INSTITUTE FOR DEFENSE ANALYSES

The RAMF-SM Material Demand Computation Program: Documentation and User's Guide

Eleanor L. Schwartz

March 2022
Approved for public release;
distribution is unlimited.
IDA Paper P-22689
Log: H 21-000200

INSTITUTE FOR DEFENSE ANALYSES
730 East Glebe Road
Alexandria, Virginia 22305

About this Publication
This work was conducted by the Institute for Defense Analyses (IDA) under contract HQ0034-14-D-0001, Task DE-6-4333, "Comprehensive Assistance to DLA Strategic Materials in preparing Reports of the DOD to the Congress and other stakeholders on National Defense Stockpile Requirements and related Assessments," for the Strategic Materials Office of the Defense Logistics Agency (DLA-Strategic Materials). The views, opinions, and findings should not be construed as representing the official position of either the Department of Defense or the sponsoring organization.

For More Information:
Dr. James S. Thomason, Project Leader
jthomaso@ida.org, 703-845-2480
ADM John C. Harvey, Jr., USN (Ret), Director, SFRD
jharvey@ida.org, 703-575-4530

Acknowledgments:
The author wishes to thank the staff of DLA Strategic Materials for their input and guidance. She is also grateful to IDA staff members Dr. David Graham, Dr. Peter Picucci, Ms. Mary Catherine Flythe, and Dr. Michael Rigdon for reviewing this paper.

INSTITUTE FOR DEFENSE ANALYSES

IDA Paper P-22689

The RAMF-SM Material Demand Computation Program: Documentation and User's Guide

Eleanor L. Schwartz

Executive Summary

This paper provides documentation of the portion of the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) that calculates demands for strategic and critical materials. The computation of material demand is performed by a computer program named the Material Demand Computation Program (MDCP).

RAMF-SM, which was developed by the Institute for Defense Analyses (IDA), is a suite of procedures, models, and databases that can be used to:

- Assess shortfalls of strategic materials,
- Estimate the risks of such shortfalls, and
- Develop strategies to help reduce those risks.

RAMF-SM has played a key role in the analyses that have supported the biennial Reports to Congress concerning requirements for the National Defense Stockpile (NDS) of strategic and critical non-fuel materials.

This paper builds on IDA Document D-5477,* which describes the methodology and computer programs that RAMF-SM used for material demand computation as of 2015. Since then, methodological improvements have streamlined the computation of material demand and have expedited the modeling of a number of additional features. These improvements enabled the four computer programs described in D-5477 to be integrated into a single computer program.

This paper describes the MDCP model's basic material demand computation methodology and additional features, both at a non-mathematical level and in mathematical detail. The paper also provides a detailed user's guide for the MDCP computer program, encompassing construction of MDCP's input files, running the program, and interpreting its output.

---

* Eleanor L. Schwartz and James S. Thomason, *Computation of Material Demand in the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) Process*, IDA Document D-5477 (Alexandria, VA: Institute for Defense Analyses, August 2015).

(U) This page is intentionally blank.

Contents

1. Introduction

The intent of this paper is to provide documentation of the portion (Substep 2b) of the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) that calculates demands for strategic and critical materials (S&CMs). The computation of material demand is performed by a computer program, named the Material Demand Computation Program (MDCP). This paper describes MDCP's methodology in some detail and provides a guide to constructing MDCP's input files, running the program, and interpreting its output.

A. A Precis of RAMF-SM

The Risk Assessment and Mitigation Framework for Strategic Materials is a suite of procedures, models, and databases that can be used to assess shortfalls of strategic materials and the risks of such shortfalls. It can also be used to develop and assess strategies to help reduce those risks.

RAMF-SM and its precursors have played a key role in the analyses that have supported the biennial Reports to Congress concerning requirements for the National Defense Stockpile (NDS) of strategic and critical non-fuel materials.[1] RAMF-SM, which was developed by the Institute for Defense Analyses (IDA) and is discussed more fully in IDA Paper P-5190,[2] has six major steps:

1. Identify (and select for study) materials of concern to the U.S. national security community;
2. Compute material shortfalls to assess whether there could be significant problems in a planning scenario (such as a national emergency scenario[3]) in

---

[1] The National Defense Stockpile was established in the World War II era and has been managed by the Department of Defense (DOD) since 1988. By law, DOD is required to submit periodic reports to Congress stating which materials, and in what amounts, the stockpile should contain. The most recent such report as of this writing is Office of the Under Secretary of Defense for Acquisition and Sustainment, *Strategic and Critical Materials 2021 Report on Stockpile Requirements* (U.S. Department of Defense, n.p., February 2021).

[2] Thomason, James S., et al., *Analyses for the 2015 National Defense Stockpile Requirements Report to Congress on Strategic and Critical Materials*, Vol. I: *Material Assessments and Associated Analyses*. IDA Paper P-5190 (Alexandria, VA: Institute for Defense Analyses, August 2015).

[3] Throughout this paper, the terms scenario, emergency scenario, and national emergency scenario are used more-or-less synonymously.

meeting critical demands for materials with supplies of materials likely to be available to the United States;

3. Assess the importance of overcoming (or the risks to the United States of not overcoming) those shortfalls by deliberate government mitigation actions;
4. Identify various promising government mitigation options to address any important shortfalls;
5. Assess and compare the specific costs and mitigation effects of these government mitigations options, both individually and together; and
6. Identify priorities among the materials for investments of taxpayer dollars, whether through stockpiling or other government investments, to mitigate important potential shortfalls.

Step 2 of RAMF-SM is concerned with determining shortfalls of materials in a specified planning scenario, typically a national emergency. It has four substeps.

- Substep 2a determines the U.S. demands for goods and services, and the corresponding demand for outputs from U.S. industry, that would occur in a certain specified national emergency. These demands are developed via economic modeling, with adjustments to model the specific characteristics of the national emergency scenario.[4] Demands are expressed in millions of constant-year dollars.
- Substep 2b determines the demands for materials, i.e., the amounts of materials that U.S. industry needs in order to produce the output that will satisfy the demands computed in Substep 2a. The demands for materials are expressed in mass units (e.g., tons) of material, and are determined from the demands for goods and services by means of material consumption information, via the methodology discussed in this paper.
- Substep 2c accepts initial material supply levels and determines the available supply of materials, taking into account the characteristics of the particular national emergency scenario examined. It then compares those supplies with the

---

[4] A distinction must be made between demands and industrial output. Domestic demands for goods (and services) can be met either by items produced in the United States or by imported items. Therefore, satisfying some of the demand via imports leads to less demand for output from U.S. industry. However, goods produced in the United States for export constitute an additional demand for output from U.S. industry. The calculations of Substep 2a estimate domestic demands for goods and services (defense, civilian, and emergency investment), exports, and imports. Adding net exports (i.e., exports minus imports) to the domestic demands yields the demand for output from U.S. industry, which in turn leads to demand for materials. This addition is performed as part of Substep 2b, but it could have been done in Substep 2a instead.

material demands from Substep 2b and computes material shortfalls. Material supplies and shortfalls are expressed in mass units of material.

- Substep 2d models three different possible actions that markets might take in response to a material shortfall. These include thrift in production (using less of a material), substitution of a non-shortfall material for a shortfall one, and seeking extra sells of material from certain countries with unused production capacity. The effects of these market responses are modeled by changing the material demand and supply amounts in an appropriate manner and rerunning Substeps 2b and 2c.

Several mathematical models and dozens of databases, encompassing thousands of data items, support the computations of these substeps. The modeling of Substeps 2a and 2c has been well documented,[5] but that of Substep 2b has not. The current paper documents the most recent version of the computer program used for Substep 2b.

Figure 1 shows the six steps of the RAMF-SM process. The vast majority of the work done so far has concerned RAMF-SM Step 2, the determination of material shortfalls. MDCP is used in RAMF-SM Step 2, Substep 2b. RAMF-SM Step 1, the selection of materials for study, has usually been performed by the government sponsor of the Requirements Report studies. At times, various studies involving the other steps of RAMF-SM have been conducted.

---

5 Substep 2a utilizes several different models, as discussed in Chapter 2, Section A.3. Substep 2c is modeled using the Stockpile Sizing Module (SSM). Documentation of the SSM is contained in the following papers: Robert J. Atwell, et al., *Generic Unclassified Stockpile Sizing Module (SSM) Training and Testing for the National Defense Stockpile (NDS) 2015*, IDA Document D-5270 (Alexandria, VA: Institute for Defense Analyses, November 2014); Tara E. Santmire, *Stockpile Sizing Module Documentation for Version 4.4*, Vol. I: *Theoretical Foundations and User's Guide*, Vol. II: *SSM Inputs*, and Vol. III: *SSM Outputs*, IDA Paper P-2867 (Alexandria, VA: Institute for Defense Analyses, March 1997). Updated documentation of the SSM is in progress.

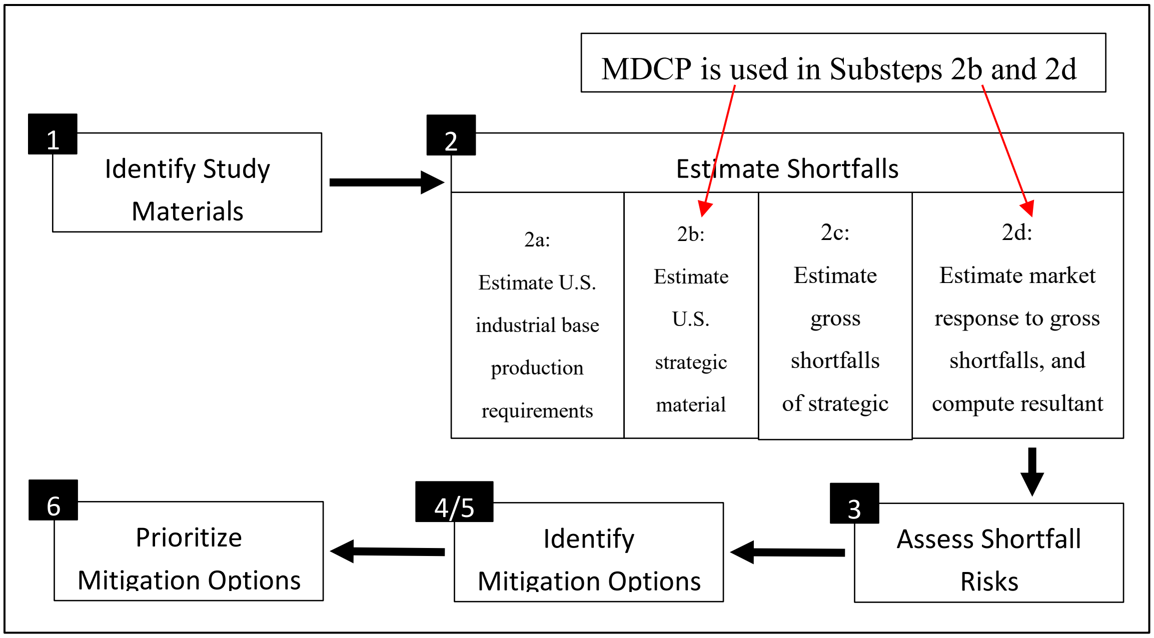

Figure 1. RAMF-SM Step and Substep Structure

B. RAMF-SM Material Demand Computation, Past and Present

This paper builds on IDA Document D-5477,[6] which describes the methodology and computer programs that RAMF-SM used for material demand computation as of 2015. The reader is encouraged to consult D-5477 for background information, but the current paper contains all the pertinent information and can be read without also reading D-5477. Since D-5477 was written, methodological improvements have streamlined the computation of material demand and have expedited the modeling of a number of additional features.

The current version of MDCP was used in preparing the Strategic and Critical Materials 2021 Report on Stockpile Requirements to Congress,[7] a slightly different predecessor version was used for the corresponding 2019 report.

Traditionally, as described in D-5477, RAMF-SM used two different algorithms for material demand computation. For most of the materials, the methodology made use of quantities called material consumption ratios (MCRs). An MCR gives the amount of material (measured in mass units) that is required for a given U.S. industry sector to produce a given dollar amount (generally a billion dollars' worth) of its output. The MCRs are computed based on material consumption and application information developed by

---

[6] Schwartz and Thomason, *Computation of Material Demand in the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) Process*.

[7] Office of the Under Secretary of Defense, *Strategic and Critical Materials 2021 Report on Stockpile Requirements*.

the Department of Commerce (DOC), the U.S. Geological Survey (USGS), and subject matter experts (SMEs). The MCR methodology has been in place for many years.

One characteristic of the MCR methodology is that it apportions material demand between civilian and defense uses based on the underlying civilian/defense breakdown of the demands for goods and services. For specialized materials with intensive defense uses, the MCR method might underestimate the amount of material used for defense purposes because the defense demand might be relatively small in dollar terms but large in material usage. For such materials, an alternative demand computation methodology was developed that explicitly considers the proportion of material used in defense applications. The concept of such a methodology has been implemented in the modeling process since the mid-1990s, with some changes over the years. D-5477 described the version used as of 2015.

Relatively recently (around 2017-2018), it was realized that given certain assumptions, the MCR methodology was a special case of the so-called alternative methodology. This discovery enabled integration of the four computer programs discussed in D-5477 into a single program. The main algorithm of MDCP is similar to what had been called the alternative algorithm. The new computer program also incorporates treatment of several options and special features, including the following:

- Thrift calculations are automated (they previously required many iterations of the MCR creation programs).
- Substitution factors can be input by application, demand category, and year.
- Special additions of materials can be modeled. For example, the 2019 Base Case used a special addition of a certain material, representing the content of that material in a planned ammo buy. Special additions are added to the material demand after the main computations are performed, and are not subject to thrift and substitution adjustments.
- If desired, the aluminum redistribution function can be invoked to compute demand for alumina and metal-grade bauxite.[8]
- The program automatically writes notes files for the main output files.

C. Structure of This Paper

This paper is organized as follows. Chapter 2 describes the basic methodology and special features at a non-mathematical level. Some of this description is adapted from D-

[8] See Chapter 2, Section E.2. The original description of the aluminum redistribution function appears in Santmire, *Stockpile Sizing Module Documentation for Version 4.4*, Vol. I: *Theoretical Foundations and User's Guide*.

5477. Chapter 3 is a detailed user's guide for the MDCP model and computer program, encompassing discussion of the input files, output files, and program operation. Chapter 4 provides a mathematical treatment of the methodology.

2. Methodology

A. Key Concepts

1. RAMF-SM Steps and Substeps

As noted in Chapter 1, step 2 of RAMF-SM concerns the computation of material shortfalls in certain emergency scenarios; it has four substeps:

- Substep 2a: Compute (domestic) demands for goods and services in the scenario. This step uses economic modeling and the Forces Mobilization Model (FORCEMOB), as described in Section A.3.
- Substep 2b: Determine the materials that U.S. industry needs to manufacture these goods and services. This substep is the purview of the MDCP model. (In the context of RAMF-SM and MDCP, the term "material demand" should be interpreted as meaning material needed by U.S. manufacturers.)
- Substep 2c: Determine available material supplies and compare them with the material demands to determine shortfalls. The computations are performed by the Stockpile Sizing Module (SSM), a separate component of RAMF-SM.[9]
- Substep 2d: Model market responses as appropriate. The computations of the thrift and substitution market responses are described in Sections C and D. (The third response, extra sell, is modeled within the SSM.)

