-parts (as opposed to higher-level assemblies and non-standard parts).

Where are advancements needed? What are the technologies involved?

Forecasting obsolescence of hardware items can take several forms (all of which are different and useful): obsolescence date, procurement life (or time-in-market), or a risk of obsolescence in a specific period of time. All of these forecast forms should be accompanied by an associated uncertainty or confidence estimate. Specific advancement areas include:

- Better standard piece-part forecasting (incorporation of machine learning approaches).
- Non-standard piece-part forecasting.
- Mechanical (non-electronic part) hardware forecasting.
- Assessing the accuracy of the commercial database forecasts – methodology and standardization needed.
- Forecasting for commercial-off-the-shelf (COTS) assemblies consisting of a combination of multiple parts and software.

- Fusion of historical records to include data-mining and precursor observations (price changes, distributor changes, etc.).
- Modeling, forecasting, and monitoring critical human skills where near-term changes or shortages could lead to hardware DMSMS issues.
- Modeling, forecasting, and monitoring sole source supplier (financial or other) vulnerability that could lead to that supplier leaving the market and thereby generating hardware DMSMS issues.
- Combined hardware and software life-cycle forecasting (in this context, software refers to embedded software). Hardware and embedded software life cycles overlap, but for COTS they may not be synchronized.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?
Better forecasting implicitly improves all DMSMS management and planning activities and will help to minimize the resolution cost and the impact. Articulating the accuracy of the forecasts (in some standard, well-defined way) will add value to the proactive management and strategic planning process and tools.

What R&D efforts are already underway for these technologies? Who is doing the work?
The Center for Advanced Life Cycle Engineering (CALCE; University of Maryland) and the University of Washington (with Naval Undersea Warfare Center (NUWC) Keyport) have performed research on data mining/machine learning forecasting techniques. Some preliminary versions of these techniques are in commercial databases.

For each of the technologies, what are the most important projects that could be initiated?
Developing a method to assess the accuracy of the commercial database forecasts is relatively short-term, requires minimal resources, and potentially has a high impact for proactive and strategic DMSMS management activities.

When could the advancements be expected?
Short-term (tactical), <5 years, starting technology readiness level (TRL) 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?
High likelihood of obtaining significant improvements over existing forecasting abilities if resources were directed at this activity.

What is the estimate of the cost of R&D efforts needed for this field of study?
Some cost ($100,000 to <$500,000).

Forecasting Software End-of-Life

Focus

Focus is on technologies and techniques that could be used to improve estimates of end of support for COTS, custom, or any combination thereof of firmware, middleware, wrappers, gateways, firewalls, application programs, or operating systems.

Why is the field of study important to DMSMS management?

Software is an integral part of any system being used today. While there are more concrete ways of determining when hardware goes obsolete (the product is no longer available for purchase), software does not behave in the same way. Software may also become obsolete as a result of upgrades to other software, end of software support, or changes to hardware. In addition, hardware can become obsolete if it has embedded software changes. Lastly, with the current market demand for new features, updates, upgrades to software, etc., frequent software updates should be expected. Since software can span multiple hardware platforms and have interactions with multiple software components, the impact on DMSMS management could be significant.

What is the current status of how this field is used by the DMSMS community?

Software obsolescence management is not common in the DMSMS management community. There has been some exploration into the problem of software obsolescence, but more work is needed.

Where are advancements needed? What are the technologies involved?

Forecasting software end-of-life is an incredibly complex task. Not only is it necessary to understand when the software itself will go obsolete, the relationships between hardware and the software components need to be detailed, as do the relationships between the different software components. For instance, will a new release of hardware create an obsolescence problem with the current software version or will a new release of a software package create an obsolescence problem in the current software being used?

When evaluating software obsolescence as part of DMSMS management, the big problem is data. The techniques used to evaluate software obsolescence, such as machine learning and graph theory, have advanced to the point where evaluating the relationships in software obsolescence (e.g., hardware to software components, software to software components, etc.) and creating forecasting models for software obsolescence are possible. To develop software obsolescence forecasting models, data from multiple systems on all type of software are needed. Examples of the necessary information include whether the software is obsolete, whether it is on a maintenance schedule or being phased out, what the software interacts with, and the type of software (e.g., operating system, embedded, application, etc.).

In addition, advancements monitoring and analyzing critical human skills where near-term changes or shortages could lead to software DMSMS issues are needed. There are situations where a DMSMS issue arises because the critical skills (e.g., expertise in a particular programming language) needed to support a software component are no longer available in the workforce. Similarly, monitoring and analyzing sole source supplier (financial or other) vulnerability that could indicate when that sole supplier will leave the market and thereby generate hardware DMSMS issues is another potential advancement area.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?
Not only would forecasting software obsolescence help plan for when updates to a new version should be made, but it can also indicate when to update a hardware component. Again, software updates may make certain hardware not reliable and when that is the case, appropriate changes to that hardware should be made.

Knowing when a necessary software component will be obsolete allows the user to plan around that eventuality. It will allow the user time to find a stable solution that can replace the current one that should be transferred over to a new system; it could also allow for testing of the new system before the current one is even obsolete. Overall, knowing when a software component will be obsolete can impact how system modifications (as well as DMSMS mitigation actions prior to the modifications) are planned and will help avoid future DMSMS problems.

What R&D efforts are already underway for these technologies? Who is doing the work?
NUWC Keyport is starting to look at forecasting software obsolescence. Other researchers from academia and private industry have begun to explore this issue.

For each of the technologies, what are the most important projects that could be initiated?
Data gathering is necessary to do any research for forecasting software obsolescence. This includes mapping the interactions between hardware and all software components, mapping all interactions between the different software components, and determining which software versions work with which hardware versions, etc. Once there is a dataset to work with, feasibility of forecasting software obsolescence can be examined.

When could the advancements be expected?
Forecasting software obsolescence is either a mid-term or long-term project, probably at TRL 4 but could be at TRL 3. There is a lot that needs to be accomplished before reaching the forecasting stage of this problem.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?
The principal risk is that forecasting software obsolescence is too complex a task. The large number of factors influencing software obsolescence limits how much software obsolescence forecasting can be accomplished.

What is the estimate of the cost of R&D efforts needed for this field of study?
The cost of R&D efforts is either a substantial cost ($1 million to <$2.5 million) or significant (>$2.5 million). Most likely, forecasting software obsolescence would be a

significant cost due to the amount of work that needs to be done before any forecasting can be accomplished.

Estimating Resolution Costs

Focus

Focus is on technologies and techniques that could be used to improve specific or average resolution cost estimates over the life cycle.

Why is the field of study important to DMSMS management?

Accurate resolution cost estimates are required to create budgets for DMSMS management programs, perform tradeoffs between different resolution approaches, and to support business cases that justify strategic approaches to DMSMS management. Without accurate resolution cost estimates, the appropriate resources for resolving DMSMS issues will not be allocated and cannot be put in place.

What is the current status of how this field is used by the DMSMS community?

Each organization has its own institutional knowledge associated with resolution costs. Efforts to standardize resolution costs have been generally confined to surveys that may have little or no basis in reality. The United Kingdom Ministry of Defense (UK MOD) has developed a tool that implements survey-based resolution costs along with system characteristics to determine DMSMS budgets – this may be a potentially useful approach, but only in so far as the resolution cost input data is reasonable and has some understood (i.e., measurable) accuracy. Lifetime buy estimators are primarily used to determine optimum buy sizes.

Where are advancements needed? What are the technologies involved?

- Resolution cost surveys, if used and continued, need to be more detailed. There could be as much as an order of magnitude variation in responses for the exact same resolution, not because the respondents are doing something different, but because the respondents do not have a clear understanding or consistent definition of what costs they are reporting. This problem has been previously pointed out, yet unfortunately people continue to use the resolution cost survey results for planning.
- In association with the resolution cost survey item above, determinations of how to gather, archive, and ultimately aggregate the relevant data resulting from normal DMSMS management operations are needed to support the development of cost-estimating relationships.
- Development of DMSMS resolution budgeting and bid evaluation tools for use in program planning. Such a tool will require the ability to better predict the mix of obsolescence resolutions types in use over time.
- Model obsolescence risk misclassification costs (i.e., develop an understanding of the costs of misclassifying a part as obsolete when it isn't and vice versa).
- Study tradeoffs involving "openness."[7] This is obviously larger than DMSMS, but being able to assess (quantify) the extent to which openness changes DMSMS

[7] Openness refers to open systems approaches (OSAs), which are used in conjunction with modular architecture, reuse, and harnessing of existing (COTS or proprietary) technologies to create more efficient design, increased competition among suppliers, more efficient innovation and technology

mitigation cost could bring more clarity to the business case for open systems beyond the ease of enhancing performance.

- The technologies involved are largely centered on the analysis of historical data. Machine learning and other data analytics methods are needed to ferret out trends within that data.
- Improved incorporation of DMSMS cost estimating tools in acquisition planning models and activities.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?
The benefits are better budgeting, better resource allocation, and better determination of the most cost effective resolution. A better understanding of resolution costs can also be used as a metric in evaluating proposals to resolve obsolescence. The payoff is more accurate programming information for both acquisition and sustainment and reduced time to generate the necessary information.