MDCP implements the modeling of Substep 2b and those portions of Substep 2d that deal with the reduction of material demand. MDCP inputs include the outputs of Substep 2a (see Section A.3). MDCP's output, a set of material demands, becomes input to Substep 2c. MDCP computes a separate demand value for each combination of material modeled, scenario year, and "tier," or category; the tiers are defense demand, emergency investment demand, and civilian demand.[10] Demands are expressed in mass units of measure, such as tons; a separate unit of measure can be specified for each material.

---

9 Schwartz and Thomason, *The RAMF-SM Stockpile Sizing Module: Updated Documentation and User's Guide*; Atwell, et al., *Generic Unclassified Stockpile Sizing Module (SSM) Training and Testing for the National Defense Stockpile (NDS) 2015*; Santmire, *Stockpile Sizing Module Documentation for Version 4.4*, Vol. I, *Theoretical Foundations and User's Guide*.

10 Emergency investment demand constitutes the goods, services, and materials required to build those new production facilities (e.g., factories) that are necessary to produce essential goods and services in a national emergency. It is zero in peacetime.

2. Scenario and Timelines

As implied by the above discussion, MDCP distinguishes between peacetime conditions and scenario conditions. The word “peacetime” is used to denote steady-state or business as usual, even though there might be some ongoing general turmoil or inherent instability. The scenario conditions are those of the particular national emergency scenario to be analyzed. The term “reference period” denotes a recent year or set of years where historical data for material consumption and economic output are available. Quantities defined “in the reference period” refer to average annual amounts over the years of the reference period under peacetime conditions. The term “historical” is also used to refer to such quantities. Different materials can have different reference periods, depending on the years for which historical consumption data are available. The scenario period is the time span of the national emergency scenario, which will generally start some years after the reference period, and might be several years long.

3. Economic Data: Underlying Goods and Services Demands

MDCP accepts as inputs demands for goods and services, i.e., the outputs of RAMF-SM Substep 2a, under both peacetime and scenario conditions. (The term “scenario” is used to refer to the emergency scenario, but it could actually have the same demands as in peacetime.)[11] The peacetime goods and services demands are determined by two economic forecasting models developed by the Inter-industry Forecasting Project at the University of Maryland (INFORUM); they are named LIFT (Long-term Inter-industry Forecasting Tool) and ILIAD (Inter-industry Large-scale Integrated And Dynamic Model).[12] Currently, Version 6 of ILIAD is used; it considers 352 different industry sectors that together span the U.S. economy.[13] RAMF-SM also uses historical economic data from INFORUM. The goods and services demands in the emergency scenario are computed by the economic models and the FORCEMOB model.[14] FORCEMOB uses the 352 ILIAD industry sectors.

---

[11] Material demand results from a peacetime scenario are used in calibrating the material supply inputs for RAMF-SM Substep 2c. See Eleanor L. Schwartz, *The Material Supply Adjustment Process in RAMF-SM Step 2*, IDA Document D-5564 (Alexandria, VA: Institute for Defense Analyses, June 2016).

[12] References are as follows: Meade, Douglas S. *The INFORUM LIFT Model*. Technical Documentation, College Park, MD, Inter-industry Forecasting Project, University of Maryland, November 2017; Meade, Douglas S., et al., *ILIAD,* College Park, MD, Inter-industry Forecasting Project, University of Maryland, December 2011.

[13] The sectors generally correspond to the North American Industry Classification System (NAICS) 4-digit level. NAICS is a classification of business establishments by type of economic activity; it is used for statistical analysis by the governments of the United States, Canada, and Mexico. “North American Industry Classification System,” United States Census Bureau Website, accessed January 2022, https://www.census.gov/naics/.

[14] FORCEMOB references: James S. Thomason, et al., *Forces Mobilization Model (FORCEMOB): Unclassified Training Tutorial,* IDA Document D-5433 (Alexandria, VA: Institute for Defense Analyses, August 2015); Eleanor L. Schwartz, et al., *Documentation of the Forces Mobilization Model (FORCEMOB), Versions 3.1 and 3.2*, Vol. I: *General Description*; Eleanor L. and James S. Thomason,

It implements appropriate adjustments to the peacetime data and computes additional goods and services demands due to weapon replacement requirements and emergency investment. For each industry sector, FORCEMOB outputs time streams of civilian demand, military demand, emergency investment demand, imports, and exports. The FORCEMOB output becomes input to MDCP (see Chapter 3, Sections A.8 and A.9).

All goods and services demands are expressed in millions of constant-year dollars (year 2009 dollars were used for the 2021 Requirements Report). They are expressed in total requirements terms, i.e., they include demands by other industries as well as demands by end-users.[15]

4. Material Application Areas and Associated Industries

The main principle of the new methodology remains the same as in the traditional methodology: link material use with industry sectors. Changes in demands for materials then are computed as the result of changes in the demand for output from the industry sectors that use that material. The linkage is implemented via the use of "application areas." Each material is assumed to be used in a number of application areas and each application area has associated with it a set of industry sectors of the economic model (see Chapter 3, Sections A.5 and A.6).

Recent Requirements Reports have divided the analyzed materials into two groups, denoted Study List 1 (SL1) and Study List 2 (SL2). SL1 materials tend to be generic commodities while SL2 materials are specialized material forms or manufactured products. The distinction is unimportant for the MDCP model itself, but the data sources for the two material groups tend to be different. SL1 material consumption and application data have generally been obtained from material specialists at the Department of Commerce or the U.S. Geological Survey. For SL2 materials, they are obtained from a variety of subject matter experts.

The industry sectors associated with each application are determined using the expert judgment of someone familiar with the industry sectors of the INFORUM models, with advice from the material specialists about the specific uses of the material in question. Note that a given industry sector can be associated with more than one application area. The Commerce data usually provide a list of associated North American Industry Classification System (NAICS) codes for each application; INFORUM provides a correspondence

---

Vol. II: *Data Preparation Guide,* IDA Paper P-2953 (Alexandria, VA: Institute for Defense Analyses, January 1996).

15 The concept of total requirements demand is discussed in Schwartz and Thomason, *Computation of Material Demand in the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) Process*. For additional information, see Ronald E. Miller and Peter D. Blair, *Input-Output Analysis: Foundations and Extensions*. Second edition (New York City, NY: Cambridge University Press, 2009).

mapping between NAICS codes and the ILIAD sectors. If no NAICS codes are provided, one can consult with SMEs about the industries that use a material, or look up NAICS codes or ILIAD sector names that contain the words used in the application area names. Fortunately, the application areas do not change much from year to year, so there is a lot of legacy information that can be used.

The basic distinction between application areas and industry sectors is that the former represent expert judgment about how and where a material is used, while the latter are tied to the particular economic model (ILIAD, in this case).

5. Military Fractions

For each application area, for each material, the user can—but is not required to and frequently does not—specify a fraction of usage of demand in that area that is for military (i.e., defense) purposes.[16] Usually, the military fraction values come from the subject matter experts who develop the application areas. If an application area is not listed in the military fractions file, MDCP computes a fraction of military use as the ratio of total peacetime defense demand to total peacetime demand of the industry sectors associated with the application over the years of the reference period for the material. (See Chapter 4 for a mathematical definition.) Many materials might have none of their application areas listed in the military fractions file. Conversely, some materials could have all their application areas listed. Because the data for SL1 and SL2 materials have traditionally been developed in different ways, using different data sources, the SL2 material applications usually have explicit military fractions while the SL1 materials generally do not. As mentioned earlier, if *none* of the application areas for a material have explicitly-input military fractions, then the MDCP methodology produces the same total defense and civilian demands as the MCR methodology. See Section B.3 and Chapter 4 for more discussion of this topic.

The discussion of the military fractions file in Chapter 3 provides specific information on how to input military fractions into the computer program.

6. Flowchart

Figure 2, which is adapted from D-5477, shows a schematic of the first three substeps of RAMF-SM Step 2. It indicates the information flows and the models used in each substep.

[16] Throughout this paper, the terms military fraction, defense fraction, and defense usage fraction are used synonymously.

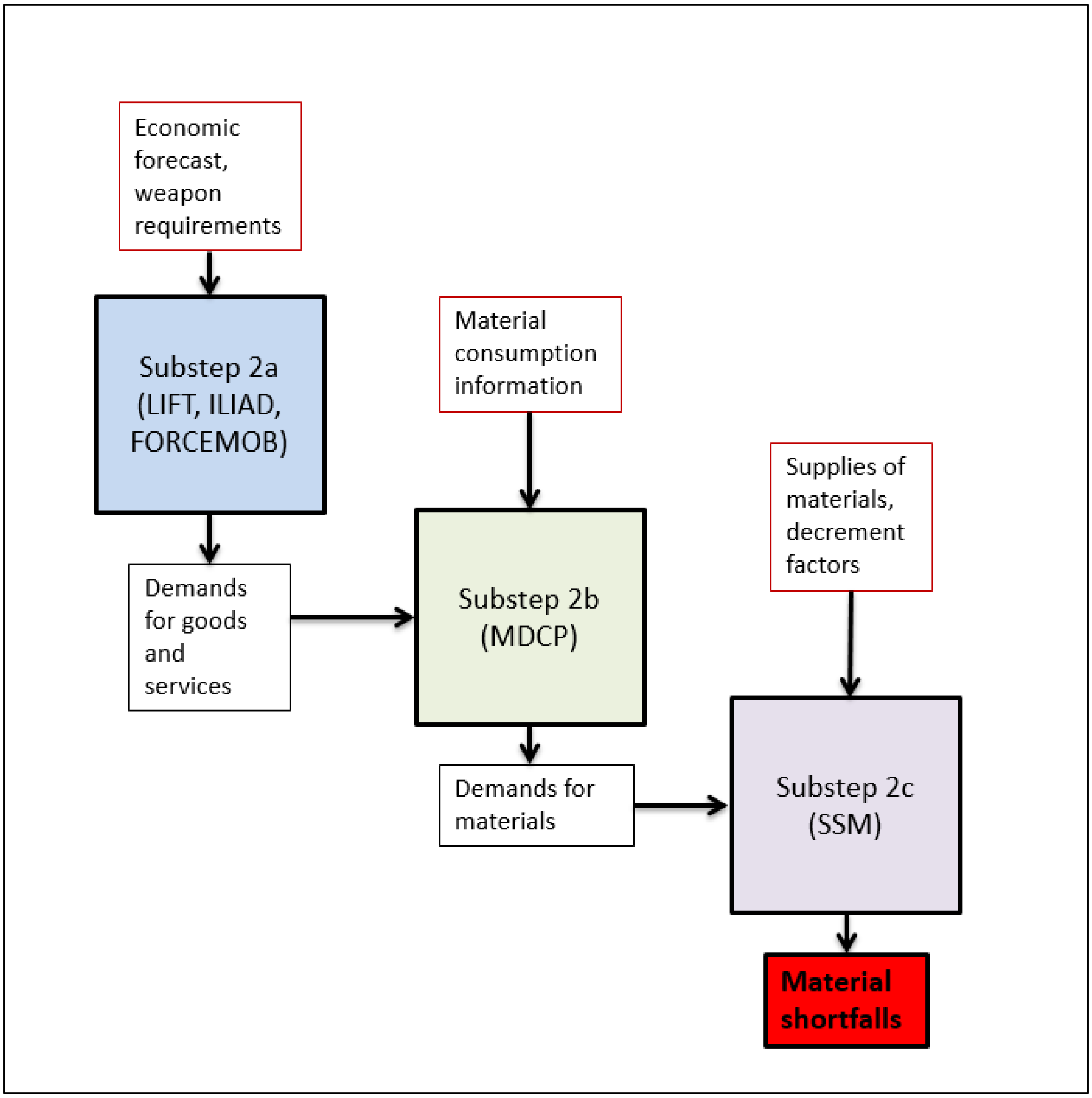

Figure 2. RAMF-SM Substeps 2a, 2b, and 2c: Flow and Models Used

B. Computation of Material Demand

Building on the key concepts laid out in the preceding section, this section describes, at a non-mathematical level, how MDCP calculates material demand. For fuller understanding, the reader is encouraged to consult the mathematical description in Chapter 4. The input file descriptions in Chapter 3 can also provide a picture of the nature of the inputs and, by inference, the computations.

1. Computation of Defense and Civilian Material Demand

The MDCP algorithm for computing defense and civilian material demand is similar to the alternative algorithm described in D-5477. It is performed for each material separately. For the remainder of this section, assume that one specific material is under consideration.

The treatment proceeds application area by application area. Consider a given application area. The average annual peacetime material consumption in the reference period is multiplied by the fraction of consumption used in that application area to obtain a historical consumption amount used in that application area. That value is separated into civilian and military parts, using the military fraction for that application area. Thus, for that application area the average annual amounts of defense consumption and civilian consumption of the material in the reference period are computed.

Two FORCEMOB runs are used. The first run is associated with the particular emergency scenario being modeled. The second one has peacetime assumptions and encompasses all years from the beginning of the reference period through the end of the scenario period. Based on the FORCEMOB output (i.e., economic demands) for the industry sectors associated with the given application area under consideration, four different factors are computed for each year of the scenario period:

- Defense growth factor;
- Civilian growth factor;
- Defense scenario adjustment factor;
- Civilian scenario adjustment factor.

The growth factors account for differences in demand between the reference period and the given scenario year (generally due to economic growth). The scenario adjustment factors account for differences between emergency scenario conditions and peacetime conditions. (For example, defense demands might be greater than in peacetime because of platform and munition regeneration requirements, while civilian demands might be less than in peacetime because only essential civilian demands are included.)

The defense demand in a given scenario year in the given application area is computed by taking the defense consumption in that application area in the reference period and multiplying it by the defense growth factor and the defense scenario adjustment factor. The corresponding computation is made for civilian demand. After all application areas have been processed, the demands are summed to yield overall defense and civilian demands for each scenario year.

2. Equivalence of the Basic Algorithm and the MCR Method

As noted in D-5477, there were two vintage algorithms for computing material demand. The MCR algorithm was oriented around industry sectors, while the alternative algorithm was oriented around material application areas. The merger of the two algorithms, as implemented in the current MDCP program, was made possible by the realization that under certain circumstances, the MCR algorithm is a special case of the alternative algorithm.

For every application area, MDCP considers the fraction of demand in that area that is for defense purposes (see Section A.5). The user is allowed to input that fraction, but for application areas without user input, the program computes a fraction of defense usage based on the defense vs. civilian demand in the industry sectors associated with that application area, using peacetime economic data in the reference period. The key theorem states that if the program computes the defense usage fraction for *every* application area for a material, then the MCR algorithm and the alternative algorithm compute the same total defense and total civilian demand. Section C of Chapter 4 formalizes the above discussion as a mathematical theorem and provides a proof of the theorem.

3. Computation of Emergency Investment Material Demand

Emergency investment material demand is a separate category of demand, in addition to the computed defense and civilian material demands. If the industry sectors associated with the material application areas do have some emergency investment demand for goods and services (as computed by FORCEMOB), it would seem appropriate to compute the amounts of material necessary to manufacture these goods and services. Under the MCR algorithm, this computation was straightforward: the MCRs were multiplied by the emergency investment demands for goods and services. When the MCR algorithm is inappropriate, modeling of emergency investment material demand becomes more problematic.[17] Early versions of the alternative demand computation algorithm simply ignored it. The version proposed in D-5477 combined it with the defense demand. Since D-5477 was written, a new formula has been developed that reproduces the MCR formula when the fractions of military demand are computed by the program for all the application areas of a material. For details, see Section D of Chapter 4.

4. Computation of Material Demand by Industry Sector

The MCR algorithm computes material demands by industry sector (an MCR applies to a single industry sector) and then sums them to compute total material demands. One of the output reports of the legacy Requirements Creation Submodule (discussed in D-5477) was a table of material demands by material, industry sector, tier, and scenario year. These demands were obtained by multiplying the MCR for a particular material/industry combination by the goods and services demand in the particular industry sector, tier, and scenario year.

[17] The main reason for this is that the alternative algorithm works by taking ratios of scenario demands for goods and services to the corresponding peacetime demands. Emergency investment demand for goods and services is zero in peacetime, so a ratio cannot be formed.

The current MDCP algorithm computes the material demands by application area; the industry sectors play a more indirect (though essential) role. Demands by industry sector can be obtained by apportioning demand in an application area among the industries associated with that application area, in proportion to the demands on those industries. For informative purposes, a section of the computer program performs such a procedure and outputs a report. Mathematical details of the computations appear in Section E of Chapter 4. If defense usage fractions for all of the application areas for a given material are computed by the program (i.e., if none of them are input), the demands by industry match those computed by the MCR method.

C. Modeling of Thrift

As a response to a material shortfall, manufacturers might decide to use material in a more thrifty manner, i.e., to use less of it in producing a certain dollar amount of economic output. RAMF-SM has a capability to model this kind of thrift. The current implementation of thrift modeling in MDCP automates what had been laborious, repetitive hand calculations and legacy computer program runs.

The thrift calculation is based on the fact that the material consumption amounts, economic output, and the ratio of the two quantities can be different for different years of the reference period. Years with a lower ratio indicate that the material is being used in a thrifty manner. MDCP uses this concept to model thrift, as follows. For each year of the given input reference period, for each application area in turn, the regular MDCP algorithm is performed using that particular year as the reference period. The reference period year that produces the lowest material demand, and the resultant material demand amount, are noted. Separate computations are performed for each combination of demand tier and scenario year (do not confuse scenario years and reference period years). These lowest material demand amounts in each application area are added up to produce total thrift demand amounts for the material in question by demand tier and scenario year.

To sum up, MDCP automatically computes a set of demands under thrift for each combination of material, application area, demand tier, and scenario year. However, only the totals over application area (i.e., total thrift demand by material/demand-tier/scenario-year combination) are kept track of for output purposes. A separate "thrift profile," which is an input file to the computer program, specifies which material/demand-tier/scenario-year combinations are to use the thrift demands and which are to use the regular demands. The structure of the thrift profile file is described in Chapter 3, Section A.11.

D. Modeling of Substitution

One strategy to mitigate the risks of a material shortfall is to use other materials to substitute for the material that is in shortfall. The use of substitution might be pursued as a deliberate government effort or might occur as a response by markets to a shortfall. Recent

Requirements Reports have proceeded on the latter assumption. Over the years, IDA has conducted extensive research into the possibility of substitution for materials that might be in shortfall in a national emergency.[18] [19]

MDCP models substitution by reducing material demand via applying substitution factors. The demands are computed by the standard algorithm and then multiplied by the substitution factor to obtain a reduced demand, which in turn will reduce or eliminate the material shortfall. The factor values are developed by subject matter experts and/or are based on previous research.

The factors can vary by material, application area, demand tier (defense, emergency investment, civilian), and year of the scenario in accordance with the following reasoning.

- Since different applications of a material might have different substitutabilities, the factor values can vary by application area.
- The varying of factors by demand tier can reflect certain policy judgments. For example, in the 2021 Requirements Report study, substitution was allowed only for civilian demand.
- Allowing the factor values to vary by year enables the modeling of cases in which manufacturing processes that use the substitute material take some amount of time to gear up so that full substitution cannot be performed until a later scenario year, for example, the second or third. An intermediate value for the factor can model partial substitution in the changeover period.

The substitution factors are input to MDCP on a file, described in Chapter 3, Section A.12. The file is optional; if it is omitted, all materials are considered to be non-substitutable. If both thrift and substitution are modeled, the demands under thrift are computed first; these are then multiplied by the appropriate substitution factors.[20]

---

[18] For example, see James S. Thomason, et al., *Analyses for the 2011 National Defense Stockpile Requirements Report to Congress on Strategic Materials,* Vol. I: *Main Report*, IDA Paper P-4695 (Alexandria, VA: Institute for Defense Analyses, March 2011); Thomason, et al., *Analyses for the 2015 National Defense Stockpile Requirements Report to Congress on Strategic and Critical Materials*, Vol. I: *Material Assessments and Associated Analyses* (especially see Appendix 11); James S. Thomason, et al., *IDA Contributions to the Strategic and Critical Materials 2019 Report on Stockpile Requirements*, Vol. I, *Unclassified Contributions*, IDA Paper P-10727 (Alexandria, VA: Institute for Defense Analyses, October 2019), (especially see Chapter 8).

[19] It is conceivable that increased use of the substitute material might induce a shortfall of the substitute material. MDCP assumes this is not the case. The substitute materials should not be among the materials considered by MDCP itself, and should not be in danger of becoming scarce during the national emergency scenario.

[20] Currently, MDCP cannot model interaction effects between thrift and substitution, such as thrift being an option only for non-substituted materials.

E. Additional Features

1. Special Additions of Material

In addition to its regular material demand computation procedure, MDCP allows for "special additions" of materials that are expected to occur as part of the scenario but are not able to be modeled by the standard methods. For example, the scenario might include a planned buy of certain kinds of ammunition that use large amounts of a certain material.[21] The amount of material in the buy can be calculated offline and then input as a special addition to MDCP. MDCP computes material demand via its regular methods, and then adds the special addition amount to the result. A separate amount of special addition can be specified for each combination of material, demand tier, and scenario year. Special additions are not subject to the thrift and substitution calculations.[22]

If modeled, the special additions amounts are input to MDCP on a file, as described in Chapter 3, Section A.2. The file is optional; if omitted, it is assumed that no special additions are to be modeled.

2. The Aluminum Redistribution Function (ARF)

The aluminum redistribution function can be invoked as an option to compute demand for alumina and metal-grade bauxite, which are precursors to the manufacture of aluminum metal.[23] Note that aluminum metal demand itself is computed by the regular MDCP method. The ARF has been an option in RAMF-SM for many years.[24] It was an option in the legacy Requirements Creation Submodule; in the current version of RAMF-SM, it has been implemented as an option in MDCP.

The ARF is predicated on the assumption that the only use of alumina and metal-grade bauxite is to produce aluminum metal. Thus, the demand by U.S. manufacturers for alumina and metal-grade bauxite is limited not only by the demand for aluminum metal, but also by the U.S. capacity to *supply* aluminum metal. If the ARF option is exercised, the program reads an input file that specifies a U.S. aluminum metal supply amount for each scenario year. (These data are also used in Substep 2c of RAMF-SM.) Aluminum metal demand is computed by the regular MDCP procedure; the program then takes the minimum

---

[21] The 2019 Requirements Report modeled a special addition of this kind.

[22] The idea is that special additions represent material demands extrinsic to the MDCP process. If appropriate, it might be possible to change the program to model thrift and substitution for special additions.

[23] The discussion in this section applies to alumina as a generic (SL1) material. Certain specialized forms of alumina are modeled as SL2 materials with their own demand and supply calculations.

[24] See Santmire, *Stockpile Sizing Module Documentation for Version 4.4*, Vol. I: *Theoretical Foundations and User's Guide*.

of that amount and the supply amount (separately for each scenario year). It is assumed that to produce a given amount of aluminum metal requires twice that amount of alumina and four times that amount of metal-grade bauxite. These conversion factors have been verified by the U.S. Geological Survey. For each scenario year, the minimum of the aluminum metal demand and supply amounts is multiplied by two and four, respectively, to obtain amounts of alumina and metal-grade bauxite demanded. These amounts are distributed among the demand tiers in proportion to the economic data for those tiers.

The 2019 Requirements Report used the ARF to compute alumina and metal-grade bauxite demand. For the 2021 Requirements Report, however, it was noted that other uses, in addition to being precursors of aluminum metal, had developed for alumina and metal-grade bauxite. It was therefore decided to use the regular MDCP methods for computing their demand. The ARF remains as an MDCP option, however.

3. The Embedded Demand Increment

In the calculation of material demand, net exports are added to the civilian demand for goods (and services),[25] for each industry sector before the calculations of MDCP are performed. The reason for this is straightforward: Goods made for export constitute a source of demand on U.S. industry, and the materials needed to manufacture them need to be accounted for. Conversely, some of the (domestic) demand for goods is satisfied by imports; such goods do not have to be manufactured in the U.S. The civilian material demand values computed by the MDCP include these export and import adjustments.[26]

Frequently, one wants to determine why civilian material demand in the scenario differs from peacetime civilian demand. Two major factors apply, which tend to work in opposite directions. The formalization below illustrates how these factors work. The notation applies to this subsection only.

Consider any one particular industry sector and one particular scenario year. Let C^{case}, E^{case}, and I^{case} denote the civilian demand, exports, and imports for goods in that sector and year under the scenario (i.e., case of interest) conditions. These quantities are computed by the FORCEMOB model. Let C^{peace}, E^{peace}, and I^{peace} denote the corresponding peacetime quantities, which are computed by the economic models and FORCEMOB. One can define the civilian plus net exports quantities

$$T^{case} = C^{case} + E^{case} - I^{case}$$

---

[25] Since most imports and exports concern goods rather than services, the "and services" term will be omitted in this section.

[26] Conceivably, some portion of net exports could be added to the defense demand. This possibility has been explored at various times, but the official versions of MDCP and its predecessors have always added net exports to the civilian demand.

and

$$T^{peace} = C^{peace} + E^{peace} - I^{peace}.$$

Suppose we subtract and then add T^{peace} to T^{case}; we obtain $T^{case} = T^{case} - T^{peace} + T^{peace}$. The right-hand side can be expanded to yield

$$T^{case} = T^{peace} + C^{case} + E^{case} - I^{case} - (C^{peace} + E^{peace} - I^{peace});$$

this expression can then be rearranged to obtain

$$T^{case} = T^{peace} + \left([C^{case} + E^{case}] - [C^{peace} + E^{peace}]\right) + \left(I^{peace} - I^{case}\right).$$

The case civilian demand plus net exports is thus the peacetime civilian demand plus net exports, plus the two terms shown in parentheses. The first term, which can be called the austerity adjustment,[27] tends to be negative. This is because the case civilian demand often includes only that portion of civilian demand that is deemed essential, which can be considerably less than the peacetime civilian demand.[28]

The second term, $(I^{peace} - I^{case})$, is often referred to as the embedded demand increment, and it can be quite large. In the case scenario, imports from adversary, hostile, or unreliable countries are usually reduced from their peacetime levels, sometimes by a considerable amount. Part of the demand for goods is satisfied by imports. The RAMF-SM analysis assumes that in an emergency scenario, all the defense demands are essential and the civilian demands have already been pared to their essential levels, so the country cannot "just do" without the goods. The demanded goods that are not satisfied by imports must be manufactured domestically, and the materials needed for such manufacture constitute part of the overall material demand. If imports of goods are cut from their peacetime levels, less demand can be satisfied by imports and more demand must be satisfied by domestically-manufactured goods. The embedded demand increment provides a measure of this latter demand amount.

The upshot is that T^{case} equals T^{peace} plus the sum of two different adjustment terms, which tend to work in opposite directions. One of the MDCP output reports[29] shows the four terms T^{case}, T^{peace}, the austerity adjustment, and the embedded demand increment, for

---

[27] The Stock Piling Act mandates stockpiling to cover essential civilian demands only. Thus, for the purpose of determining shortfalls, normal projected civilian-sector demands are decremented to eliminate nonessential civilian goods and services. However, the emergency scenario used for the Requirements Reports assumes that the U.S. government will *not* take any regulatory measures to curtail or prevent the production of nonessential civilian goods and services. That is, there is no formal government-mandated civilian austerity. Informally, however, the term "austerity" has been used to refer to the inclusion of essential civilian demand only.

[28] In practice, the export adjustments, which are added in here, are usually a minor factor.

[29] The report has the file code "emb," standing for embedded demand increment. See Chapter 3, Section D for information on the output file codes.

each combination of industry sector and scenario year. For materials with valid MCRs, it also shows the corresponding material amounts for the four quantities (obtained from the industry amounts via multiplying by the MCRs and summing) for each scenario year. Examination of this file can frequently uncover the cause of a major change in material demand between peacetime and case conditions. The program's calculation of the embedded demand increments automates what had been a time-consuming search through intermediate output files.

This page is intentionally blank.

3. MDCP User's Guide

This chapter constitutes a user's guide for MDCP. It provides detailed descriptions of the input files with examples. It also shows how to run the program and discusses the output files.

Among the input files, the so-called control inputs file has a special role. The control inputs file lists the other input files for the given MDCP run to use. It specifies certain date ranges and various option indicators. It can also contain notes about the run; the user is strongly urged to write such notes since they help greatly in keeping track of the particulars of different runs. The control inputs file is discussed in Section B. First, Section A discusses the other input files, which are termed data files.

A. MDCP Input Data Files

This section describes the structure of the input data files to MDCP. Table 1 lists the MDCP input data files along with their associated file type numbers (used on the control inputs file). Some of the files are optional, as indicated in the table. The name of each data file (including extension, but not including the path) must be 32 characters or less and must not contain spaces (the underscore character is allowed). If no extension is specified, the program will assume the extension is '.txt'. Each file is discussed in turn in the sections below.

Table 1. MDCP Input Data Files

File Type Number	File Type	Optionality Status
1	Element File (list of industry names)	Required
2	Special Additions File	Optional
3	Material Consumption File	Required
4	Material Year Spans File	Required
5	Material Applications File	Required
6	Application by Industry File	Required
7	Optional Application Weights File	Optional
8	FORCEMOB Case File	Required
9	FORCEMOB Peace File	Required
10	Military Fractions File	Optional

File Type Number	File Type	Optionality Status
11	Thrift Profile	Optional
12	Substitution Factors File	Optional
13	Aluminum Supply File	Optional

1. File 1: Element File

The element file is one of the input files to FORCEMOB. It contains a lot of basic information, including lists of industry sectors and weapon types. It is a text file with a fixed-column format, and is best prepared in a text editor.[30] MDCP is set up to read the same element file as used in FORCEMOB. MDCP reads the header lines and the names of the industry sectors, then stops. Figure 3 shows a portion of the element file, including the first several lines.

```
Element File revised July 8, 2020
2009      Dollar year IDOLYR
Database Years
2012   2026
Industry Data  Set of 352 sectors compatible with Iliad Version 6
352
  1  Oilseed farming               Oilseed farming
  2  Grain farming                 Grain farming
  3  Vegetable and melon farming   Vegetable and m
  4  Fruit and nut farming         Fruit and nut f
  5  Greenhouse/nursery/floricult  Greenhouse/nurs
  6  Other crop farming            Other crop farm
  7  Cattle ranching & dairy farm  Cattle ranching
[rest of industry sectors]
```

Figure 3. Top Portion of Sample Element File

FORCEMOB requires the element file to have the hard-coded name element.db. Usually, the element file is prepared in a text editor under some other name and is then copied to a file named element.db. MDCP does not require a hard-coded name. The name of the element file is input on the control inputs file.