What R&D efforts are already underway for these technologies? Who is doing the work?
Miscellaneous models exist at the academic level; the next step for these models is to connect them with (or apply them to) real applications at real DMSMS management organizations. The UK MOD has funded Cranfield University to this end. NUWC Keyport is involved in predicting obsolescence, which could result in information that will be useful in budgeting.

For each of the technologies, what are the most important projects that could be initiated?
Bullets 1 and 2 in the advancements needed section: improved surveys and regular collection and analysis of case date.

When could the advancements be expected?
Short-term (tactical), <5 years, starting TRL 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?
High likelihood of obtaining significant improvements over existing resolution cost estimates if resources were directed at this activity. The risk is that Department of Defense (DoD) and the services do not buy into the need to collect this type of data. Unless there is a top-down directive to do so, there is little chance that programs will develop and initiate a uniform method of data collection.

What is the estimate of the cost of R&D efforts needed for this field of study?
Some cost ($100,000 to <$500,000).

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insertion, and modularization of qualification. However, OSA strategies require significant investment and may increase risk exposure. To determine if openness should be pursued, and to what degree, a quantitative model assessing the costs associated with openness is required.

Forecasting Supportability Impacts of DMSMS

Focus
Focus is on technologies and techniques to improve the determination of the timing, duration, and magnitude of the impact of DMSMS issues on subsystem and systems supportability, and mission success.

Why is the field of study important to DMSMS management?
The impact of DMSMS on the supportability (sustainability) of the system it is in extends beyond cost to system availability, readiness, and ultimately system retirement decisions. Cost issues aside, if the performance or availability of a critical system is impacted by DMSMS, knowing the timing of that impact (when it will occur and its duration) are critical to overall mission success. In addition, making business cases for subsystem technology refreshment (either as a standalone activity or in conjunction with a capability improvement) or ultimately system replacement requires an understanding of when the ability to support the subsystem or system ends.

What is the current status of how this field is used by the DMSMS community?
Some commercial database providers have attempted to create system health "dashboards" indicating the overall DMSMS status of the consolidated inventory of parts within a system. Others with a view into the inventories associated with multiple programs have built an understanding of how to merge end-of-life forecasts with inventory and demand to assess the need for implementing a resolution to mitigate a DMSMS issue.

Where are advancements needed? What are the technologies involved?
- End-of-Maintenance (EOM) Models – Given existing non-replenishable inventories, part demand, and part loss in inventory, EOM models forecast when maintenance can no longer be performed. They are used to support business cases for subsystem or system replacement.
- Supply Chain Prognostics and Health Management (PHM) – While supply chain health is a starting point, this area goes beyond health to also encompass prognosis, i.e., given the current state of health, the probability of success (survival) of the system's supply chain for some future period of time.
- Consolidated DMSMS forecasting (manufacturer end-of-life forecasting) coupled with existing inventory and demand to determine effective obsolescence and impact dates for parts.
- Models for determining the impact of DMSMS issues on system availability and readiness.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?
Improvement in forecasting opens the window for more proactive DMSMS management that includes regular planning to mitigate DMSMS issues before they occur, further extending the window of opportunity for avoiding an impact to a system and generally

enabling the consideration of lower cost resolutions. Ultimately, the payoff is better mission success.

What R&D efforts are already underway for these technologies? Who is doing the work?
There are academic research efforts underway developing end-of-maintenance models. Also, there is a large body of research on availability forecasting and optimization for systems, however, it is not supply chain driven.

For each of the technologies, what are the most important projects that could be initiated?
See advancements section.

When could the advancements be expected?
Mid-term (strategic), 5–10 years, starting TRL 4–6.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?
High likelihood of obtaining significant improvements over existing forecasting abilities if sufficient resources were directed at this activity.

What is the estimate of the cost of R&D efforts needed for this field of study?
Moderate cost ($500,000 to <$1 million).

Technology Refresh Planning

Focus

Focus is on technologies and techniques that can (1) improve estimates of when replacement technologies will be available and what those technologies are, and (2) identify optimal refresh strategies.

Why is the field of study important to DMSMS management?

The majority of the total cost of a system is realized during operations and sustainment, however, these costs are committed during the system's design and development phases. In order to maximize the impact of DMSMS management, it is critical to apply strategic sustainment planning principles during the design and development of the system and incorporate them into the Life Cycle Sustainment Plan.

One such principle is the use of planned, periodic design *refresh*[8] as an integral part of system maintenance. This principle is driven by a desire to sustain a system essentially unchanged from its original performance and functionality. In practice however, given a commitment to design refresh, it is not uncommon to add additional capability during refresh activities. Design refresh planning (DRP) not only depends on assumptions about the availability of newer parts/technology to replace obsolete (and soon-to-be obsolete) portions of a system, it is also constrained by technology-driven system upgrade roadmaps. DRP may extend beyond managing the replacement of individual parts to the concurrent management of hardware, software, and other relevant processes and materials.

DRP is a strategic approach to managing DMSMS that focuses on life-cycle cost minimization through life-cycle planning for the system. It generally involves the management of multiple DMSMS issues (e.g., multiple actual or impending obsolescence issues) in a single refresh activity and is used in conjunction with other DMSMS management approaches.

What is the current status of how this field is used by the DMSMS community?

DRP relies on upfront investments to avoid future cost; therefore, technology refresh planning is underused. Also, such strategic thinking with regards to DMSMS management is limited due to budget constraints, general DMSMS problem awareness, and the lack of involvement of the sustainment community in applying strategic sustainment planning principles in design. The DMSMS community is not solely responsible for design refresh (other organizations are making refresh decisions and controlling refresh funding), but it provides important input to design refresh planners.

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[8] Alternatively, *redesign* represents a desire to upgrade a system's performance or functionality through the incorporation of newer technology. Redesign is not a distinct field of study within DMSMS, since it represents a larger programmatic endeavor that is not primarily driven by DMSMS management requirements.

Where are advancements needed? What are the technologies involved?

- The form of current obsolescence forecasts is not necessarily conducive to DRP. DRP would benefit from procurement life (also referred to as time-in-market) forecasts for parts (in addition to obsolescence date or risk forecasting).
- Forecasting of disruptive technologies is needed to support design refresh (note, this needed advancement also appears in the "Forecasting hardware end-of-life" field of study).
- Refresh planning tools need to better aggregate and analyze existing logistics data and take integrated logistics support (ILS) and the broader DoD Acquisition Framework into account. This involves machine learning, database and application development, big data aggregation and analysis, and new DMSMS management techniques. This overlaps into the "Forecasting hardware end-of-life" field of study.
- DRP is arduous – it takes time, expertise and has a significant data overhead. Therefore, streamlined modeling capabilities would be beneficial. Streamlined modeling would be less general, but could still be very valuable, for example:
  - Non-simulation direct-calculation refresh planning approaches,
  - Refresh frequency determination (instead of refresh dates),
  - Operations research inspired approaches are needed.
- Configuration proliferation models and costs of supporting multiple configurations need to be included within technology refresh planning.
- Technology and DRP is not just for hardware. Approaches must accommodate hardware and software (and possibly other materials and human assets).
- Most DRP tools (and algorithms) are focused only on "refresh" (i.e., keeping the performance and functionality of the system approximately the same). Although the refresh and redesign communities are integrated in many program offices, the tools that support DRP (e.g., determining optimum refresh schedules) do not integrate refresh and redesign.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

DMSMS management teams, system designers, and Program Offices would have much greater opportunity to team with other activities that are directly affected by DMSMS in order to work various issues more effectively. This would result in significant improvements in operational availability and reductions in the total life-cycle cost of systems.

What R&D efforts are already underway for these technologies? Who is doing the work?

Discrete-event simulators exist (but they are arduous to use – require lots of data and modeling expertise). The Mitigation of Obsolescence Cost Analysis (MOCA) tool from CALCE at the University of Maryland is a well-known discrete-event, simulation-based DRP solution.

NUWC Keyport has developed the Obsolescence Management Information System (OMIS) database and applications and is conducting research on machine learning and meta-analysis tools to conduct part level DMSMS forecasting. The Keyport Logistics community has a multitude of tools and data bases to perform logistic data analysis to identify problems in the supply support area. Many of the individual technologies are quite mature and are currently being enhanced and refined, but they have not been integrated to specifically address technology refresh planning.

For each of the technologies, what are the most important projects that could be initiated?
The integration of existing tools into both a DMSMS Management process and a Technology Refresh planning tool.

When could the advancements be expected?
Both short-term (tactical), <5 years, starting TRL 7–9, and mid-term (strategic), 5–10 years, starting TRL 4–6.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?
Given the state-of-the-art experience with discrete-event simulation-based DRP solutions, there is a very reasonable expectation that significant value can be added here in both the short-term and mid-term time frames.

The primary risk is that even with an enhanced ability to create and identify strategic life-cycle management plans, Program Offices (and other stakeholders) will not have the available resources (funding, human capital, etc.) or resolve to carry out a long-term strategic solution. This is a long-term cost avoidance, which is difficult to sustain when budgets and objectives are in flux.