MDCP reads the top five lines of the element file, but then ignores them. The number of industry sectors appears on line six. It should be the same as the number of industry sectors shown on the control inputs file. If not, the program prints an error message and terminates.[31] The individual industry sectors then appear in the following format:

---

[30] The easiest procedure is to take an existing element file and edit it.

[31] The MDCP computer program generates a file of informative messages about program progress. Messages about error conditions are printed on this file; the other information in the file can assist the user in determining where and why the error occurred. For more information on the message file, see Section D.

- Columns 1-3. Sector number (1,2,3)
- Columns 4-5. Blank
- Columns 6-35. Sector name, 30-character maximum, no commas.
- Columns 36-50. Short sector name, 15-character maximum, no commas (used by FORCEMOB, but not MDCP).

The industry sector numbers and names are those of the underlying economic model (currently, ILIAD Version 6). The names must be shortened to 30 characters. For the program to parse certain files correctly, they should not contain commas (semicolons are acceptable). These remarks apply to preparation of the Element file both for FORCEMOB and for MDCP.

2. File 2: Special Additions File

In addition to its regular material demand computation procedure, MDCP allows for "special additions" of materials that are expected to occur as part of the scenario but are not able to be modeled by the standard methods, as explained in Chapter 2, Section E.1.

The special additions file is a rectangular array of numbers with one header row. It is a tab-delimited text file that can be viewed and edited as such in Excel. The file is optional; if it is not listed in the control inputs file, MDCP assumes there are no special additions. Table 2 shows the fields of the special additions file with a brief description of their contents.[32] The special addition amounts should be expressed in the units of measure shown on the consumption file in Section 3. To avoid inconsistent results, a given material should not be listed more than once. The data preparer should check for this as the program does not check automatically.

Table 2. Fields of the Special Additions File

Field	Item & Description	Header
1	short material name	Material
2 through n+1	amount of special addition to defense demand in y^{th} scenario year (y=1,…,n)	Calendar year corresponding to y
n+2 through 2n+1	amount of special addition to emergency investment demand in y^{th} scenario year (y=1,…,n)	Calendar year corresponding to y
2n+2 through 3n+1	amount of special addition to civilian demand in y^{th} scenario year (y=1,…,n)	Calendar year corresponding to y

n = number of years in the scenario

[32] This table and subsequent similar ones that describe fields of a data file, have a column that shows the contents of the header line for the file for each given field. Except for calendar years, which should be in standard 4-digit format (e.g., 2021), the entries in this column are intended to be descriptive rather than literal text strings. The example files should make this idea clear. Except for calendar years, the program does not make use of the contents of the header line.

Figure 4 shows a sample special additions file. This file specifies that 200 metric tons of Material_1 be added to the defense demand each year of the scenario, in addition to the defense demand computed by the regular algorithm.[33]

MATERIAL	2023	2024	2025	2026	2023	2024	2025	2026	2023	2024	2025	2026
Material_1	200	200	200	200	0	0	0	0	0	0	0	0

Figure 4. Sample Special Additions File

3. File 3: Material Consumption File

The material consumption file is one of the basic, essential input files to MDCP. It shows the historical material consumption amounts, but also specifies the set of materials and units of measure that will be used throughout Substeps 2b and 2c of RAMF-SM.

The material consumption file is a rectangular array of numbers with one header row. It is a tab-delimited text file that can be viewed and edited as such in Excel. Table 3 shows the fields of the material consumption file with a brief description of their contents.

Table 3. Fields of the Material Consumption File

Field	Item & Description	Header
1	Short material name (25-character limit)	Material
2	Long material name (more descriptive; 50-character limit)	Long_name
3	Units of measure	Units
4 through m+3	Amount of U.S. consumption of the material in historical calendar year y	Calendar year y

m = number of years for which historical information will be provided for at least one material

The short material names, long material names, and units of measure should match those used in the SSM (as listed in the SSM Basic Information input file).[34] The short material names should not contain spaces, but underscore characters are allowed. Short material names appearing in the other MDCP input files will be matched against the list of names appearing in this file; if a material is not found, the program prints an informative error message and terminates. Long material names should not contain commas, but

33 See the discussion of material names in Section 3 below.

34 The SSM is the major model used in RAMF-SM Substep 2c. The Basic Information file is one of the input files to the SSM (not MDCP). For more information on the SSM and its files, see Atwell, et al. *Generic Unclassified Stockpile Sizing Module (SSM) Training and Testing for the National Defense Stockpile (NDS) 2015*. Also see Schwartz and Thomason, *The RAMF-SM Stockpile Sizing Module: Updated Documentation and User's Guide*.

semicolons are acceptable. The consumption data in this file come from subject matter experts. For the SL1 materials, the SMEs are usually at the Department of Commerce or USGS. There is often a choice of several sets of consumption data to use, and sponsor judgment should be followed. The consumption values are often, though not always, proprietary. (The values in the sample consumption file shown below were generated via random numbers.)

The range of historical years specified on the top row of the file will be compared to the consumption year range shown on the control inputs file; if the ranges are not the same, the program prints an informative error message and stops. A consumption value need not be given for every material for every year; zeroes can be used to fill in the matrix for unavailable data. The program will use the consumption data only for the historical years specified on the year spans file (Section 4).

Some of the programs that were precursors to MDCP had a capability of converting units of measure. This is not the case with MDCP; conversion of the consumption values to the units of measure for the study must be performed during the data preparation process. One particular kind of units conversion merits special discussion. For some materials, the consumption data from the Department of Commerce are expressed in terms of contained metal or contained non-ferrous metal, but the material supply values from USGS are expressed in gross weight. Given that the SSM uses gross weight values, a contained-to-gross conversion factor must be obtained from an SME and applied. For example, manganese ore is 48% contained manganese. The manganese ore consumption values from Commerce, which are expressed in terms of contained manganese, must be divided by 0.48 before being listed on the material consumption file. The MDCP results will then be compatible with the SSM supply values, which measure manganese ore in gross weight.[35]

If the aluminum redistribution function option is being exercised, the short material names ALMNM_METAL, ALMNA, and BAUXITE_METAL must be used for aluminum metal, alumina, and metal-grade bauxite, respectively. The program looks for those specific text strings. All three materials must appear in the material consumption file with the same units of measure (e.g., metric tons). The aluminum supply file values (see Section 13) must also be expressed in this unit of measure. The alumina and metal-grade bauxite units should be gross weight, not contained aluminum.

---

[35] For manganese ore, an additional conversion factor from metric tons to short tons was also necessary.

A sample material consumption file appears in Figure 5. The material names have been chosen to match those in the sample SSM database used in the SSM tutorial.[36] MDCP does not require that the materials or their names be numbered in sequential order.[37]

Material	Long_Name	Units	2014	2015	2016	2017	2018
Material_1	Material 1	MT	0	800	1100	0	0
Material_2	Material 2	MT Oxide	2300	2100	1700	1900	1600
Material_3	Material 3	Kg	3500	2400	3100	3400	0
Material_4	Material 4	Kg	0	0	4600	3900	3700
Material_5	Material 5	Kg	5800	5400	5000	4200	5500
Material_6	Material 6	MT	6300	6000	6300	6600	5800
Material_7	Material 7	ST	0	6800	7300	5900	0
Material_8	Material 8	Oz	0	7600	6700	7500	6900
Material_9	Material 9	MT	0	7500	9900	9700	7600
Material_10	Material 10	MT Oxide	8700	8000	8100	10900	9900

Note: Kilogram (Kg), Metric Tons (MT), Metric Tons of Oxide Equivalent (MT Oxide), Ounces (Oz), Short Tons (ST).

Figure 5. Sample Material Consumption File

4. File 4: Material Year Spans File

The material year spans file specifies, for each material, the span of years to be included in the reference period for computing historical material consumption and industrial demand. These are calendar years, e.g., 2015 through 2018. A separate span can be specified for each material. MDCP makes use of the material consumption values for the years in the span, and reads the industrial demands for those years from the peacetime FORCEMOB run (see Section 9). MDCP will compute results for only those materials listed in the year spans file; materials listed in the material consumption file but not the year spans file will not be processed. Each year span must fit into the range of years specified by the top row of the material consumption file; otherwise, the program prints an informative error message and terminates. (The spans should be consistent with the years in the material consumption file for which actual consumption data are specified, but the program does not check for this.)

This file is a rectangular array of numbers with one header row. It is a tab-delimited text file that can be viewed and edited as such in Excel. Table 4 shows the fields of the file with a brief description of their contents. A sample file is shown in Figure 6.

---

36 Atwell, et al., *Generic Unclassified Stockpile Sizing Module (SSM) Training and Testing for the National Defense Stockpile (NDS) 2015*.

37 For maximum readability of results, it is recommended that the short material names be listed in alphabetical order, but the computer program does not require this.

Table 4. Fields of the Year Spans File

Field	Item & Description	Header
1	Short material name	Material
2	Starting year of year span	Start_year
3	Ending year of year span	End_year

Material	StartYear	EndYear
Material_1	2015	2016
Material_2	2014	2018
Material_3	2014	2017
Material_4	2016	2018
Material_5	2015	2017
Material_6	2015	2018
Material_7	2015	2017
Material_8	2015	2018
Material_9	2015	2017
Material_10	2014	2018

Figure 6. Sample Material Year Spans File

5. File 5: Material Applications File

The material applications file shows the application areas for each material, the proportion of overall historical material consumption used in each application area, and some information on the associated industries. This file is a rectangular array of numbers with one header row. It is a tab-delimited text file that can be viewed and edited as such in Excel. Table 5 shows the fields of the material applications file with a brief description of their contents.

Table 5. Fields of the Material Applications File

Field	Item & Description	Header
1	Material short name	Material
2	Application area number (1, 2, 3,…)	App#
3	Application area name (50-character limit)	Application Name
4	Proportion of overall U.S. consumption of the material used in that application area	Fraction
5	Number of associated industry sectors	NumInd
6	Sector number (ILIAD) of first associated industry sector	LeadInd

The application areas and proportions of consumption are furnished by subject matter experts as part of the data development process. The applications must be numbered sequentially within each material name. If not, the program prints an error message and terminates. The application area names should not contain commas, but semicolons are acceptable. The proportions are frequently considered to be proprietary information. For each material, the proportions must sum to 1, otherwise the program prints an error message and stops. If the number of associated industry sectors (field 5) is greater than 1, it must match the number of industries listed for that application area in the application by industry file, and the first associated industry sector (field 6) must match the first sector listed for that application area in the application by industry file (see Section 6). Although the program does not currently check that these conditions are met, the data preparer should in order to avoid inconsistent results.

A sample material applications file is shown in Figure 7. The application areas and associated industries are actual data from recent Requirements Report studies, but they have been chosen randomly, and the proportions of consumption are random numbers.

MATERIAL	App#	Application Name	Fraction	NumInd	LeadInd
Material_1	1	Motor Vehicle Parts	0.49	2	217
Material_1	2	Bearings	0.02	2	147
Material_1	3	Pressurizing; purging; other gas and liquid	0.49	1	190
Material_2	1	Aluminum master alloys	1	3	223
Material_3	1	Electrical Equipment	1	6	198
Material_4	1	Machine Tool Accessories	0.74	1	167
Material_4	2	Water; sewage and other systems	0.26	1	24
Material_5	1	Military applications	0.19	5	81
Material_5	2	Medical and Hospital Equipment	0.2	5	235
Material_5	3	Radiation Windows	0.1	1	159
Material_5	4	Prefab Metal Buildings	0.25	1	136
Material_5	5	Welding	0.26	1	175
Material_6	1	Electrochemical	0.33	1	93
Material_6	2	Copper alloys	0.1	1	130
Material_6	3	Power-driven handtool manufacturing	0.08	1	174
Material_6	4	Cooking Equipment	0.49	1	158
Material_7	1	Furniture	0.64	4	231
Material_7	2	Automotive	0.36	1	219
Material_8	1	Sandpaper	0.36	1	122
Material_8	2	Fuel Cells	0.64	1	205
Material_9	1	Petroleum refineries	1	1	87
Material_10	1	Electrical Industrial Apparatus	0.37	4	205
Material_10	2	All other electronic components	0.03	1	187
Material_10	3	Photographic and photocopying equipment	0.21	1	160
Material_10	4	Household Appliances	0.39	4	201

Figure 7. Sample Material Applications File

6. File 6: Application by Industry File

The application by industry file shows the industry sectors associated with each material application area. This information is at the heart of the material demand computation process. The underlying idea is that a change in demand for the products of a given industry leads to a change in the demand for the associated material. The file is a rectangular array of numbers with one header row. It is a tab-delimited text file that can be viewed and edited as such in Excel. Table 6 shows the file's fields with a brief description of their contents.

Table 6. Fields of the Application by Industry File

Field	Item & Description	Header
1	Short material name	Material
2	Application area number	AppNo
3	Order number (i = 1, 2, 3…); see below	OrderNo
4	Industry sector number of the i^{th} industry sector associated with that application	IndSector

The industry sectors numbers should be consistent with those of the ILIAD model (or whichever economic model is being used). For each combination of material name and application area, the associated industries must appear in ascending order, each identified by an order number (1, 2, 3,…). The total number of industries listed should match the number of industries indicated on the material application file for that combination. Also, the first industry listed (order number 1) should match the corresponding first industry listed on the material application file for that combination. However, the program does not automatically check that these conditions are met. To avoid unpredictable results, the data preparer should do so. If an application is not listed on the application by industry file, it is assumed that there is only one associated industry sector for that application—the sector shown on the material application file.

A portion of a sample application by industry file appears in Figure 8.

Material	AppNo	OrderNo	IndSector
Material_1	1	1	217
Material_1	1	2	219
Material_1	2	1	147
Material_1	2	2	169
Material_1	3	1	190
Material_2	1	1	223
Material_2	1	2	224
Material_2	1	3	241
Material_3	1	1	198
Material_3	1	2	199
Material_3	1	3	205
Material_3	1	4	206
Material_3	1	5	207
Material_3	1	6	208
Material_4	1	1	167
Material_4	2	1	24
[rows deleted because of space considerations]			
Material_9	1	1	87
Material_10	1	1	205
Material_10	1	2	206
Material_10	1	3	207
Material_10	1	4	208
Material_10	2	1	187
Material_10	3	1	160
Material_10	4	1	201
Material_10	4	2	202
Material_10	4	3	203
Material_10	4	4	204

Figure 8. Sample Application by Industry File

7. File 7: Optional Application Weights File

This optional file was used when the MDCP program was being developed in order to examine the effects of certain historical data. The use of this file is not recommended. If file type 7 is not listed on the control inputs file, the file will not be used.

8. File 8: FORCEMOB Case File

MDCP makes use of the main output file from the FORCEMOB model. Two such files are used, resulting from two different FORCEMOB runs. One of these runs, described in this section, is the case of interest. This is generally an emergency scenario case, such as a Requirements Report Base Case, involving some amount of conflict and some adjustments to demands, imports, and exports. The output file that FORCEMOB generates is ready to be input to MDCP (after being copied to the MDCP input file directory). The file is often referred to as a “pfc file” (mnemonic for “postprocessor file comma-delimited”), since FORCEMOB provides the hard-coded extension ‘.pfc’ for it.[38] It is an unformatted text file with comma-delimited values. For the current version of the MDCP computer program, the file name, including the extension ‘.pfc’, should appear in the control inputs file.

It is generally recommended that the FORCEMOB output file be used as is, without any editing. If desired, it can be viewed in Excel as a comma-delimited text file. Occasionally, it might be appropriate to edit an existing pfc file to use in a special sensitivity case. Some remarks about the structure of the pfc file are, therefore, in order. The file has some information at the top showing various file names and quantities. Then comes a line with five asterisks, marking the start of the main content of the file. The next line, which is space-delimited, shows the number of industry sectors, the number of years in the scenario, and the start year of the scenario. (The line also shows the dollar year and the conflict start date; MDCP does not read these.) From the start year and number of years, the end year of the scenario can be computed. The start year and end year must match the corresponding values shown on the control inputs file. If not, the program prints an error message and terminates.

After that comes the main part of the file. It is organized into eight sections, each of which treats a different category of industrial output requirements. The sections are:

1. Delta (conflict) military output requirements
2. Base military output requirements
3. Total military output requirements (sum of preceding two sections)
4. Civilian output requirements
5. Investment (i.e., emergency investment) output requirements
6. Total output requirements (sum of preceding three sections)
7. Imports
8. Exports

Each section has a top line with the name of the section, then a set of rows, one for each industry sector. Each such row contains the industry sector number, its name (as listed in the element file, 30 characters with no commas), and a series of numerical values, one for each year of the scenario, corresponding to the particular category of results. The values

[38] FORCEMOB also generates a similar postprocessor file in fixed-column format with the extension ‘.ppf’ (“postprocessor file”). MDCP was intended to be able to process either a ppf or a pfc file, but it is recommended that the pfc version be used.

are in millions of constant-year dollars, where the dollar year is as shown in the element file. (MDCP does not use the dollar year in any of its computations.) After the rows for the individual industries appears a totals row with the total dollar amounts for that category by year. After the eight sections comes concluding information that is relevant to FORCEMOB, but not MDCP.

When processing the data, MDCP uses the third (total military) section, the fifth (emergency investment) section, and adds net exports to civilian demand, thus adding the fourth and eight sections and subtracting the seventh section term by term.. The civilian adjustment factors computed by MDCP are based on the civilian demands plus net exports.

Figure 9 displays a facsimile of a small portion of a sample pfc file that shows the comma delimiting.

```
CIVILIAN OUTPUT REQUIREMENTS
   1,Oilseed farming             ,   30125.631,   30827.000,   31529.039,   32282.900,
   2,Grain farming               ,   59087.809,   60370.609,   61638.699,   63015.930,
   3,Vegetable and melon farming ,   27572.230,   28057.660,   28519.100,   29026.820,
   4,Fruit and nut farming       ,   31206.520,   31754.609,   32282.850,   32872.930,
   5,Greenhouse/nursery/floricult ,  28709.430,   29735.699,   30718.439,   31733.900,
   6,Other crop farming          ,   23433.570,   23858.461,   24273.971,   24715.770,
   7,Cattle ranching & dairy farm ,  81410.820,   83090.328,   84766.289,   86577.172,
   8,Poultry and egg production  ,   37386.660,   38011.320,   38637.070,   39335.102,
   9,Animal prod excl cattle/poult , 26675.859,   27320.971,   27955.119,   28629.330,
  10,Forestry and logging        ,   24249.561,   25136.359,   26019.070,   26857.029,
      [rest of industry sectors]
 351,Noncomparable imports       ,       0.000,       0.000,       0.000,       0.000,
 352,Rest of the world adjustment ,      0.000,       0.000,       0.000,       0.000,
 TOTAL,                          ,21466636.000,22108340.000,22780696.000,23461308.000,
```

Figure 9. Portion of Sample FORCEMOB.pfc File

9. File 9: FORCEMOB Peacetime File

The FORCEMOB peacetime file, a pfc file with the structure discussed in the preceding section, is the output of a peacetime run of FORCEMOB. MDCP works by comparing (1) goods and services demands in future years under scenario-specific conditions with (2) peacetime historical goods and services demands and (3) projected future peacetime goods and services demands. The latter two sets of demands are read from the FORCEMOB peacetime file.

In comparison with the case FORCEMOB run, the peacetime FORCEMOB run has no conflict military demand, no adjustments to civilian demand, imports, or exports, and no emergency investment demand. The delta military and emergency investment sections of the pfc file are filled with zeroes.

The year span of the peacetime FORCEMOB run must encompass all of the scenario years and all of the years for which historical material consumption is provided (see Section 3 above). The program checks that this is the case; if not, it prints an informative error message and terminates. FORCEMOB is currently dimensioned to hold a maximum of 15 years of data. For the 2021 Requirements Report, the peacetime year range was set at 2012 through 2026, a 15-year span. This was long enough to encompass the Base Case scenario years (2023 through 2026) and historical information starting at 2012 or later. Like FORCEMOB, MDCP's arrays have a limit of 15 years of industry data. If necessary, the programs could be modified to increase this limit.

10. File 10: Military Fractions File

As discussed in Chapter 2, Section A.5, for each application area, for each material, the user can specify a fraction of usage of demand in that area that is for military purposes. These fractions are listed in the military fractions file. The file is a rectangular array with one header row. It is a tab-delimited text file that can be viewed and edited as such in Excel. Table 7 shows the fields of the military fractions file with a brief description of their contents.

Table 7. Fields of the Military Fractions File

Field	Item & Description	Header
1	Material short name	Material
2	Application area number (as listed in the material applications file)	AppNo
3	The word "MILFRAC"	Mnemonic
4	Proportion of material use in the application area that is for defense purposes (number between 0 and 1, inclusive).	Military Fraction

Note: MILFRAC is mnemonic for military fraction.

For material applications not listed in the military fractions file, the military fraction will be computed from the economic data as explained in Chapter 2, Section A.5 (also see the mathematical details in Chapter 4, Section C). The military fractions file is optional; if it is omitted, all the military fractions will be computed from the economic data. MDCP produces an output report that shows the military fractions for all the application areas, indicating which ones were computed and which ones were input on the military fractions file. A sample military fractions file appears in Figure 10.

Material	AppNo	Mnemonic	Military_Fraction
Material_5	1	MILFRAC	1
Material_10	1	MILFRAC	1
Material_10	2	MILFRAC	0.85
Material_10	3	MILFRAC	0.25
Material_10	4	MILFRAC	0

Figure 10. Sample Military Fractions File

11. File 11: Thrift Profile File

The MDCP program computes a thrift demand value for every combination of material, demand tier, and scenario year. However, the study sponsor or other model user might want the thrift market response to be modeled for only certain combinations. The thrift profile input file allows the user to do this; the file specifies the material/tier/year combinations for which the thrift demand values will be printed on the main thrift output file (other combinations will show the regular demand values). When the SSM reads this file, the effect will be to model the thrift response only for the desired combinations. The thrift profile file is an optional file; if it is omitted, a main thrift output file will be generated but will contain *none* of the thrift demand values, only the regular demand values.

In general, the sponsor will specify the thrift profile to use. For the 2021 Requirements Report, for SL1 materials, thrift was applied to civilian demand in all years, but was applied to the other demand tiers only in the third and fourth scenario years.

This file is a rectangular array of numbers with one header row. It is a tab-delimited text file that can be viewed and edited as such in Excel. Table 8 shows the fields of the thrift profile file with a brief description of their contents.

Table 8. Fields of the Thrift Profile File

Field	Item & Description	Header
1	short material name	Material
2 through n+1	value for defense demand in y^{th} scenario year (y=1,…,n); 1, use thrift, 0, do not	Calendar year corresponding to y
n+2 through 2n+1	value for emergency investment demand in y^{th} scenario year (y=1,…,n); 1, use thrift, 0, do not	Calendar year corresponding to y
2n+2 through 3n+1	value for civilian demand in y^{th} scenario year (y=1,…,n); 1, use thrift, 0, do not	Calendar year corresponding to y

n = number of years in the scenario

A default profile should be specified with the reserved word "DEFAULT" (all caps) in the first column. This profile will be used for all materials not listed in the file. The line with the default profile should appear just below the header line. A sample thrift profile file appears in Figure 11. In the sample, most materials have thrift applied to civilian demand in all years and to the other demand tiers in the third and fourth scenario years, but Material_8 is not to have thrift applied.

MATERIAL	2023	2024	2025	2026	2023	2024	2025	2026	2023	2024	2025	2026
DEFAULT	0	0	1	1	0	0	1	1	1	1	1	1
Material_8	0	0	0	0	0	0	0	0	0	0	0	0

Figure 11. Sample Thrift Profile File

Note that the profiles can vary by material, but not by application area within a material, even though MDCP does initially compute different thrift demands for different application areas (see Chapter 2, Section C). The reason for this lack of capability is unclear, but it could be because the option was not of primary importance to the sponsor. The program could be modified to model selection by application area. In contrast, the substitution modeling allows the substitution factors to be explicitly input by application area, as explained below.

12. File 12: Substitution Factors File

The substitution factors file is used to model the market response of substitution (see Chapter 2, Section D). The file is optional; if it is not listed on the control inputs file, all materials will be considered to be non-substitutable. The factor values, which are developed by subject matter experts, indicate the proportional reduction of material demand that can occur because of substitution. The factors can vary by material application, demand tier (defense, emergency investment, civilian), and year of the scenario. This file is a rectangular array of numbers with one header row. It is a tab-delimited text file that can be viewed and edited as such in Excel. Table 9 shows the fields of the substitution factors file with a brief description of their contents.

Table 9. Fields of the Substitution Factors File

Field	Item & Description	Header
1	Short material name	Material
2	Application area number (as listed in the material applications file)	AppNo
3 through n+2	Substitution factor for defense demand for given material and application in y^{th} scenario year (y=1,…,n)	Calendar year corresponding to y
n+3 through 2n+2	Substitution factor for emergency investment demand for given material and application in y^{th} scenario year (y=1,…,n)	Calendar year corresponding to y
2n+3 through 3n+2	Substitution factor for civilian demand for given material and application in y^{th} scenario year (y=1,…,n)	Calendar year corresponding to y

Note: n = number of years in the scenario

Note that the factor values represent the proportion of demand that *cannot* be substituted. The program *multiplies* a demand by the appropriate substitution factor to obtain a reduced demand due to substitution. During the data preparation process, subject matter experts often specify a percentage of demand that *can* be substituted. For input to the model, this value must be divided by 100 and then subtracted from 1 (e.g., 30% substitutability translates to an input value of 0.7).

The special code 999 for the application area number will cause the substitution factors to be applied for all application areas for the listed material. Any materials and/or applications not listed are assumed to be not substitutable; the program assigns a factor value of 1 to them. Figure 12 shows a sample substitution factors file.

MATERIAL	AppNo	2023	2024	2025	2026	2023	2024	2025	2026	2023	2024	2025	2026
Material_1	999	1	1	1	1	1	1	1	1	1	0.7	0.7	0.7
Material_4	1	1	1	1	1	1	1	1	1	0.8	0.8	0.8	0.8
Material_6	3	1	1	1	1	1	1	1	1	0.6	0.6	0.6	0.6
Material_6	4	1	1	1	1	1	1	1	1	0.4	0.4	0.4	0.4

Figure 12. Sample Substitution Factors File

13. File 13: Aluminum Supply File

The data in the aluminum supply file are used by the aluminum redistribution function, as discussed in Chapter 2, Section E.2. If the control inputs file specifies that the aluminum redistribution function is to be invoked, this file is required, otherwise it is ignored. It shows the amount of U.S. supply of aluminum metal for a number of years. This file is a rectangular array of numbers with one header row and one data row. It is a tab-delimited text file that can be viewed and edited as such in Excel. Table 10 shows the fields of the aluminum supply file.

Table 10. Fields of the Aluminum Supply File

Field	Item & Description	Header
1	ALMNM_METAL (hard-coded name)	Material
2 on	Aluminum supply in the calendar year y	Calendar year y

The supply values in the file must be in the units of measure specified for aluminum in the material consumption file (and the SSM). The supply data should also be used in the SSM. Any number of years of values can be specified (up to the dimension limit of 15), but should include all the scenario years; if not, the program prints an informative error message and terminates. The program parses the header line to identify the columns corresponding to the year span of the scenario and picks out the corresponding aluminum supply values. A sample aluminum supply file appears in Figure 13 (the data are for illustrative purposes; the values are not the same as the actual ones).

MATERIAL	2020	2021	2022	2023	2024	2025	2026
ALMNM_METAL	100	100	110	120	130	130	130

Figure 13. Sample Aluminum Supply File

B. The Control Inputs File

As noted earlier, the control inputs file for MDCP lists the input data files for a given MDCP run to use and specifies certain date ranges and various option indicators. The first action of a MDCP run is to prompt the user for the name of the control inputs file for the run.

The control inputs file is an unformatted text file and can be constructed and edited in a text editor such as Notepad. Its name must be eight characters or less; the extension is arbitrary, but usually '.in' is used. MDCP constructs the output file names using the name of the control inputs file (see Section D). The information on the control inputs file lines is space-delimited. Most of the lines have an initial informative gloss or short descriptive phrase, which must not be null and should have no spaces (underscore characters are allowed; 100-character limit). The example in Figure 14 demonstrates this.

A line-by-line guide to the control inputs file appears in Table 11 and a sample control inputs file appears in Figure 14.

Table 11. Structure of the Control Inputs File

Line	Contents	Structure
1	Comment line	Top comment line; read and printed on the message file.
2	Run name	Gloss, then the run name. The run name has a 32-character limit; it is essentially for display purposes. Generally, the run name will be the same as the control inputs file name.
3	Number of industry sectors	Gloss, then the number of industry sectors. This should equal the number of industries used in the FORCEMOB runs and the underlying economic model (352 sectors for ILIAD Version 6).
4	Year span for material consumption file	Gloss, then two calendar year numbers that indicate the start and end years of data contained in the material consumption file. The years in the header line of that file will be compared to this year span; if there is a mismatch the program prints an error message and terminates.
5	Two option indicators	Gloss, then two integer numbers. The first is not currently used. The second indicates whether the aluminum redistribution function is to be used to compute alumina and bauxite demand; a value of 2 or greater signals that it is.