What is the estimate of the cost of R&D efforts needed for this field of study?
Moderate cost ($500,000 to <$1 million).

DMSMS Data Visualization

Focus

Focus is on technologies and techniques to improve the collection, collation, and communication of data or information associated with DMSMS issues, resolutions, and impact thresholds for weapon system supportability and mission capability.

Why is the field of study important to DMSMS management?

Data visualization involves the creation and study of the visual representation of data, meaning "information that has been abstracted in some schematic form, including attributes or variables for the units of information."

One primary goal of data visualization is to communicate information clearly and efficiently via statistical and informational graphics. Effective visualization helps users more readily analyze; reason; and communicate trends, problematic areas, and impending market availability changes, both positive and negative. Data visualization makes complex data more accessible, immediately understandable, and usable by each audience member. Another goal is to make it easier for the decision maker to grasp the scope and magnitude of the problem or the recommendation solution.

What is the current status of how this field is used by the DMSMS community?

Most graphical representations are commonly created using Excel or Excel-based products. However, there are commercial providers with high-cost, subscription-based big data capabilities that produce "dashboards" to visualize DMSMS system statistics. Some programs try to tailor the selection and presentation of the data as a function of the specific circumstances. This is usually done on an ad hoc basis.

Where are advancements needed? What are the technologies involved?

- Consolidated information on metrics that could be developed from DMSMS data and how they could be used to better communicate and to improve DMSMS management operations.
- The use of graph theory, 3D data representation, and heat maps have shown promise and would be a good starting point; however, these techniques are currently applied through add-ins to Excel, where the interfaces are difficult to use.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

Ultimately, the payoff would allow complex data to be used for forecasting and averting the impact of DMSMS issues caused by obsolescence. It is easier for the DMSMS management community to make decisions on where to apply mitigation, how to prioritize mitigation, and what the impact of the issues and mitigation might be. This could lead to better use of the information provided by the DMSMS management practitioner.

What R&D efforts are already underway for these technologies? Who is doing the work?

Both academic research and commercial product development or expansion (high costs associated with subscriptions).

For each of the technologies, what are the most important projects that could be initiated?

In addition to the ideas expressed in the “Where are advancements needed?” section, perhaps a survey of various programs to document how they present and visualize the data could be useful. Non-DoD organizations could be surveyed as well.

When could the advancements be expected?

Mid-term (strategic), 5–10 years, starting TRL 4–6.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

It is highly likely that these advancements could be achieved, since the same principles are being addressed in other disciplines**.** These efforts would come at a high cost.

What is the estimate of the cost of R&D efforts needed for this field of study?

Substantial cost ($1 million to <$2.5 million).

Prioritization of DMSMS Issues

Focus

Focus is on technologies and techniques that improve decision making to determine which issue to address next; considerations include cost, mission criticality, impact date, etc.

Why is the field of study important to DMSMS management?

DMSMS issues may lead to enormous variations in resolution costs and impacts. Additionally, the systems that those issues potentially affect have differing cost, mission importance, and life-cycle concerns. When a DMSMS management team (DMT) is confronted with multiple DMSMS issues, it is important to address them in a way that ensures the most impactful issues are handled first. Another aspect of this field of study is to be in a better position to prioritize items based on DMSMS risk. Understanding the risk leads to an improved risk-based monitoring strategy.

What is the current status of how this field is used by the DMSMS community?

There is acknowledgement of the need for this prioritization in SD-22 and evidence that some DMTs are putting some effort to assign urgency to cases. It is not clear how effectively this is being done, or if the teams are using similar, repeatable practices to assign priorities. Program offices today usually determine the items to monitor proactively using an ad hoc heuristic approach.

Where are advancements needed? What are the technologies involved?

Improvements could be examined in several areas.

- Determining the factors that are the primary indicators of an urgent problem.
- Developing tools to quantitatively estimate the cost and other consequences of delaying action on a particular issue.
- Developing decision aids that identify priority as a function of key characteristics of the situation at hand.
- Determining and automating the key factors in determining how to monitor a specific item.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

Impact assessment is currently a fairly difficult effort requiring lots of data from different sources as well as assumptions about behavior. Developing a tool that could expedite the process and reduce the amount of manual effort needed to obtain meaningful results would aid not only in prioritization of DMSMS issues but also in determining which systems should be considered for upgrades based on current and forecasted DMSMS issues. Advancements could also build a framework for making strategic life-of-need buys before the issuance of a discontinuation notice. Impact assessment associated with risk-based monitoring (i.e., the determination of reactive vs. proactive monitoring) is not done today. Programs may be spending too much or too little in this regard.

What R&D efforts are already underway for these technologies? Who is doing the work?

Keyport is working on improving the impact assessment and forecasting tools in OMIS and is conducting research into improving capability to predict obsolescence.

For each of the technologies, what are the most important projects that could be initiated?

- Improved forecasting (see also the field of study on forecasting hardware end-of-life).
- Data feeds from existing supply systems.
- Data feeds from reliability systems.
- Machine learning to look across large sets of data to determine, based on the above inputs, the relative priority of DMSMS issues (known and forecasted) and to determine the optimal DMSMS management approach.

When could the advancements be expected?

Short-term (tactical), <5 years, starting TRL 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

The key risk to this effort is the ability to predict future obsolescence and to predict impacts based on those projections. Some progress has been made on these fronts, and it is likely that this could be a successful effort.

What is the estimate of the cost of R&D efforts needed for this field of study?

Some cost ($100,000 to <$500,000).

Technical Data Package (TDP) Modernization

Focus

Focus is on technologies that can be used to convert between formats to produce a more readily usable TDP.

Why is the field of study important to DMSMS management?

The entire supply chain relies on TDPs of record to define the form, fit, function, interface, and test requirements for repaired and newly purchased items and for redesign or other actions necessary to resolve DMSMS issues. The requirements in many existing TDPs are decades old and in archaic formats not interchangeable with the data formats used in modern design and manufacturing, resulting in increased cost and the risk of errors in the data translation actions necessary to use the current supply chain to procure replacement items. Additionally, validation of part design cannot be readily automated using legacy data formats. As the dates for removing legacy systems from the inventory continue to be extended, the likelihood of obsolescence increases. If TDPs are not maintained in a current and usable format, the risk of systems being grounded for lack of parts increases. Unclear TDPs also lead to vendor misinterpretation, as indicated by the high vendor first article testing failure rates (10–60%) experienced by one Military Department.

What is the current status of how this field is used by the DMSMS community?

A majority of legacy mechanical and dimensional TDP data exists in various two-dimensional formats that were in use in prior decades, and not in modern 3D and computer-aided design (CAD) formats. Legacy requirements for analog and digital electronics are generally not expressed in the ideal formats for modern electronics redesign and validation. If a potential new supplier uses modern computer-based design and manufacturing technology, it will have to translate the legacy data into the needed modern format.

Where are advancements needed? What are the technologies involved?

A broad survey of legacy TDP data across the services is needed to compare against modern data formats. Then, a survey of existing data conversion technology would be needed to identify gaps. Finally, development of new conversion technologies to fill the gaps would be necessary. The technologies involved would most likely be primarily software development.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

Advancements in this field of study should reduce the cost and time for resolving a DMSMS issue when a new item or source is required. Automated technologies to achieve the needed data conversions would reduce the cost because vendors would no longer have to convert the data in their own unique ways and would reduce the delays and costs associated with vendor misinterpretation of data. Validated conversion technologies would reduce the risk of data errors being created in the conversion process. Issuance of validated data by the government, as opposed to vendor conversion of the legacy data, would reduce the risk of contract disputes and associated delays and costs. Automated validation of prototype and production parts would be enabled because existing technology can validate parts by comparing modern-formatted 3D requirements data to actual item 3D measurements made with laser scanners and other modern dimensioning technology. Likewise, electronics functionality requirements, if expressed in modern terms, allow a greater degree of automated design validation.

What R&D efforts are already underway for these technologies? Who is doing the work?
Unknown.

For each of the technologies, what are the most important projects that could be initiated?
See the answer to, "Where are advancements needed?" As a starting point, to achieve quicker results, it may be possible to target either a class of parts that can easily be impacted due to their technology or the most prevalent existing formats (e.g., Pro E or CATIA).

When could the advancements be expected?
Short-term (tactical), <5 years, starting TRL 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?
Very likely. Risk would be that associated with any software development effort that experienced poor project requirements management throughout the life of the project.

What is the estimate of the cost of R&D efforts needed for this field of study?
Significant cost (>$2.5 million).

DMSMS Parts Statusing Process Improvement

Focus
Focus is on technologies and techniques that reduce the manual effort required to status a part and make that effort as efficient and seamless as possible.

Why is the field of study important to DMSMS management?
"Statusing a part" means verifying whether that part is obsolete or not. In some cases that can be a labor intensive process. Process improvement will increase the efficiency of DMSMS management service providers and thereby lower the total cost of obsolescence management

What is the current status of how this field is used by the DMSMS community?
Part statusing is the foundation of obsolescence management. It relies on data from multiple predictive tools/commercial databases, as well as manual research. The degree to which parts statusing is automated today varies. Also, there may be inefficiencies in its automation.