Line	Contents	Structure
6	Year span for FORCEMOB case file	Gloss, then two calendar year numbers that indicate the start and end years of the FORCEMOB run for the case. The year span shown in the FORCEMOB case pfc file will be compared to this year span; if there is a mismatch, the program prints an error message and terminates.
7	Year span for FORCEMOB peacetime file	Gloss, then two calendar year numbers that indicate the start and end years of the FORCEMOB peacetime run. The year span shown in the FORCEMOB peacetime pfc file will be compared to this year span; if there is a mismatch, the program prints an error message and terminates.
8	Input file directory name	Gloss, then a character string giving the full path for the directory in which the input data files reside. The path can contain spaces; there is an 80-character maximum. (This directory applies to the input files; the output files are generated in the directory from which the program is being run.)
9	First data file	Gloss showing the type of file, then the file type number (see Section A) of the first data file; then the name.extension of the first data file (32-character maximum), no spaces. If no extension is specified, the program assumes it is '.txt'. An optional gloss, spaces allowed, can go at the end of the line, but is ignored.
10	Second data file	Gloss showing the type of file, then the file type number of the second data file; then the name.extension of the second data file, with optional gloss at the end.
	…	[additional data files, as listed]
n	Last data file	Gloss showing the type of file, then the file type number of the last data file; then the name.extension of the last data file, with optional gloss at the end.
n+1	End of data line	Gloss, then the number 99, indicating the end of the data file inputs.
	Comment lines	Up to 180 comment lines can appear beyond the end of data line. They are printed on the message file and on the note files associated with the main output files. The use of comments is highly recommended. They can provide valuable information about the run, which is deliberately not captured in the short, at times cryptic, file and run names.

```
Run test1.in  March 16, 2021. Test database for MDCP
Run_name       test1
Number_of_industries    352
Year_span_MatConsumption_File   2014  2018
Options   1   1
Year_span_Case_File   2023  2026
Year_span_Peace_File   2012  2026
Input_dir c:\ellyroot\stkp2020\mdcp\data\
Element_file                      1    elem708a.prn   Iliad V6
Special_Additions_File            2    test1spa.txt
Material_Consumption_File         3    test1cns.txt   random numbers
Material_Year_Spans_File          4    test1ys.txt
Material_Applications_File        5    test1app.txt
Application_by_Industries_File    6    test1api.txt
FORCEMOB_Case_file                8    test1pfc.pfc
FORCEMOB_Peace_file               9    pt2020tp.pfc   peacetime full
Military_fractions_file          10    test1mf.txt
Thrift_profile                   11    test1thp.txt
Substitution_factors_file        12    test1sbf.txt
End_of_files_indicator           99


Notes:
Run test1.in, March 16, 2021
This is a dummy test database for the material demand
computation program. Some of the data are adapted from
the 2021 Requirements Report data, but are filled with
random numbers as necessary.
```

Figure 14. Sample Control Inputs File

C. Running the Program

To run MDCP, double click on the executable file name in Windows Explorer. A command window will pop up and a prompt will ask the user to type in the name.extension of the control inputs file, encased in single quotes. To run the sample file, one would type ‘test1.in’. A few messages will appear in the command window. If the program runs normally, the user will be asked to strike any key plus <enter> to terminate the program.

Alternatively, the user can invoke a command window from the system and can type the executable file name in the command window.

A few words about the directory structure are in order. The executable program and the control inputs files should be in the same directory, which can be called the main directory for the MDCP run. The program will write the output files to this directory. The input data files should be located in the input file directory specified in the control inputs file (noted as Input_dir in the example above). If the program cannot find an input data file (perhaps because of a mis-specified input file directory), it prints an informative error message and terminates.

D. MDCP Output Files

MDCP produces a number of output files. The SSM has a 12-character limit on its input file names (not including the extension ‘.txt’), and some of the MDCP output files are intended as input files for the SSM. Accordingly, MDCP uses the following scheme for file naming. The name of the control inputs file (without extension) should be at most eight characters. Each output file name is the concatenation of the control inputs file name, the underscore character, and a three-letter output file code. This adds up to at most 12 characters for the name. The extension '.txt' is then appended. The output file codes indicate the type of file and are often used to refer to the output files. Table 12 shows the codes and the types of files.

Table 12. MDCP Output Files and Codes

Output File Code	Description and Comments
out	Main output file—material demands by material, tier, and year. Suitable for input to the SSM.
tfo	Material demands with thrift only, using given profile. Suitable for input to the SSM.
sbo	Material demands with substitution only, using given profile. Suitable for input to the SSM.
tso	Material demands with thrift and substitution, using given profiles. Suitable for input to the SSM.
mss	Informative message file.
rpt	Detailed report by application; shows steps of computation.
ind	Material demand by tier, year, and industry (see Chapter 2, Section B.4).
in2	Detailed working file: demands by application, tier, year, and industry.
app	Material demand by year, tier, and application.
ap2	Material demand by tier and application.
emb	Shows the embedded demand increment, by industry and material; see Chapter 2, Section E.3.
mcr	MCRs
mco	Material demands computed via MCR method.
mlf	Military fractions for each application.
mtf	Thrift MCRs
mto	Output file of demands computed with thrift MCRs via the MCR method without thrift profile by year and tier. Useful for diagnostic purposes.
tdo	Demands with thrift only totals by year and tier without profile. Useful for diagnostic purposes.

The major MDCP output file is the _out file. A tab-delimited text file ready to be input to the SSM, it shows the material demands by material and year of the scenario for each tier of demand: defense, emergency investment, and civilian, in that order. Suppose the scenario is *n* years long. The output file then consists of a column with the material names, followed by *n* columns for defense demands, by year, then *n* columns for emergency investment demands, by year, and then *n* columns for civilian demands, by year. All demands are expressed in the mass units specified in the material consumption input file. If desired, the file can be viewed in Excel as a tab-delimited text file. Figure 15 shows a sample _out file.

MATERIAL	2023	2024	2025	2026	2023	2024	2025	2026	2023	2024	2025	2026
Material_1	253.8412	253.4568	252.8	252.5047	1.2435	0	0	0	1296.873	1229.87	1247.319	1225.234
Material_2	1472.519	1465.251	1448.394	1444.241	0.523	0	0	0	449.1293	405.6623	399.4955	394.5453
Material_3	174.7395	172.5394	169.2166	167.372	5.1911	0	0	0	5092.1	4827.922	4583.774	4282.073
Material_4	119.4243	118.6512	117.1364	116.565	3.0029	0	0	0	4579.127	4389.737	4208	4054.383
Material_5	1368.691	1355.015	1333.788	1322.551	4.0977	0	0	0	3735.864	3624.046	3653.681	3622.611
Material_6	232.6809	229.6309	225.1855	222.6005	10.6458	0	0	0	6508.177	6203.907	6235.143	6279.919
Material_7	177.2272	175.5039	172.7859	171.374	13.4496	0	0	0	11800.12	11524.51	11667.4	11735.88
Material_8	291.787	288.925	284.3781	282.0844	20.4402	0	0	0	12517.17	12092.8	11652.92	10383.11
Material_9	662.5645	646.1834	625.1885	610.7203	7.6689	0	0	0	10159.92	10082.55	10001.98	9844.208
Material_10	6173.652	6099.055	5983.917	5921.778	13.3122	0	0	0	11748.43	11313	11423.77	11063.19

Figure 15. Sample MDCP Main Output File

Three other output files, similar in structure to the _out file, show the material demands if the thrift and/or substitution market responses are modeled. These are SSM-ready files:

- Substitution only output file (_sbo)—material demands with substitution only;
- Thrift only output file (_tfo)—material demands with thrift only;
- Thrift and substitution ouput file (_tso)—material demands with thrift and substitution.

For each of these files, as well as the _out file, MDCP generates a small file of informative notes. The file has the same name as the corresponding output file, with the extension '.not' rather than '.txt'. These files can be viewed in Notepad. They consist of a reproduction of the lines of the control inputs file for the run, including comments, along with a notation about the market responses modeled, run date, and program version.

The message output file, which has code _mss, contains informative messages. This file provides some information about program progress, and is useful for troubleshooting if the program terminates in error. The other output files show various intermediate quantities of computation, which might be useful and informative. The reader is advised to look through the files while reading the short descriptions in Table 12.

One output file deserves special mention—the _emb file, which shows the so-called embedded demand increment for each industry and for each material with a valid MCR. Discussion of the methodology behind this file appears in Chapter 2, Section E.3.

This page is intentionally blank.

4. Mathematical Details and Derivations

This chapter presents mathematical derivations of the important theoretical results that form the basis of the MDCP model. Although not completely identical, the notation is similar to that of IDA Document D-5477, which the reader is encouraged to consult. MDCP treats each material separately.[39] The derivations presented here assume that one particular material is under consideration.

Caution: treatment of negative values. The processing of the economic data ensures that the all demand quantities, imports, and exports are nonnegative for each historical and scenario year, under both peacetime and scenario conditions. When net exports are added to civilian demand, however, the result is occasionally negative. The significance of this situation depends on the year and type of data, as explained in the following sections. When it occurs, however, zero is used instead, and the computer program prints an informative message. This kind of treatment is conservative in that it does not allow negative industrial demands to lower the material demand.

Zero values. More generally, some of the formulas derived in this chapter need special interpretation and treatment if certain quantities in them are zero. The text explains these treatments, which are concordant with the implementation in the computer program.

A. Basic Notation

1. Indexing Notation

The reference period is indexed as time $t = 0$ even though it might span several years. The T years of the scenario period are indexed as $t = 1,\dots, T$ even though the scenario might be posited as occurring some years after the reference period. Let j ($j = 1,\dots, J$) index application area (for the given material) and i ($i = 1,\dots, I$) index industry sector (in the underlying economic model, applicable to all materials).

[39] The one exception is for alumina and bauxite when the aluminum redistribution function is being used; assume that is not the case here.

2. Notation for Economic Data

All the economic data (goods and services demand data) input to MDCP have been computed by the underlying economic models and the FORCEMOB model.[40] They are expressed in millions of constant year dollars and vary by category of data, industry sector, year, and peacetime vs. emergency scenario. Demands are expressed in total requirements terms, i.e., they include inter-industry output flows as well as output that goes to end users.[41]

a. Reference Period

Let d_{i0}, denote the average annual defense demand in sector i during the reference period under peacetime conditions. The economic modeling ensures that all defense demands are nonnegative (they might be zero for certain sectors).

The economic modeling ensures that values for civilian demand, imports, and exports are always nonnegative. As noted above, however, it is theoretically possible that civilian demand plus net exports, i.e., civilian demand plus exports minus imports, can be negative for some years of the reference period. For each year of the reference period, the civilian demand plus net exports is computed and if negative, is set to zero. The value q_{i0}, which is used as the reference period civilian demand plus net exports value for industry sector i, is computed as the average of these nonnegative quantities over the years of the reference period. If civilian demand plus net exports is nonnegative for each year of the reference period, then q_{i0} is the average annual civilian demand plus the average annual exports, minus the average annual imports for sector i, where the averages are taken over the years of the reference period.

A condition in which the civilian demand plus net exports is zero or negative for any year of the reference period can indicate a severe problem with the underlying economic data. The MDCP computer will print an informative message, which should be a cue for the user to examine the data. The program will print a message and stop when division by zero is imminent.

The "net demand sum," ω_{i0}, is defined by $\omega_{i0} = d_{i0} + q_{i0}$. This sum represents defense demand plus civilian demand plus net exports (with corrections for negative values as

---

40 Douglas S. Meade, *The INFORUM LIFT Model*; Douglas S. Meade, *ILIAD*; James S. Thomason, et al., *Forces Mobilization Model (FORCEMOB): Unclassified Training Tutorial*; Eleanor L. Schwartz, et al., *Documentation of the Forces Mobilization Model (FORCEMOB), Versions 3.1 and 3.2*, Vol. I: *General Description*; Eleanor L. Schwartz and James S. Thomason, Vol. II: *Data Preparation Guide*.

41 Schwartz and Thomason, *Computation of Material Demand in the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) Process*; Ronald E. Miller and Peter D. Blair, *Input-Output Analysis: Foundations and Extensions*.

necessary); MDCP uses it as a measure of overall average annual industrial output for sector i in the reference period.[42]

b. Scenario Period, Peacetime Conditions

For years t=1,…,T, let d_{it}, c_{it}, x_{it}, and m_{it} denote the defense demand, civilian demand, exports, and imports, respectively, in sector i during year t of the scenario, under peacetime conditions. The processing of the economic data ensures that d_{it}, c_{it}, x_{it}, and m_{it} are all nonnegative, but the quantity $c_{it} + x_{it} - m_{it}$ (i.e., peacetime civilian demand plus net exports) occasionally will be negative for some i and t. This condition indicates a possible problem with the underlying economic data, which should be examined. In this case, the computer program uses zero instead of the negative value and prints an informative message. The treatment of this zero value depends on the particular section of the code, and will be explained as appropriate. In symbols, the quantity

$$q_{it} = \max\{(c_{it} + x_{it} - m_{it}), 0\}$$

is used in the subsequent calculations for civilian demand plus net exports.

c. Scenario Period, Scenario Conditions

Under the scenario conditions, the economic modeling and the FORCEMOB model have computed the following quantities for each industry sector and scenario year, all expressed in total requirements terms:

- d'_{it} = defense demand in sector i in year t under scenario conditions (might be higher than peacetime because of weapon and munitions regeneration requirements).
- c'_{it}= civilian demand in sector i in year t under scenario conditions (might be lower than peacetime because nonessential demand is excluded).
- e'_{it}= emergency investment demand in sector i in year t under scenario conditions (not relevant, and set to zero under peacetime conditions).
- x'_{it}= exports in sector i in year t under scenario conditions (might be different from peacetime because of policy decisions).
- m'_{it}= imports in sector i in year t under scenario conditions (might be lower than peacetime because of unreliability of supplier countries).

FORCEMOB ensures that the scenario economic quantities d'_{it}, c'_{it}, e'_{it}, x'_{it}, and m'_{it} are all nonnegative, but it can happen that the civilian demand plus net exports, $c'_{it} + x'_{it} - m'_{it}$, is negative for certain i and t. This situation does not necessarily indicate

---

42 See the discussion of the net demand sum in D-5477, Chapter 3, Section C.

a problem with the economic data because the three components are adjusted separately from their peacetime values. Even so, the computer program uses zero instead of the negative value and prints an informative message; i.e., the quantity

$$q'_{it} = \max\{(c'_{it} + x'_{it} - m'_{it}), 0\}$$

is used in the subsequent calculations for civilian demand plus net exports.

3. Consumption and Application Area Notation

Define the following variables:

- Γ = average annual amount of consumption (of the given material) in the reference period (measured in mass units).
- φ_j = proportion of consumption used in application area j.
- $\gamma_j = \Gamma\varphi_j$, = average annual amount of consumption of the material in application area j during the reference period.
- δ_{ij} = 1 if industry sector i is associated with application area j, 0 if not.
- ω_{i0} = average annual output of industry sector i in the reference period (MDCP uses the net demand sum $d_{i0} + q_{i0}$ for this quantity).
- μ_j = the proportion of demand in application area j that is used for defense purposes in the reference period. For each application area, μ_j either is input or is computed by the program.
- $\mu_j\gamma_j$ = average annual amount of consumption of the material in application area j during the reference period that is used for defense purposes.

The following intermediate variables can be defined.

For each j, let S_j be the set of industry sectors associated with application area j, i.e. $S_j = \{i|\delta_{ij} = 1\}$.

Let $\Omega_j = \sum_{i\in S_j} \omega_{i0}$. This quantity is the total average annual amount of economic output of the industries associated with application area j in the reference period. It is clear that Ω_j is also equal to the quantity $\sum_{i=1}^{I} \delta_{ij}\,\omega_{i0}$. Note that it is possible for Ω_j to be strictly positive even if $\omega_{i0} = 0$ for some of the industry sectors i that are associated with application area j. A situation in which Ω_j =0, however, indicates a severe problem in the input data; in this case, the program prints an informative message and stops, to avoid division by zero.

The MCR for industry sector i, denoted ρ_i, indicates the amount of material used in producing a given dollar amount of demand in industry sector i.[43] Document D-5477 derives the formula

$$\rho_i = \sum_{j=1}^{J} \gamma_j \frac{\delta_{ij}}{\Omega_j}.$$

B. Computation of Defense and Civilian Material Demand

1. Basic Computations

Using the notation developed in the previous section, the following variables can be defined:

- $U_{jt} = \sum_{i=1}^{I} \delta_{ij} d_{it}$ t=0,…,T, the defense demand for goods and services in the industries associated with application area j in year t under peacetime conditions.
- $V_{jt} = \sum_{i=1}^{I} \delta_{ij} q_{it}$ t=0,…,T, the civilian demand plus net exports (adjusted to be nonnegative) for goods and services in the industries associated with application area j in year t under peacetime conditions.
- $U'_{jt} = \sum_{i=1}^{I} \delta_{ij} d'_{it}$ t=1,…,T, the defense demand for goods and services in the industries associated with application area j in year t under emergency scenario conditions.[44]
- $V'_{jt} = \sum_{i=1}^{I} \delta_{ij} q'_{it}$ t=1,…,T, the civilian demand plus net exports (adjusted) for goods and services in the industries associated with application area j in year t under emergency scenario conditions.

It is possible that some of the quantities are zero; if so, appropriate treatments are discussed below, in context. If all the quantities are strictly positive, one can define the defense growth factor in application area j in year t (for t=1,…,T) as U_{jt}/U_{j0} , the civilian growth factor as V_{jt}/V_{j0} , the defense scenario adjustment factor as U'_{jt}/U_{jt} , and the civilian scenario adjustment factor as V'_{jt}/V_{jt}.

---

[43] FORCEMOB expresses goods and services demands in millions of constant-year dollars, so the MCRs should be expressed in terms of mass units per million constant-year dollars. The mathematical discussion here assumes such compatibility of units. Historically, the MCRs have been expressed as mass units per billion constant-year dollars; the MDCP computer program keeps this assumption and applies the appropriate adjustment factors.

[44] Unlike the discussion in Schwartz and Thomason, *Computation of Material Demand in the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) Process*, emergency investment demand is *not* added in with defense demand. See Section D for a discussion of how emergency investment material demand is computed.

2. Defense Demand Computation

The defense material demand in application area *j* in year *t* under emergency scenario conditions, call it D'_{jt}, is the product of the defense consumption in the reference period, the defense growth factor, and the defense scenario adjustment factor, i.e.

$$D'_{jt} = \mu_j\gamma_j\,(U_{jt}/U_{j0})\;U'_{jt}/U_{jt}).$$

The terms U_{jt} cancel each other, so one can write $D'_{jt} = \mu_j\gamma_j(U'_{jt}/U_{j0})$. This derivation assumes that U_{j0} and U_{jt} are strictly positive.

If $U_{j0} = 0$, the growth factor ratio cannot be formed; if $\mu_j = 0$ (i.e. application area *j* has no defense usage), then it is reasonable to regard D'_{jt} as zero. Otherwise, the program prints a message and stops; the underlying data should be examined.

If $U_{j0} > 0$ but $U_{jt} = 0$ (for some nonzero *t*), this indicates a possible problem with the underlying data, but it is reasonable to interpret the fraction 0/0 as 1, so the formula $D'_{jt} = \mu_j\gamma_j\,(\,U'_{jt}/U_{j0})$ can still stand. If in addition $U'_{jt} = 0$ (i.e., there is no defense demand for goods and services in the scenario for this *j* and *t*; then zero is an eminently reasonable value for D'_{jt}.

The overall defense demand for the material in year *t* under emergency scenario conditions is the sum over all application areas *j* of the D'_{jt}, i.e.,

$$D_t^{\mathrm{tot}} = \sum_{j=1}^{J} D'_{jt}.$$

3. Civilian Demand Computation

Similarly, the civilian material demand in application area *j* in year *t* under emergency scenario conditions is the product of the civilian consumption in the reference period, the civilian growth factor, and the civilian adjustment factor, i.e.

$$C'_{jt} = (1-\mu_j)\gamma_j(V_{jt}/V_{j0})(V'_{jt}/V_{jt}) = (1-\mu_j)\gamma_j(\,V'_{jt}/V_{j0}).$$

This formula assumes that V_{j0} and V_{jt} are both strictly positive. It is possible (more likely than in the defense case) that one or the other of them is zero.

If $V_{j0} = 0$ (indicating a possibly severe problem with the economic data), the program prints a message and stops unless $\mu_j = 1$ (no civilian demand), in which case C'_{jt} is set to zero.

If $V_{j0} > 0$ but $V_{jt} = 0$ (for some nonzero *t*), this indicates a possible problem with the underlying data, but it is reasonable to interpret the fraction 0/0 as 1, so the formula $C'_{jt} = (1-\mu_j)\gamma_j(\,V'_{jt}/V_{j0})$ can still stand. If in addition $V'_{jt} = 0$ (i.e., there is no civilian demand for goods and services in the scenario for this *j* and *t*), then zero is a reasonable value for C'_{jt}.

The overall civilian demand for the material in year t under emergency scenario conditions is the sum over all application areas j of the C'_{jt}, i.e.,

$$C_t^{\text{tot}} = \sum_{j=1}^{J} C'_{jt}.$$

The quantities D_t^{tot} and C_t^{tot} constitute some of the main outputs of the material demand computation process. The computer program prints them, along with the emergency investment demand, on the main output file.

C. The Basic Theorem

The discussion in Chapter 2, Section B.2 has noted that under certain circumstances, the MCR algorithm described in D-5477 is a special case of the MDCP algorithm. This statement can be formalized in the following theorem.

Theorem 1: Suppose the following conditions hold.

- Instead of being an input, μ_j, the defense fraction of material use in each application area, is computed from the relative proportions of defense and civilian peacetime economic demands for the industry sectors associated with that application area in the reference period under peacetime conditions.
- For each industry sector, the average annual net demand sum in the reference period under peacetime conditions is used as the measure of industrial output.
- All quantities U_{j0}, V_{j0}, and Ω_j are strictly positive.

Then the defense and civilian material demands computed by the method discussed in Section B are identical to the defense and civilian demands computed via the MCR method.

Proof. By the second condition, the industrial output values ω_{i0} used for the MCR construction satisfy the condition

$$\omega_{i0} = d_{i0} + q_{i0}$$

for each industry sector i. Consider the subset S_j , the set of industry sectors associated with application area j, which is equal to $\{i|\delta_{ij} = 1\}$. Summing over the industry sectors i in S_j, one obtains

$$\sum_{i=1}^{I} \delta_{ij}\omega_{i0} = \sum_{i=1}^{I} \delta_{ij}d_{i0} + \sum_{i=1}^{I} \delta_{ij}q_{i0}.$$

Each of these sums has had notation developed for it in Section A. Using that notation, we have $\Omega_j = U_{j0} + V_{j0}$. Under the third assumption, Ω_j is assumed to be strictly positive so it can be used as a denominator in a ratio.

Under the MDCP algorithm, if a defense usage fraction μ_j is not explicitly input for application j, then the program computes μ_j via the calculation $\mu_j = U_{j0}/\Omega_j$. It follows that $(1 - \mu_j) = V_{j0}/\Omega_j$ is the fraction of usage in the application area that is for civilian purposes. The defense demand in application area j in year t of the scenario period, which is given by $D'_{jt} = \mu_j\gamma_j(U'_{jt}/U_{j0})$, then becomes $D'_{jt} = \gamma_j\ (U'_{jt}/\Omega_j)$ (the terms U_{j0}, which are assumed to be nonzero, cancel) and the total defense demand in year t, $D_t^{\text{tot}} = \sum_{j=1}^{J} D'_{jt}$, becomes

$$D_t^{\text{tot}} = \sum_{j=1}^{J} \gamma_j\ (U'_{jt}/\Omega_j).$$

Under the MCR method, as derived in D-5477, the MCR ρ_i for industry i (i.e., the amount of material used in producing a given dollar amount of output of industry sector i) is computed as

$$\rho_i = \sum_{j=1}^{J} \gamma_j \frac{\delta_{ij}}{\Omega_j}$$

and the defense demand is equal to the sum

$$D_t^{\text{tot\_mcr}} = \sum_{i=1}^{I} \rho_i d'_{it}.$$

Inserting the formula for ρ_i into the formula for $D_t^{\text{tot\_mcr}}$, interchanging the order of summation and simplifying yields the result that the two total demand values are the same. That is, we have

$$D_t^{\text{tot\_mcr}} = \sum_{i=1}^{I}\sum_{j=1}^{J} \gamma_j \frac{\delta_{ij}}{\Omega_j} d'_{it}$$

$$D_t^{\text{tot\_mcr}} = \sum_{j=1}^{J}\sum_{i=1}^{I} \gamma_j \frac{\delta_{ij}}{\Omega_j} d'_{it}$$

$$D_t^{\text{tot\_mcr}} = \sum_{j=1}^{J} \frac{\gamma_j}{\Omega_j}\left(\sum_{i=1}^{I} \delta_{ij}\, d'_{it}\right)$$

The inner sum is the quantity U'_{jt}, so we get

$$D_t^{\text{tot\_mcr}} = \sum_{j=1}^{J} \gamma_j U'_{jt}/\Omega_j,$$

which is identical to the formula derived above for D_t^{tot} .

A similar argument can be applied to the civilian demands, using the quantities V_{j0}, V'_{jt}, and $1-\mu_j$. Under the main MDCP algorithm, the total civilian demand is

$$C_t^{\text{tot}} = \sum_{j=1}^{J} C'_{jt} = \sum_{j=1}^{J} (1-\mu_j)\gamma_j V'_{jt}/V_{j0} \,.$$

If the civilian usage fraction, $1-\mu_j$, is defined by the economic data, so that it equals V_{j0}/Ω_j, the addend in the latter sum becomes $\gamma_j V'_{jt}/\Omega_j$. We then have

$$\sum_{j=1}^{J} \gamma_j V'_{jt}/\Omega_j = \sum_{j=1}^{J} \frac{\gamma_j}{\Omega_j} \left(\sum_{i=1}^{I} \delta_{ij} q'_{it} \right) = \sum_{i=1}^{I} q'_{it} \left(\sum_{j=1}^{J} \gamma_j \delta_{ij}/\Omega_j \right) = \sum_{i=1}^{I} \rho_i q'_{it} \,.$$

That is, the inner sum in the next to last expression is recognizable as the formula for the MCR ρ_i, and the last expression, the sum on i, is the formula for civilian demand when the MCR method is used.

D. Computation of Emergency Investment Material Demand

1. Introduction

This section derives the formula for emergency investment material demand that was alluded to in Chapter 2, Section B.3. This formula reproduces the MCR formula when the fractions of military demand are computed by the program for all the application areas of a material.

2. Formula for Emergency Investment Material Demand

Use the notation developed in Sections A and B. Let e'_{it} equal the emergency investment demand for the output of industry sector i in year t under scenario conditions. For each material application area j and year t define

$$W'_{jt} = \textstyle\sum_{i=1}^{I} \delta_{ij} e'_{it},$$

the emergency investment demand for goods and services in the sectors associated with application area j in year t under scenario conditions. By definition, there is no peacetime emergency investment demand, but one can compute ratios of the quantity W'_{jt} to the peacetime defense and civilian demands. Let θ be a parameter between 0 and 1, inclusive. The choice of θ will be explained later; it is the same for all application areas. The formula for emergency investment in application area j, denoted E'_{jt}, is given by the weighted sum of the ratios. In symbols

$$E'_{jt} = \theta\mu_j\gamma_j(W'_{jt}/U_{j0}) + (1-\theta)(1-\mu_j)\gamma_j(W'_{jt}/V_{j0}).$$

(It is assumed that U_{j0} and V_{j0} are strictly positive.) The overall emergency investment demand for the material in year t under emergency scenario conditions is the sum over all application areas j of the E'_{jt}; i.e.,

$$E_t^{\text{tot}} = \sum_{j=1}^{J} E'_{jt}.$$

3. Proof of Equivalence to the MCR Algorithm

Theorem 2: Suppose the following conditions hold.

- Instead of being a fixed quantity μ_j, the defense fraction of material use in each application area is computed from the relative proportions of defense and civilian peacetime economic demands for the industry sectors associated with that application area in the reference period under peacetime conditions;
- For each industry sector, the average annual net demand sum in the reference period under peacetime conditions is used as the measure of industrial output.
- All quantities U_{j0}, V_{j0}, and Ω_j are strictly positive.

(These conditions are the same as those for Theorem 1.) Then the formula E_t^{tot} for emergency investment demand is equal to the quantity $\sum_{i=1}^{I} \rho_i e'_{it}$., i.e., the emergency investment demand as computed via the MCR method, regardless of the value of θ.

Proof: The proof is similar to the proof of Theorem 1. Consider a given application area, j. Under the first condition, $\mu_j = U_{j0}/\Omega_j$ and $(1-\mu_j) = V_{j0}/\Omega_j$. The formula for E'_{jt} then collapses to $E'_{jt} = \gamma_j(W'_{jt}/\Omega_j)$, regardless of the value of θ. When the sum $\sum_{i=1}^{I} \delta_{ij} e'_{it}$ is substituted for W'_{jt}, then the total emergency investment demand, E_t^{tot}, becomes (after interchanging the order of summation and rearranging terms)

$$E_t^{\text{tot}} = \sum_{j=1}^{J} E'_{jt} = \sum_{j=1}^{J} \gamma_j(W'_{jt}/\Omega_j) = \sum_{j=1}^{J} \frac{\gamma_j}{\Omega_j}\left(\sum_{i=1}^{I} \delta_{ij} e'_{it}\right) = \sum_{i=1}^{I} e'_{it}\left(\sum_{j=1}^{J} \gamma_j \frac{\delta_{ij}}{\Omega_j}\right).$$

The inner sum on j is recognizable as the definition of the MCR ρ_i.

4. Discussion

As noted earlier, the traditional alternative material demand computation algorithm worked by taking ratios of scenario demands for goods and services to the corresponding peacetime demands for goods and services. Emergency investment demand for goods and services is zero in peacetime, so a ratio cannot be formed. This situation makes the modeling of emergency investment material demand not a straightforward process.

Early versions of the alternative demand computation algorithm simply ignored emergency investment demand. The version posited in D-5477 did not compute a separate emergency investment material demand, but accounted for it by increasing the defense demand. An intermediate version computed an explicit emergency investment material demand, but the computation only used the defense ratio W'_{jt}/U_{j0}. This resulted in some materials with only military usage having an emergency investment material demand too, since some of the associated industry sectors had emergency investment goods and services demand. This result looked odd. Eventually it was recognized that the civilian ratio W'_{jt}/V_{j0}, or some combination of the defense and civilian ratios, could be used as a measure of the extent to which material demand changed from peacetime to scenario conditions. This realization led to the formulation with the parameter θ.

Currently, MDCP assumes that θ is 0, i.e., only the civilian multiplier is used for the emergency investment material demand calculation. MDCP could be changed to accept input values of θ, possibly varying for different materials.

In general, a situation in which $U_{j0} = 0$ or $V_{j0} = 0$ for some j indicates severe problems in the underlying economic data, which should be examined. A stopgap solution for computing emergency investment demand in this case is as follows.