Where are advancements needed? What are the technologies involved?
Advancement is needed in data centralization: increasing types of data that are housed in "data warehouses" and increasing data accessibility. These enhancements do not encompass the idea of centralizing tool use among DMSMS management operations providers. There are a number of issues associated with such a consolidation and they are being addressed elsewhere. Advancements may also be needed in automating some of the web searches conducted to status parts. Such enhancements could involve the development of strategies to find the needed information, the search engine to look for the information, and language parsing (recognizing phrases of interest and assessing their pertinence).

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?
Advancements would increase the number of manufacturer part numbers that can be automatically researched, which would result in a lower cost for parts statusing. It would also increase data accessibility, which would reduce the amount of time spent in research and obsolescence data analysis.

What R&D efforts are already underway for these technologies? Who is doing the work?
Plans exist. The extent to which they are funded and associated timelines are unknown.

For each of the technologies, what are the most important projects that could be initiated?

- Improving the identification/matching of specific parts across predictive tools/commercial databases.
- Replacing existing DMSMS management application software in order to overcome limitations on speed and processing power.

- Enabling more automated statusing of software items.
- Developing enhanced “web crawling” capability to improve part research and to decrease the extent to which manual efforts are required.

When could the advancements be expected?
Short-term (tactical), <5 years, starting TRL 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?
High likelihood, pending funding.

What is the estimate of the cost of R&D efforts needed for this field of study?
Some cost ($100,000 to <$500,000).

Development and Validation of Parts Lists Needed to Manage DMSMS Issues

Focus

Focus is on technologies and techniques to enable proactive monitoring processes by improving (1) the development of parts lists, in cases where no bills of material (BOMs) are available and (2) the validation of bills of material BOMs to detect errors within BOM-scrubbing processes.

Why is the field of study important to DMSMS management?

Accurate and complete data is the foundation of obsolescence management. DoD does not always acquire the Technical Data Package, BOMs, or parts lists necessary to conduct proactive DMSMS management. In some instances where data have been obtained, there may be errors, omissions, or recursive relationships (where the same part is both the child and the parent to another part). It is important to correct these mistakes to ensure the BOMs load properly before drawing any conclusions from (or even initiating) any monitoring processes.

What is the current status of how this field is used by the DMSMS community?

BOMs or parts lists are used to monitor for obsolescence and provide early warning notification to the Program Office, prime contractor, or supplier in order to mitigate prior to impacting the production line or system availability.

Where are advancements needed? What are the technologies involved?

Other than going back to the prime contractor to ask for or purchase the data, parts lists must be constructed from a very expensive and time-consuming product audit that manually breaks down Line Replaceable Units to develop BOMs by inspecting the parts themselves. This approach requires a thorough examination of parts marking. Parts marking may include a symbol identifying the manufacturer, an orderable part number, the manufacturing date, or other specific information. Advancements are needed to develop less manual methods for examining parts marking. Machine learning, artificial intelligence, graph theory, and data visualization may help automate BOM scrubbing processes to check BOMs for proper structure such as recursive relationships, bad Commercial and Government Entity (CAGE) codes, bad parts descriptions or specs, missing data, etc.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

DoD would have options other than prime contractor or supplier to provide the data needed to implement a proactive obsolescence program. Programs in sustainment who have no other option for obtaining data would be able to develop a BOM more readily.

What R&D efforts are already underway for these technologies? Who is doing the work?

Some BOM validation tools exist, and improvements are planned. Otherwise unknown.

For each of the technologies, what are the most important projects that could be initiated?

- One possibility is the development of a filterable and searchable parts marking database that can be used across DoD. This would allow faster part recognition and faster manufacturer part number determination.
- Another possibility is the development of scanning and magnification technology that could use image comparison to identify items from an item/piece part recognition data base, similar to facial recognition technologies.
- A third possibility is the development of a BOM analysis tool to check for errors before loading.

When could the advancements be expected?

Short-term (tactical), <5 years, starting TRL 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

- A part marking data base could be easily achieved with available software programming and personnel.
- Improved scanning, magnification, and associated recognition techniques may be more complicated.

What is the estimate of the cost of R&D efforts needed for this field of study?

Some cost ($100,000 to <$500,000).

Appendix B
Diminishing Manufacturing Sources and Material Shortages (DMSMS) Resolutions Fields of Study Summaries

Field Programmable Gate Arrays (FPGAs)

Focus
Focus is on hardware-, software-, and firmware-related technologies to improve bit stream analysis to deduce the functionality of the electronic item and other means of FPGA obsolescence mitigation.

Why is the field of study important to DMSMS management?
FPGAs provide a flexible digital platform. FPGAs contain basic digital logic blocks that are able to create complete digital systems. They are often used to perform complex digital signal processing (DSP). This flexible architecture allows for the design of digital systems that previously required an application-specific integrated circuit (ASIC). The vast majority of all military hardware that makes decisions based on sensors (cameras, etc.) is using an FPGA to do so. From a DMSMS management perspective, when obsolete FPGAs fail and there are none remaining in inventory, resolutions generally rely on reverse engineering or redesign.

What is the current status of how this field is used by the DMSMS community?
Due to the increasing size and capabilities of FPGAs, they are becoming more and more difficult to reverse engineer. The capability to reverse engineer FPGA circuitry is scarce as it requires specialized skills, software tools, and training that most businesses do not possess. In addition, this is often just a first step in upgrading and expanding the functionality of the next generation system to be supported. Consequently, these projects can afford to spend a great deal of time and effort (money) to use brute force in reverse engineering their specific niche of FPGAs, because their efforts will not just keep current hardware supportable, but will also lay the groundwork for the upgraded FPGA system and new capabilities being integrated into future versions of the system. While this has been effective for many high priority projects (cruise missiles, aircraft, etc.) this has left many mid-tier priority projects that use FPGAs unable to be efficiently reversed engineered. The bottom line is that more expensive redesigns are more often the resolution of choice.

Where are advancements needed? What are the technologies involved?
Currently, it is often cost-effective for an engineer to reverse engineer the hardware of an FPGA. However, reverse engineering the FPGA firmware is usually not cost-effective

with currently available tools. Some FPGA designs are too complex to reverse engineer without being able to re-create the digital logic from the bit stream. Migrating a bit stream from a legacy device to a current device is not as simple as copying and pasting the firmware from one device to another. The process to upgrade or downgrade the firmware from one device to another requires a complex set of in-depth software manipulation processes that are not easy to execute, as they each have their own complexities and custom requirements. The main complexity factor is that every firmware is unique to a given project. Thus, the reverse engineering of the firmware is different for every project. Furthermore, an extremely high level of subject matter expertise is needed to convert the output of the existing FPGA reverse engineering tools into a design that can be readily manufactured using current technology. A higher level tool is needed that can function as a common interface for certain types of functional modules regardless of the hardware involved. This tool would need to provide key libraries and other functionalities to analyze the unencrypted bit stream. This tool would not reinvent the bottom level functionalities. Instead, it would provide a higher layer of abstraction that would use currently available lower level tools (MacB, etc.) in a more informed way. It would act as a model where knowing what type of FPGA is the starting platform and what FPGA is the final platform would dictate how the conversion process would proceed. The lower level tools would handle a register-transfer level conversion, while this tool would control the conversion of the higher level objects such as high-speed input/outputs (I/Os), hardcoded features, clock management, necessary glue logic, and optimal configurations of carry chains. Ultimately, higher level tools that cut across a wider gamut of functions are needed.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

The DMSMS management community would be able to recreate a digital system from an obsolete FPGA and migrate it to another current FPGA. The cost and time to reverse engineer FPGAs would be reduced. A higher level analyzing tool would allow these designs to be migrated with reduced cost and improved reliability. Ultimately, a series of such higher level tools may be able to drastically expand the cost and time reductions because it enables the reverse engineering of substantially more FPGA projects than can currently be done cost effectively.

What R&D efforts are already underway for these technologies? Who is doing the work?

FPGAs are used and researched by academia, industry, and the militaries of the most significant nations (both allies and adversaries). However, since FPGAs vary so much in both hardware and firmware, most efforts focus on only a small niche when addressing obsolescence efforts because commonality is only applicable across parts within that niche or family. They were therefore focused on specific device problems to resolve their issues but were unable to gain strong common tool efficiencies with devices that differed from the original focus.

For each of the technologies, what are the most important projects that could be initiated?

The most important projects associated with a proof of concept for certain types of modules that could be initiated are projects with a mid-tier priority system that has an FPGA for which a replacement is not currently planned, but there is still a need to keep producing more of the current systems that are being used. This would include lower level weapon systems and subsystems that analyze sensor information that is integrated into higher level systems using an FPGA. While some commonality can be realized across part families to reduce cost, a universal tool may be a bridge too far with today's technology.

When could the advancements be expected?

Short-term (tactical), <5 years, starting technology readiness level (TRL) 7–9 for a proof of concept on one higher level analyzing tool; mid-term (strategic), 5–10 years, starting TRL 4–6 for a set of higher level analyzing tools; long-term (next generation), >10 years, starting TRL 1–3 for a universal tool.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

The principal risks are finding a common means to manage and model specific modules within FPGAs and being able to decode and model an FPGA's internal logic from the bit stream. Overall, the risk is medium.