- If $U_{j0} = 0$ but V_{j0} is strictly positive, the computations can proceed normally because $\theta = 0$.
- If $V_{j0} = 0$ but the defense usage fraction is 1 for that application, i.e., all the demand is military, then the emergency investment demand in that application is set to 0. This procedure is reasonable because $\theta = 0$.
- If $V_{j0} = 0$ and the defense usage fraction is less than 1, the program stops—this case cannot be handled.
- If both U_{j0} and V_{j0} are 0, the program would have stopped previously—this case cannot be handled.

E. Computation of Material Demand by Industry Sector

As noted in Chapter 2, Section B.4 of the main paper, MDCP computes total demand by first computing the demand in each application area. It would be informative to have a breakdown of demand by industry sector. This section presents and derives formulas that compute such a breakdown. Throughout, assume that one particular material is under consideration. Let all notation be as developed in the previous sections, and assume that all relevant quantities U_{j0}, V_{j0}, and Ω_j are strictly positive.

1. Defense Demand

Consider defense demand first. We would like to develop values z_{it} for each combination of industry sector and scenario year, such that for each scenario year t, the following properties hold:

- $\sum_{i=1}^{I} z_{it} = D_t^{\text{tot}}$, the total defense demand in year t.
- If the military fractions for all the application areas are computed by the program, then the quantity z_{it} equals $\rho_i d'_{it}$ where ρ_i is the MCR for industry i.

A set of such quantities can be derived as follows. For each application area j and scenario year t, the defense demand in that area in year t is defined by $D'_{jt} = \mu_j \gamma_j \, (U'_{jt}/U_{j0})$, where $U'_{jt} = \sum_{i=1}^{I} \delta_{ij} d'_{it}$. The total defense demand D_t^{tot} is the sum over j of the D'_{jt}. Substituting and expanding, we obtain the double sum

$$D_t^{\text{tot}} = \sum_{j=1}^{J} \sum_{i=1}^{I} \mu_j \gamma_j \, \delta_{ij} d'_{it} / U_{j0}.$$

Define ζ_{ijt} as the individual term $\mu_j \gamma_j \delta_{ij} d'_{it}/U_{j0}$ in this double sum, and define $z_{it} = \sum_{j=1}^{J} \zeta_{ijt}$. It is clear (by interchanging the order of summation) that the sum over i of the z_{it} is equal to D_t^{tot}.

If the military fraction μ_j is computed by the program via the calculation, i.e., $\mu_j = U_{j0}/\Omega_j$; then $\mu_j/U_{j0} = 1/\Omega_j$ for each j. The formula for ζ_{ijt} then becomes $d'_{it}\gamma_j\delta_{ij}/\Omega_j$, and the formula for z_{it} becomes $z_{it} = d'_{it} \sum_{j=1}^{J} \gamma_j \delta_{ij}/\Omega_j$. The sum on j in this equation is recognizable as the formula for the MCR ρ_i.

2. Civilian Demand

An argument similar to the one for defense demand can be applied to civilian demand (including net exports) using the quantities $(1 - \mu_j)$, $V'_{jt} = \sum_{i=1}^{I} \delta_{ij} q'_{it}$, and V_{j0}, where the notation is as developed previously. Redefining the notation z_{it} to denote the civilian demand attributable to industry sector i in scenario year t, we have

$$z_{it} = \sum_{j=1}^{J} (1 - \mu_j) \gamma_j \, \delta_{ij} q'_{it} / V_{j0}.$$

3. Emergency Investment Demand

Section D has derived a formula for emergency investment demand, E_t^{tot}, which uses an arbitrary parameter θ between 0 and 1, inclusive. (The computer program currently uses the value of 0 for θ.) Redefining the notation z_{it} to denote the emergency investment demand attributable to industry sector i in scenario year t, we would like to develop values

z_{it} for each combination of industry sector and scenario year, such that for each scenario year t, the following properties hold:

- $\sum_{i=1}^{I} z_{it} = E_t^{\text{tot}}$, the total emergency investment demand in year t.
- If the military fractions for all the application areas are computed by the program, then the quantity z_{it} equals $\rho_i e'_{it}$, where ρ_i is the MCR for industry sector i and e'_{it} is the emergency investment demand for goods and services in industry sector i in year t computed by FORCEMOB.

Section D has derived the formula $E_t^{\text{tot}} = \sum_{j=1}^{J} E'_{jt}$

where

$$E'_{jt} = \theta\mu_j\gamma_j(W'_{jt}/U_{j0}) + (1-\theta)(1-\mu_j)\gamma_j(W'_{jt}/V_{j0}),$$

and

$$W'_{jt} = \sum_{i=1}^{I} \delta_{ij} e'_{it},\ \ t=1,\ldots,T.$$

Substituting the formula for W'_{jt} in the formula for E'_{jt} , we obtain

$$E'_{jt} = \left[\theta\mu_j\gamma_j/U_{j0} + (1-\theta)(1-\mu_j)\gamma_j/V_{j0}\right]\sum_{i=1}^{I} \delta_{ij} e'_{it}$$

and E_t^{tot} becomes the double sum

$$E_t^{\text{tot}} = \sum_{j=1}^{J}\sum_{i=1}^{I}\left[\theta\mu_j\gamma_j/U_{j0} + (1-\theta)(1-\mu_j)\gamma_j/V_{j0}\right]\delta_{ij} e'_{it.}$$

If the term z_{it} is defined by

$$z_{it} = \sum_{j=1}^{J}\left[\theta\mu_j\gamma_j/U_{j0} + (1-\theta)(1-\mu_j)\gamma_j/V_{j0}\right]\delta_{ij} e'_{it,}$$

then it is clear (by changing the order of summation in the double sum above) that the sum over i of the z_{it} for any particular t is equal to E_t^{tot}.

If all the military fractions are computed by the program, then $\mu_j = U_{j0}/\Omega_j$ and $(1-\mu_j) = V_{j0}/\Omega_j$, thus $\mu_j/U_{j0} = 1/\Omega_j$ and $(1-\mu_j)/V_{j0} = 1/\Omega_j$, for each j. The formula for z_{it} then collapses to

$$z_{it} = e'_{it}\sum_{j=1}^{J}\gamma_j\delta_{ij}/\Omega_j$$

regardless of the value of θ. The sum on j is recognizable as the formula for the MCR ρ_i. Then z_{it} has the second property that is desired.

4. Implementation in the Computer Program

The preceding sections have derived formulas for computing demand by industry sector for each combination of tier and scenario year. The MDCP computer program implements these formulas, but uses slightly different intermediate variables in doing so. As a guide for interpreting the computer code, this section briefly reviews the structure of the equations as implemented in the MDCP program.

Consider defense demand first. All notation is the same as in previous sections. Look at a specific application area, j. For each industry sector i associated with application area j, the program computes the fraction d'_{it}/U'_{jt}. This fraction represents the proportion of scenario goods and services defense demand in application area j in scenario year t that is attributable to industry sector i. (If U'_{jt} =0, all relevant quantities are set to zero.) The program multiplies this fraction by the quantity D'_{jt}, which represents the material defense demand in application area j in scenario year t; $D'_{jt} = \mu_j\gamma_j(U'_{jt}/U_{j0})$. When the multiplication occurs, the terms U'_{jt} cancel; the result is $\mu_j\gamma_j d'_{it}/U_{j0}$, which is the term ζ_{ijt} defined in Section E.1 for those industry sectors associated with the application. (These are the industry sectors for which $\delta_{ij} = 1$; the remaining sectors have $\delta_{ij} = 0$ and result in a zero value for ζ_{ijt}.) Summing the ζ_{ijt} over j yields the formula z_{it}, the amount of material demand associated with industry sector i in scenario year t, as defined in Section E.1.

The process for computing civilian and emergency investment demand by industry sector is similar, mutatis mutandis. The emergency investment calculation proceeds as if the parameter θ is equal to zero.

Appendix A.
Illustrations

Figures

Tables

This page is intentionally blank.

Appendix B. References

Atwell, Robert J., Eleanor L. Schwartz, James S. Thomason, Thomas J. Wallace. *Generic Unclassified Stockpile Sizing Module (SSM) Training and Testing for the National Defense Stockpile (NDS) 2015*. IDA Document D-5270. Alexandria, VA: Institute for Defense Analyses, November 2014.

Meade, Douglas S. *The INFORUM LIFT Model*. Technical Documentation. College Park, MD: Inter-industry Forecasting Project, University of Maryland, November 2017. https://www.researchgate.net/publication/266049640_The_LIFT_Model.

Meade, Douglas S., et al. ILIAD. College Park, MD: Inter-industry Forecasting Project, University of Maryland, December 2011.

Miller, Ronald E., and Peter D. Blair. *Input-Output Analysis: Foundations and Extensions*. Second edition. New York City, NY: Cambridge University Press, 2009.

Office of the Under Secretary of Defense for Acquisition and Sustainment. *Strategic and Critical Materials 2019 Report on Stockpile Requirements*. U.S. Department of Defense. n.p., January 2019.

Office of the Under Secretary of Defense for Acquisition and Sustainment. *Strategic and Critical Materials 2021 Report on Stockpile Requirements*. U.S. Department of Defense. n.p., February 2021.

Santmire, Tara E. *Stockpile Sizing Module Documentation for Version 4.4*. Vol. I: *Theoretical Foundations and User's Guide*, Vol. II: *SSM Inputs,* and Vol. III: *SSM Outputs*. IDA Paper P-2867. Alexandria, VA: Institute for Defense Analyses, March 1997.

Schwartz, Eleanor L. and James S. Thomason. *Computation of Material Demand in the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) Process*. IDA Document D-5477. Alexandria, VA: Institute for Defense Analyses, August 2015.

Schwartz, Eleanor L. and James S. Thomason. *The Material Supply Adjustment Process in RAMF-SM Step 2*. IDA Document D-5564. Alexandria, VA: Institute for Defense Analyses, June 2016.

Schwartz, Eleanor L., An-Jen Tai, Richard H. White, and James S. Thomason. *Documentation of the Forces Mobilization Model (FORCEMOB), Versions 3.1 and 3.2*. Vol. I, *General Description*; Schwartz, Eleanor L. and James S. Thomason. Vol. II, *Data Preparation Guide*. IDA Paper P-2953. Alexandria, VA: Institute for Defense Analyses, January 1996.

Thomason, James S., Robert J. Atwell, D. Sean Barnett, James P. Bell, Nicholas S. J. Karvonides, Michael F. Niles, Whitney C. Picard, and Eleanor L. Schwartz. *Analyses for the 2011 National Defense Stockpile Requirements Report to Congress on Strategic Materials*. Vol. I: *Main Report*. IDA Paper P-4695. Alexandria, VA: Institute for Defense Analyses, March 2011.

Thomason, James S., Robert J. Atwell, Eleanor L. Schwartz, and Thomas J. Wallace. *Forces Mobilization Model (FORCEMOB): Unclassified Training Tutorial*. IDA Document D-5433. Alexandria, VA: Institute for Defense Analyses, August 2015.

Thomason, James S., Wallace Ao, Robert J. Atwell, D. Sean Barnett, Jerome Bracken, Kevin E. Burns, Caroline R. Earle et al. *Analyses for the 2015 National Defense Stockpile Requirements Report to Congress on Strategic and Critical Materials*. Vol. I: *Material Assessments and Associated Analyses*. IDA Paper P-5190. Alexandria, VA: Institute for Defense Analyses, August 2015.

Thomason, James S., Eli Alster, Maxwell W. Camp, Jacqueline DuBois, Caroline R. Earle, Anthony C. Hermes, Eliza Johannes et al. *IDA Contributions to the Strategic and Critical Materials 2019 Report on Stockpile Requirements*. Vol. I, *Unclassified Contributions*. IDA Paper P-10727. Alexandria, VA: Institute for Defense Analyses, October 2019.

United States Census Bureau Website. “North American Industry Classification System.” Accessed January 2022. https://www.census.gov/naics/.

Appendix C.
Abbreviations

ALMNA	Alumina
ALMNM_METAL	Aluminum metal
ARF	Aluminum redistribution function
BAUXITE_METAL	Metallurgical-grade bauxite
DOC	Department of Commerce
DOD	Department of Defense
_emb	Embedded demand increment (output file)
FORCEMOB	Forces Mobilization Model
IDA	Institute for Defense Analyses
ILIAD	Inter-Industry Large-Scale Integrated and Dynamic Model
INFORUM	Inter-Industry Forecasting Project at the University of Maryland
Kg	Kilograms
LIFT	Long-Term Inter-Industry Forecasting Tool
M	Number of years for which historical information will be provided for at least one material
MCR	Material consumption ratio
MDCP	Material Demand Computation Program
MILFRAC	Military fraction
_mss	Message output file
MT	Metric tons
MT Oxide	Metric tons of oxide equivalent
N	Number of years in the scenario

NAICS	North American Industry Classification System
NDS	National Defense Stockpile
.not	Notes file
Oz	Ounces
.pfc	Postprocessor file, comma-delimited
.ppf	Postprocessor file
RAMF-SM	Risk Assessment and Mitigation Framework for Strategic Materials
S&CM	Strategic and critical material
_sbo	Substitution only (output file)
SL1	Study List 1
SL2	Study List 2
SME	Subject matter expert
SSM	Stockpile Sizing Module
ST	Short tons
_tfo	Thrift only (output file)
_tso	Thrift and substitution (output file)
.txt	Text file
USGS	United States Geological Survey

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE (DD-MM-YY)	2. REPORT TYPE	3. DATES COVERED (From – To)
XX-03-2022	Final	

4. TITLE AND SUBTITLE	5a. CONTRACT NO.
The RAMF-SM Material Demand Computation Program: Documentation and User's Guide	5b. GRANT NO.
	5c. PROGRAM ELEMENT NO(S).
6. AUTHOR(S)	5d. PROJECT NO.
Eleanor L. Schwartz	5e. TASK NO. DE-6-4333
	5f. WORK UNIT NO.
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Institute for Defense Analyses 730 East Glebe Road Alexandria, VA 22305	8. PERFORMING ORGANIZATION REPORT NO. IDA Paper P-22689 Log: H 21-000200
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Strategic Materials Office, Defense Logistics Agency 8725 John J. Kingman Rd. #2545, Fort Belvoir, VA 22060	10. SPONSOR'S / MONITOR'S ACRONYM(S) DLA
	11. SPONSOR'S / MONITOR'S REPORT NO(S).

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This paper documents the methodology and associated computer program for the portion of the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) that calculates demands for strategic and critical materials. The paper provides detailed documentation, including mathematical derivations, of the methodological improvements that have been made to the RAMF-SM material demand computation process in the past few years. The paper also provides a user's guide to the computer program, with sample input and output files. A goal of the paper is to enable a new user to be able to run the program, set up its inputs, and interpret its output. Developed by the Institute for Defense Analyses, RAMF-SM has played a key role in the analyses that have supported the Reports to the Congress from the Department of Defense concerning requirements for the National Defense Stockpile of strategic and critical non-fuel materials.

15. SUBJECT TERMS

strategic materials, critical materials, National Defense Stockpile, Defense Logistics Agency, material requirements, mathematical modeling, methodology, computer program documentation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NO. OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Thomas Rasmussen
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include Area Code)
U	U	U	U	74	571-757-5478

This page is intentionally blank.