What is the estimate of the cost of R&D efforts needed for this field of study?

Some cost ($100,000 to <$500,000) for the proof of concept. Substantial cost ($1 million to <$2.5 million) for a broader effort.

Application Specific Integrated Circuits (ASICs)

Focus

Focus is on hardware-, software-, and firmware-related technologies to improve delayering and imaging techniques to deduce functionality of the electronic item.

Why is the field of study important to DMSMS management?

As integrated circuit (IC) technology progresses, obsolescence also progresses to include increasingly complex ICs. This effort is to further develop the technologies to image and analyze ICs for reverse engineering, remanufacturing, and to support verification and validation efforts. Furthermore, the non-destructive methods being researched would add the new capability of imaging from a single sample.

What is the current status of how this field is used by the DMSMS community?

The DMSMS community normally uses destructive methods combined with IC image analysis tools to resolve issues. These efforts are time intensive and limited in scope by the complexity of the ICs being analyzed. Furthermore, these destructive techniques realistically destroy a large number of ICs to obtain the necessary data. Non-destructive X-ray GDS-II data extraction was demonstrated as part of Defense Advanced Research Projects Agency (DARPA) trusted integrated circuits (TRUST), but the technology has not been further developed into a tool available for use. As newer and more complicated ICs become obsolete, the tools used to support the analysis efforts will need to be improved as well to handle the larger datasets and reduce operator time.

Where are advancements needed? What are the technologies involved?

There are two areas of advancement:

1. *Non-destructive imaging using X-rays.* Non-destructive X-ray imaging methods become viable when ICs switch from aluminum to copper. Non-destructive techniques have the potential to better support situations where there are limited quantities of the IC, and they may potentially be faster than the destructive methods. There are various lab-based and synchrotron-based technologies that can be explored to meet this need. The various technologies have tradeoffs in terms of speed, cost, and resolution.
2. *Improvements to IC analysis software.* The software used to support both destructive and non-destructive IC analysis will need to scale with the increasingly complex ICs being analyzed. Furthermore, the increased complexity also means that many error detection and correction tasks that have historically been left to an operator need to be automated. This may require the development of advanced algorithms and, most likely, machine learning.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

These technologies would allow for imaging and analysis to be performed on increasingly complex ICs as obsolescence continues to push into smaller node sizes. Non-destructive imaging technologies will also enable analysis based on a single sample with much less risk.

The enhancement of existing synchrotron beamlines that could scan an entire IC in days (vs. weeks) would be a useful tool for re-fabrication. Improving existing beamlines instead of creating a new beamline has significant cost savings and should allow for the low cost purchase of small amounts of beam time throughout the year. The goal would be a partner user proposal (PUP) or other agreement that would reserve the beamline for various blocks of time throughout the year in exchange for the funds to improve the beamline. This type of arrangement could be easily modified to meet demand by adding more time, expanding to other existing beamlines, or constructing a new beamline if needed.

What R&D efforts are already underway for these technologies? Who is doing the work?

The Intelligence Advanced Research Projects Activity (IARPA) Rapid Analysis of Various Emerging Nanoelectronics (RAVEN) program is funding similar efforts to support imaging at 10nm resolution. RAVEN is more advanced than what is being proposed here. However, the technology in RAVEN will most likely be more expensive, at a lower TRL, and more time consuming to develop.

Defense Microelectronics Activity (DMEA) is developing a lab-based X-ray microscopy solution. This technology could be enhanced to run at a synchrotron beamline to significantly speedup the scan times. DMEA has performed IC scans at various synchrotron beamlines and has an in-depth understanding of the challenges and merits.

There are a few software efforts to support the large jump in complexity for IC analysis. In particular, the Air Force Research Laboratory (AFRL) is funding an effort at Micronet Solutions, Inc. (MSI) to fully parallelize their software (allow multiple operations simultaneously). Efforts such as these are going to need to be paired with fundamental process and algorithm changes to help reduce errors and operator time.

For each of the technologies, what are the most important projects that could be initiated?

1. Non-destructive imaging:
    a. Setting up partnerships with synchrotrons to establish scanning capability,
    b. Software development to support these efforts,
    c. Establishing on-going partnerships or creating a new beamline to sustain the capability to scan ICs at a synchrotron,
    d. Establish the protocols to do IC scanning at higher security levels (whether that involves using a lab source or modifying a beamline at a synchrotron).
2. IC analysis software:
    a. Fully parallelizing existing software,
    b. Process and algorithm development to automate more processes and reduce errors,
    c. Incorporating machine learning to automate advanced tasks that currently require an operator.

When could the advancements be expected?
Non-destructive X-ray Imaging: This is a short-term project, <5 years, starting TRL 7–9. This project could start immediately with initial meetings with beamlines to develop a plan to improve their hardware and develop user proposals. Software development is currently being developed at DMEA and could be enhanced to support the beamlines. It would be reasonable to expect to be able to demonstrate scanning a whole 90nm, 65nm, or 45nm process IC in a 2-year timeline and establishing a service within 3–4 years. Scanning more advanced process ICs would need new hardware advances such as those being developed under IARPA RAVEN.

IC analysis software enhancement: This is also a short-term project. A new parallel version of software could be created in 2–3 years with some new algorithms and processes integrated from the start to help reduce operator time and errors. It will then take a few more years to continue to identify areas that can be enhanced to really support large and complex ICs. The software will need to continue to be developed to support more complex ICs; even if the computing power can scale, the accuracy of the program will need to advance as well.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?
Non-destructive X-ray imaging has a high likelihood of success. The technology has been demonstrated as part of DARPA TRUST, and DMEA has demonstrated the ability to scan ICs with both a synchrotron and lab-based X-ray microscope system. Further development is to increase the TRL level and speed of the scans.

IC analysis software has a high likelihood of success. The parallelization efforts are complex but mostly an engineering challenge that just take time. The efforts to improve process and user interaction have some risk in their degrees of success; there will be improvements, but there is a risk that they will not scale to the degree needed for increasingly complex analysis projects.

What is the estimate of the cost of R&D efforts needed for this field of study?
Non-destructive X-ray imaging should cost <$500,000. There are various tradeoffs to be made with improvements to an X-ray microscope, but significant improvements should be possible for much less. There is a significant cost savings on software being shared with the software developed for DMEA for their lab-based X-ray microscope.

IC analysis software's initial parallelization and automation efforts should be <$500,000. This would create the expandable infrastructure to build upon for further increases in complexity in the future. Further algorithm and machine learning developments would add additional costs over time.

Combined, these efforts would have a moderate cost.

Reverse Engineering – Electronic Assemblies and Printed Circuit Boards

Focus

Focus is on technologies to improve function analysis and characterization to enable faster and lower cost reverse engineering of electronics items.

Why is the field of study important to DMSMS management?

An enormous problem for the Department of Defense (DoD) is the growing number of obsolete electronic assemblies. The service life of many of these systems has been extended for years creating critical shortages of spare parts. With great advances in technology and the passage of time, original equipment manufacturers (OEMs) no longer support these systems. In addition, many new systems are being fielded without a comprehensive drawing package available. Often, the prime vendor or original equipment manufacturer is relied upon for logistics support. Once that vendor or OEM decides to advance their product line, all support is lost for systems that are now widely fielded across the military. In addition, these companies may go out of business and consequently the drawings and technical data would no longer be available.

What is the current status of how this field is used by the DMSMS community?

Reverse engineering of circuit card assemblies (CCAs) and printed wiring boards is done to replace them with modern equivalent substitutes. Reverse engineering is used when repair is not feasible and technical data is unavailable. Reverse engineering is often pursued when future demand for the item is expected to be low. When high demand is anticipated, a larger scale redesign is more common. However, without technical data, reverse engineering may be a necessary step in the redesign. Reverse engineering is expensive. It involves a labor intensive, manual, and trial and error process; often the specific, original item being reverse engineered is destroyed.

Where are advancements needed? What are the technologies involved?

Advancements are needed to improve the accuracy and reduce the cost and time associated with reverse engineering, as well as the development of non-destructive techniques. One area of research is the use of X-ray reverse engineering to analyze the functionality of printed wiring boards and to redesign the entire original circuits with modern programmable digital components. Another area of research is development and automation of an end-to-end process that obtains raw reverse engineering data and converts it to a Gerber file that can be sent as digital instructions to a manufacturer. Having tech data, however, does not guarantee an alternative manufacturing source is available.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

The DMSMS community would benefit from a source for reliable spare parts for aging electronic systems, thereby allowing for service life extension decisions. The payoff would be in mitigation of shortages of critical items. Reverse engineering can alleviate shortages of essential components and allow the systems on which they reside to be used longer. Another potential payoff would be the development of government-owned technical data packages.

What R&D efforts are already underway for these technologies? Who is doing the work?

Naval Undersea Warfare Center (NUWC) Keyport, Rapid Prototyping and Fabrication Technology Division, has been engaged in research and development of X-ray reverse engineering of printed wiring boards and assembled replacement integrated circuits (ARICs), functional equivalents of obsolete ICs.

Several other organic facilities have intermediate and advanced facilities dedicated to electronics reverse engineering (e.g., Naval Surface Warfare Center (NSWC) Crane, Kansas City National Security Campus, the H-53E Flight Computer reverse engineering effort, Missile Defense Agency (MDA), and Wright-Patterson Air Force Base have all made large investments into this technology area to provide reverse engineering services. DMEA has 20 years of experience reverse engineering CCAs. However, both efforts use physical delayering techniques (destructive). DMEA also has experience reverse engineering printed wire boards using non-destructive techniques.

For each of the technologies, what are the most important projects that could be initiated?

A first project should be an investigation of current reverse engineering efforts to identify lessons learned and where other organizations may have been successful. This will help target follow-on efforts to higher payoff areas. The first project will benefit from interfaces with the DoD Executive Agent for Printed Circuit Board and Interconnect Technology who has the responsibility to "facilitate collaboration within and across the DoD to conduct research, development, and sustainment efforts targeting Component-unique requirements.[9]"

After that, the most important projects would be more automated generation of computer aided drawing packages, schematics, and Gerber files that could lead to digitized circuit development, improvement of X-ray reverse engineering methods, and further research into obsolete IC replacement.

When could the advancements be expected?

Short term (tactical), <5 years, starting TRL 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

These advancements are very likely to succeed. One risk is associated with the demand for advanced reverse engineering capabilities. If older systems are replaced with new

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[9] DoD Directive 5101.18E; *DoD Executive Agent for Printed Circuit Board and Interconnect Technology*; Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics; June 12, 2016.

equipment instead of maintained over a longer period of time, the demand could be small and consequently the investment may not be worthwhile.

What is the estimate of the cost of R&D efforts needed for this field of study?
Some cost ($100K–$500K). If equipment investment is included, significantly more cost would be involved.

Reverse Engineering – Mechanical and Other

Focus

Focus is on technologies to improve function analysis and characterization to enable to enable faster and lower cost reverse engineering of non-electronics items including materials.

Why is the field of study important to DMSMS management?

While DMSMS issues are most prevalent in the field of electronics, the DoD supports many systems that require sustainment for much longer timeframes than what is standard in industry. As such, the likelihood of encountering diminishing manufacturing sources for mechanical components is high; the risk of obsolescence increases the longer a system is in-service. The problem is exacerbated by the fact that the DoD does not own the technical documentation for a large number of these systems, meaning that fabrication from alternate manufacturers as a means for replacement of mechanical components is not possible. Under those circumstances, the potential DMSMS resolutions are (1) develop a replacement item either through reverse engineering or redesign of the item itself or (2) redesign at a higher level of assembly. Although reverse engineering may be a labor intensive process, it generally requires a lesser engineering effort than a redesign since producing something as close as possible to the original typically reduces the engineering effort necessary to ensure that requirements are satisfied.

What is the current status of how this field is used by the DMSMS community?

Mechanical reverse engineering is currently a niche approach due to the differences in scale between mechanical and electronics obsolescence. Mechanical reverse engineering is typically a low quantity fabrication process and therefore less attractive for industry to pursue. Further, if obsolete materials are involved and key to functionality, the cost of characterizing those materials may further weaken the business case.

Where are advancements needed? What are the technologies involved?

A primary barrier to mechanical reverse engineering is the labor, cost, and time associated with reproducing a technical data package (TDP) when none exists. There are two major steps in the TDP generation process: (1) collecting the raw data on the item to be reverse engineered and (2) translating that data to either engineering drawings or the input needed by fabrication equipment.

- Data collection. Advanced coordinate measuring machines (CMMs) and laser scanning technologies have the potential to semi-automatically generate the geometric and dimensional data needed to produce computer aided drafting models that can be used for TDP development. Advancement in reliable point cloud (the points on the external surface of the object to be reverse engineered) generation and scanning technologies are also key.
- Translation software. Software that translates that raw data into usable solid 3D models is key in furthering the effectiveness of mechanical reverse engineering.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

Advancements in mechanical reverse engineering technologies (both data measurement and the software to increase the usability of measurement data) have the potential to increase the life cycle of systems throughout the DoD in a more cost-effective manner. Also, by making reverse engineering easier, advancements could help proliferate the use of mechanical reverse engineering and thereby increase the incentive to reverse engineer in lieu of more expensive redesigns. These mechanical reverse engineering advancements would also be of value to the additive repair field of study.

What R&D efforts are already underway for these technologies? Who is doing the work?

Currently, there are commercially available advanced CMMs and laser scanning technologies, such as the GOM Metrology's ATOS products, that are relatively mature in technology development. NUWC Division Keyport regularly uses CMMs for part fabrication inspection and has both traditional CMMs and articulating arm inspection machines. Commercial point cloud generation software, such as Geomagic, is advancing to the point of becoming functionally relevant for use in mechanical reverse engineering.

For each of the technologies, what are the most important projects that could be initiated?

Research into how current technology can be best leveraged could be a first step to aid in the generation of TDPs for obsolete mechanical components, both the data collection techniques (point cloud generation, laser scanning, etc.) and data translation software. In addition, using mechanical reverse engineering to identify key critical mechanical components that could significantly extend life cycles would highlight important targets of opportunity. These steps could be followed by pursuing appropriate specific advances in data collection and translation software.

When could the advancements be expected?

Short-term (tactical), <5 years, starting TRL 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

The primary technologies are currently available in the commercial market; however, it is not well understood how the DoD could use them to solve mechanical obsolescence. The principal risk is the relatively immature translation software, and how it would integrate with the DoD's current CMMs and computer-aided design (CAD) systems.

What is the estimate of the cost of R&D efforts needed for this field of study?

Some cost ($100,000 to <$500,000).

Additive Repair

Focus

Focus is on improving additive technologies for repairing items that are currently not economically repairable, as well as technologies to qualify and approve the results.[10]

Why is the field of study important to DMSMS management?

DMSMS may create a situation whereby the service life of certain items must be extended because new replacements cannot be purchased. Additive repair can be used to return items to service that are both no longer reparable using existing manufacturing practices and out of production. The typical item has lost dimensionality due to wear, corrosion, or other cause. Additive repair would seek to repair the dimensionality and maintain or recover required material properties. For example, mechanical parts, in particular, may sometimes require additive material buildup to restore worn or corroded surfaces. When an obsolete item fails, the use of additive repair processes may be the only option to restore the item and get it back into service. Additive repair may also be a cost-effective alternative to reverse engineering and re-fabricating high value items from scratch.

What is the current status of how this field is used by the DMSMS community?

Additive repair technologies allow for the re-use and salvage of parts that would normally be thrown away. Although the approval process for the use of an additively repaired item is lengthy and cumbersome, the return on investment is almost immediate in situations dealing with high value items that have no other source of supply. While some additive repair is used today, its use is not institutionalized or widespread. Many of the additive repair processes are still in the design phase and have only been approved for use on operational systems on a case by case basis. A large effort will be required in order to qualify these processes for widespread use. Currently, there is no standardized protocol established across the DoD for the transition of additive repair technologies. To date, cold spray (CS) and laser cladding have been mainly used for non-structural repairs (i.e., the reclamation of worn, damaged or corroded parts).

Where are advancements needed? What are the technologies involved?

Traditional additive repair methods (i.e., brush electroplating, arc-welding, hot-epoxy, adhesives, etc.) have significant limitations both on where they may be applied and performance of the repaired items (e.g., durability, reaction to the environment, dimensional tolerances, hazardous waste, and changes in properties caused by the repair). Some newer potential alternative additive repair technologies beyond CS and laser cladding include plasma thermal spray, High Velocity Oxy-Fuel (HVOF) spray, electron beam (E-beam) welding, twin wire arc spray, as well as other variants of thermal spray processes. Additionally, direct metal laser sintering (DMLS) offers the potential to re-build damaged sections of parts. While significant DMLS technology development is underway, efforts to use DMLS to build new parts sections onto existing metal structures

[10] The broader field of additive manufacturing could also be important to DMSMS resolutions; however, since its application is far broader than obsolescence, this field of study is limited to additive repair.

are just beginning. One of the largest barriers to implementing these technologies for additive repair is determining a streamlined qualification and certification process for their application.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?

The potential benefits from improved additive manufacturing in general are fairly well known. Contributions can be made to reducing cycle times, increasing readiness, reducing logistics footprint, ensuring environmental compliance, increasing capabilities, and sustaining legacy systems. The greatest DMSMS impact is in the sustainment of legacy systems. As weapon systems age and the industrial base support for components related to these systems fluctuates, DMSMS issues can materialize. Using additive repair on items where the OEM is no longer available to repair the conventionally manufactured parts in order to mitigate wear or damage extends service life by allowing assets to be reclaimed where otherwise not possible.

What R&D efforts are already underway for these technologies? Who is doing the work?

- The DARPA Open Manufacturing program has been investing in Integrated Computational Materials Engineering (ICME), a qualification framework that would reduce the time and dollars necessary to qualify a process. While none of the DARPA programs targeted additive repair technologies, the framework is designed to be applicable to any process or material.
- CS has been developed for repair by the US Army Research Laboratory.
- The Army, Air Force and Navy have sponsored work to accelerate the development and implementation of CS, but these efforts are often not coordinated across the tri-services, and standardized qualification protocol remains a challenge.
- The Air Force has addressed wear problems on aluminum alloy aircraft skin panels.
- H. F. Webster Engineering Services, the South Dakota School of Mines and Technology (SDSM&T) Repair Refurbish and Return to Service (R3S) Research Center and the Army Research Laboratory (ARL) Center for Cold Spray jointly developed a repair process.
- Penn State Applied Research Laboratory has been actively performing research in CS, laser cladding, thermal spray, and additive manufacturing.
- The Edison Welding Institute (EWI) has been doing work with advancing welding technologies as well as laser metal deposition technology.
- SDSM&T R3S Research Center has been working on the development and transition of CS technology in collaboration with the ARL, Navy, and Air Force.
- NUWC Division Keyport has been involved in laser cladding, plasma thermal spray, twin wire arc thermal spray, and CS processes for use in additive repair processes. There are many universities involved with these technologies. Keyport currently has a Naval Engineering Education Consortium (NEEC) partnership with Purdue University for collaboration on laser metal deposition projects.

- America Makes Maturation of Advanced Manufacturing for Low-Cost Sustainment (MAMLS) program is addressing multiple aspects of additive manufacturing to address sustainment and obsolescence including tooling, powder reuse in DMLS, qualification issues and reverse engineering.

For each of the technologies, what are the most important projects that could be initiated?

Numerous R&D efforts are underway for additive repair for a variety of reasons. DMSMS is only one of those reasons and it may not be the most important. In order to more specifically impact DMSMS, it is important to be strategic when selecting investments in R&D funded projects. This field of study recommends funding development and implementation of R&D targeted towards specific implementation cases as opposed to funding general foundational research for new initiatives. This is consistent with the approach that the DMSMS community should adopt – let other communities do the heavy lifting to the maximum extent possible.

From a DMSMS R&D perspective, the first step should be an assessment of where the most important targets of opportunity from a DMSMS perspective exist. In order to assess projects suitable to additive repair, the following types of questions should be addressed:

- What types of items are in need of additive repair strictly because of obsolescence?
- To what extent will the cost of implementing a DMSMS resolution be reduced because of an additive repair capability?
- For the most important cost savings opportunities, what additive repair technologies offer the greatest potential for realizing these cost savings? What is the current state of the art and current level of use for these technologies? Depending on desired outcome and functional requirements certain technologies may be better suited to various repairs (i.e., there is no single technology to solve all additive repair solutions)
- What needs to be done to advance those technologies to a state necessary to realize the cost savings?
- What is the return on investment?

If, for example, the DMSMS perspective is identical to the broader perspective, then perhaps DMSMS-unique investments are not necessary. The following is an *a priori* list of project ideas that must be matched to the DMSMS-related returns on investment (ROIs) before being finalized.

CS: Using a building block approach to develop, qualify, and field a CS repair capability that will be capable of repairing high-cost magnesium non-structural aerospace components that can be transitioned across rotorcraft and fixed wing aircraft.

Laser Cladding: Naval qualifications for laser cladding applications to date have been treated as a "special weld" process and followed guidance outlined in Naval Sea Systems Command (NAVSEA) S9074-AQ-GIB-010/248 and NAVSEA S9074-AQ-GIB-010/278. The specifications do not specifically address laser cladding by name, but the approach to qualification is very similar to a welding qualification. This particular technology may be beneficial for repair applications if (1) the component cannot be arc welded due to material incompatibility, (2) welding temperatures will distort or damage the component, (3) stray electrical current from arc welding would damage populated electronics, (4) superior material properties from laser cladding process are desired, and (5) full metallurgical bonding is required for strength. There is a wide range of applicable uses for DoD repair to aircraft, naval components, ground vehicles, unmanned vehicles, and weapons systems.

Thermal Spray: Various thermal spray technologies, such as HVOF, plasma spray, twin-wire, and others, have traditionally been used during new manufacture to apply protective coatings to components. From a DMSMS perspective, these processes could also potentially be used for repair applications due to their additive nature. Dimensional restoration could be achieved with thermal spray technologies. Advantages of these technologies are (1) they are fairly inexpensive processes; (2) they can apply ceramics and other extremely durable materials; and (3) some thermal spray technologies, such as Twin-Wire, are fairly portable, allowing the process to go to where the part is and minimizes downtime.

When could the advancements be expected?

Short-term (tactical), <5 years, starting TRL 7–9 for CS, laser cladding, and thermal spray.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

CS risk appears to be minimal, because of the existing experience of DoD organizations, state-of-the-art facilities, and OEM support. DoD transition sites have been identified that already have or are acquiring CS capability by FY18.

Laser cladding risk appears to be minimal, because of the existing experience of DoD organizations, state-of-the-art facilities, and maturity of the commercial sector. DoD transition sites need to be determined based on operational requirements.

Thermal spray risk appears to be minimal because of the existing experience of DoD organizations, state-of-the-art facilities, and large industrial support base. DoD transition sites need to be determined based on operational requirements.

What is the estimate of the cost of R&D efforts needed for this field of study?

The CS, laser cladding, and thermal spray processes could be developed for a single non-structural application for minimal costs (<$100,000). This cost estimate assumes that the basic qualification requirements have been established, such as quality assurance systems, specifications and standards, manufacturing processes, and equipment capitalization. However, a large tri-service effort that establishes a standard protocol for the qualification and approval on a widespread scale for a non-structural application and applied across various weapons platforms for the tri-services would require an investment of $500,000–$1 million. Additionally, on any structural application the cost would likely double due to the testing required. Any of the other technologies would likely require much more investment (over $5 million) and higher risk due to lower TRLs and other unknowns.

Resolution Cost Reduction Based on Identification and Exploitation of Common Technology

Focus

Focus is on the data science and analysis technologies that would enable identification and consolidation of existing obsolete and at-risk components by technology variant or other identifying factors, leading to cost reduction through economy of scale manufacturing.

Why is the field of study important to DMSMS management?

Currently, obsolescence resolutions are implemented on a case-by-case basis and usually do not involve keeping a production line open because it is usually not profitable to do so. Depending on the part and technology, it can therefore cost several hundreds of thousands of dollars to develop (or emulate) a form-fit-function replacement to which the cost of low-volume, high overhead manufacturing is the significant cost driver. However, if multiple obsolete or at-risk parts of a similar technology can be identified and concurrently addressed through a consolidation of orders, the business case for a manufacturer for reopening or keeping its production line open changes because sales volume would increase. If this happened, the cost of manufacturing paid by customers can be significantly reduced through sharing of fixed costs among more entities. The appropriate application of the field of data science and big data analytics can be the enabling technology in the identification of obsolete parts based in a similar technology.

This field of study is most directly applicable to electronic parts because there has been a common practice of scheduling windows when production occurs due to high production line setup costs associated with masking. This field of study could conceivably be applied to non-electronic items if there were an analogous situation of high setup cost for production.

What is the current status of how this field is used by the DMSMS community?

Though the Defense Logistics Agency (DLA) recently created the Strategic Data and Analysis office for the purpose of exploiting data science and employing data analytics to improve business processes, this field is not currently being used by the DMSMS community. However, the concept of shared manufacturing is one that has been embraced by the semiconductor industry for decades. The DMSMS community has expressed interest in combining orders to keep a production line open, but such consolidation has been almost exclusively limited to buyers of the exact same part. The idea of combining different parts of a similar technology has not been pursued.

Where are advancements needed? What are the technologies involved?

Advancements in the application of data science and data analytics across the DoD parts and DMSMS databases are needed to identify obsolete and at-risk parts of similar technology lineage in order to realize opportunities for reduced costs through shared manufacturing. The necessary technology advancements include data science and big data analytics, machine learning, and data mining of obtuse data sets. (If this field of study were to be applied to mechanical items, advancements would also be needed in 3D model creation for mechanical parts.)

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved?
Advancements in these technologies bring two primary benefits to the DMSMS management community: streamlining DMSMS management process through the ability to potentially resolve multiple obsolete parts simultaneously, and significant cost reduction in the per-part manufacturing cost through economy of scale manufacturing (i.e., setup costs allocated over a greater volume of parts).

The data obtained through this research may also provide a basis for the DoD to shore up the industrial or organic semiconductor manufacturing base; for example, compare the results of the research (DoD technology posture) against the available technology base.

What R&D efforts are already underway for these technologies? Who is doing the work?
A literature review of this field of study did not produce R&D efforts related to the application of data science and analytics toward identifying technology commonality between obsolete and at-risk parts. However, the concept of shared manufacturing is well known within the semiconductor industry—for example, multiple project wafer runs (MPWR), in which several different parts share a common manufacturing run for the purpose of producing prototype parts and reducing manufacturing costs.

For each of the technologies, what are the most important projects that could be initiated?
A concept demonstration project could be initiated using the application of state-of-the-art data science and big data analytics, machine learning, data mining methodologies and statistical methods for the purpose of demonstrating the feasibility and applicability of this approach to DMSMS management and cost reduction. (For mechanical parts, the demonstration would necessitate having 3D digital data for the parts and component families being analyzed.)

For context, this concept demonstration may include the development of a relational database associating the FSC 5962 zero-source listing; the Standard Microcircuit Cross Reference (SMCR), and Standard Microcircuit Drawing (SMD) databases; the application of machine learning, data mining methods, and statistics for identifying or developing associative data for classification at the lowest levels of abstraction; and the development of data reporting and visualization tools. The databases would not necessarily be limited to those aforementioned, but could include any number of additional databases, such as a program BOM, to be added to the repository of data.

Once developed, an example of the concept in operation could be demonstrated with the input of a known obsolete part number into a system, which results in a system output that reports other known obsolete or at-risk parts that share a number of critical characteristics in kind along with a probability of match for each characteristic and overall technology match. Critical characteristics could be classified, for example, as

OEM, base technology (e.g., 5V CMOS), and absolute maximum electrical ratings. Other characteristics of interest may include weapon systems, etc.

Once parts have been determined to match within a certain probability, further analysis can be performed (perhaps by subject matter experts) to determine the fitness of that match and whether or not the parts are true candidates for shared manufacturing.

When could the advancements be expected?

Short-term (tactical), <5 years, starting TRL 7–9. Within this time frame initial concept demonstration and feasibility could be achieved, with the potential for immediate cost reduction benefits to the warfighter and the DMSMS community.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

It is highly likely that technological advancements could be achieved. Principal risks are:

- Cooperation and participation across the DMSMS ecosystem,
- Willingness and ability to combine procurements,
- Quality of the data (scanned hardcopy vs. softcopy drawings),
- Interdependence of the data science, logistics, and engineering communities for success.

What is the estimate of the cost of R&D efforts needed for this field of study?

Either some cost ($100,000 to <$500,000) or moderate cost ($500,000 to <$1 million).

Better Use of Reclaimed or Salvaged Items

Focus
Focus is on technologies to extract the desired items, estimate remaining life after extraction, and increase shelf life both before and after extraction.

Why is the field of study important to DMSMS management?
When an item becomes obsolete, reclaimed or salvaged items may be used as a bridge to a longer-term resolution or, under some circumstances, may be sufficient to avoid capability impact through the life of need. The use of repair and salvage processes may be an option to restore an item and return it to service. This option may be a cost effective alternative to reverse engineering and re-fabricating high value components from scratch.

DMSMS resolutions themselves may also inhibit a longer service life of certain components. In-service parts, in particular, may sometimes require more refined repair or testing to enable extended life cycles. Note that similar concerns apply to testing itself and the resources and knowledge needed to perform the tests. This could be a major issue for older systems, where some test capability is no longer maintained.

What is the current status of how this field is used by the DMSMS community?
Many operational and maintenance facilities use reclaimed, repaired, or salvaged items as a source of supply, particularly for long lead-time items. Due to the fact that many parts are repaired or overhauled today, there is a lot known about some items. However, there is also a lot that is not known. General unknowns include the life of a part not previously repaired (typically a part not repaired for economic reasons will not have had any testing done on it) once it needs to be repaired for obsolescence reasons, interfaces with newer parts, electromagnetic interference effects, software, and the impact of repetitive repairs (i.e., how many times can a part be welded, soldered, etc.).

Where are advancements needed? What are the technologies involved?
Advancements are needed in new repair technologies (e.g., additive manufacturing, CS) such as their effect on fatigue life, the effect of new and re-solders on tin whiskers or dendrite growth, how to repair composite material and the repair's longevity, and how to measure the impact of extreme environments on repairs (e.g., "shake, rattle, and roll," temperature, salt, fog, etc.) without destructive testing.

How would such advancements in these technologies benefit the DMSMS management community? What would the payoff be? What could be achieved? Advancements in this area would allow for more repairs to be done without having to develop a new part or process. It would save money not having to do the development of a new part or getting a vendor to produce the parts. Additionally, it would add confidence about the capability (and limitations) of old platforms to perform the missions they were designed to do beyond their planned life.

What R&D efforts are already underway for these technologies? Who is doing the work?

ARL is conducting research on additive manufacturing and CS. The Aviation and Missile Research Development and Engineering Center (AMRDEC) is examining electronic tin whiskers and dendrite growth. It is not known whether either of them is working on the longevity of repairs. An organization associated with Massachusetts Institute of Technology (MIT) has performed non-destructive testing using a conductivity measurement. The tool was called the Magnetic Winding Magnetometer (MWM). It required a lot of data on known defects to ensure detection and was limited to metals. The current status is unknown. AMRDEC is doing some work on composite repairs. The other services are also doing composite research. The status of environmental testing research is unknown.

For each of the technologies, what are the most important projects that could be initiated?

There could be several approaches to get to an acceptable repair including advances in non-destructive testing and inspection devices and recent experience. Some potential projects include:

- Reviewing the available information on how the parts for repair are selected, how the repair process is approved, what defines success, what the acceptance tests on repaired parts would be, and whether there are life cycle limitations on the repaired parts or on systems with repaired parts.
- Developing an understanding of which parts are at such risk and making an inventory of such parts from abandoned products or performing repairs as needed and harvesting the parts.
- Determining what is being done in the environmental testing area.
- Developing a formal method for selection of what can be repaired—not every failed system can be a source of replacement parts. Limiting factors should include the age of the part, where it is in the life cycle, and the wear and tear that may have led to the part’s failure (e.g., boards that were submerged or exposed to fire may not be sources of spare parts).
- Completing an assessment of harvest and repair processes to estimate how much life is consumed from the spare part or from the assembly due to repair.
- Creating new life and environment setting for the harvested parts and the systems repaired by them.

When could the advancements be expected?

Advances could be achieved in each category. CS, composite, and solder repairs could show important results in the short term, <5 years, starting TRL 7–9.

What is the likelihood that these technological advancements would be achieved? What are the principal risks?

There is always a risk that any repair will not work and would need to be analyzed to see what went wrong. However, for the higher TRL items, the risk is low.

What is the estimate of the cost of R&D efforts needed for this field of study?
Substantial category ($1 million to $2.5 million). While limited research or limited characterization testing would cost less, the impact would be very limited.

Appendix C
Contributors

The following is an alphabetical list of the names of team members, subject matter experts, and peer reviewers who contributed to this effort.

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Appendix D.
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Appendix E.
Illustrations

Appendix F.
Acronyms and Abbreviations

AFRL	Air Force Research Laboratory
AMRDEC	Aviation and Missile Research Development and Engineering Center
ARL	Army Research Laboratory
ASIC	Application specific integrated circuit
BAA	Broad Area Announcement
BOM	bill of material
CAD	computer aided design
CAGE	Commercial and Government Entity
CALCE	Center for Advanced Life Cycle Engineering, University of Maryland
CCA	Circuit Card Assembly
CMM	coordinate measuring machines
COTS	commercial-off-the-shelf
CS	cold spray
DARPA	Defense Research Projects Agency
DLA	Defense Logistics Agency
DMEA	Defense Microelectronics Activity
DMLS	Direct Metal Laser Sintering
DMSMS	diminishing manufacturing sources and material shortages
DMT	DMSMS management team
DoD	Department of Defense
DRP	design refresh planning
DSP	digital signal processing
EOM	end-of-maintenance
EWI	Edison Welding Institute

FPGA	Field programmable gate arrays
HVOF	High Velocity Oxy-Fuel
I/O	input/output
IARPA	Intelligence Advanced Research Projects Activity
IARPA RAVEN	IARPA Rapid Analysis of Various Emerging Nanoelectronics
IC	integrated circuit
ICME	Computational Materials Engineering
ICME	Integrated Computational Materials Engineering
IDA	Institute for Defense Analyses
ILS	integrated logistics support
MAMLS	Maturation of Advanced Manufacturing for Low-Cost Sustainment
MIT	Massachusetts Institute of Technology
MOCA	Mitigation of Obsolescence Cost Analysis
MSI	Micronet Solutions, Inc.
MWM	Magnetic Winding Magnetometer
NAVSEA	Naval Sea Systems Command
NUWC	Naval Undersea Warfare Center
OEM	Original Equipment Manufacturer
OMIS	Obsolescence Management Information System
OSA	open systems approach
PHM	Prognostics and Health Management
R&D	research and development
R3S	Repair Refurbish and Return to Service
RFI	Request for Information
RFP	Request for Proposal
SDSM&T	South Dakota School of Mines and Technology
TDP	Technical data package
TRL	technology readiness level
UK MOD	United Kingdom Ministry of Defense

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14. ABSTRACT

This document, developed in conjunction with teams of subject matter experts, lists and describes fields of study where research and development investments would be beneficial to the DMSMS management community. Ten fields of study were developed and prioritized for improving and reducing the cost of DMSMS management operations. Seven fields of study were developed and prioritized for identifying where technology advances would enable more cost-effective resolutions to DMSMS issues.

15. SUBJECT TERMS

DMSMS; obsolescence; DMSMS management; DMSMS research; obsolescence management; obsolescence research

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