IDA

Supply Chain Modeling: Downstream Risk Assessment Methodology (DRAM) Summary of Development and Application

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INSTITUTE FOR DEFENSE ANALYSES

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Executive Summary

This briefing summarizes the Institute for Defense Analyses' (IDA) development of the Downstream Risk Assessment Methodology (DRAM). This work was done for Defense Logistics Agency Strategic Materials (DLA SM) to provide the capability to analyze supply chains of strategic and critical materials and the applications or products in which they are used. That capability allows DLA SM to assess and mitigate risks that may arise from supply-chain vulnerabilities that would not be revealed by traditional analysis of the supply of and demand for materials at the raw material level.

This briefing is a summary of the longer briefing that fully documents the development and use of DRAM (IDA Document D-5347).[1] This summary briefing was presented at the Conference on Diminishing Manufacturing Sources and Material Shortages in December 2013 and at the Military Operations Research Society workshop, How Risk Assessments Inform National Security Decision Making in October 2014.

The analysis of supply chains is an important addition to DLA SM's capabilities because the supply chains for strategic and critical materials and their applications used by the United States have become increasingly global. Thus, the United States relies on offshore material processing capabilities "downstream" from the step of raw material production to obtain many goods important to its economy and to the Department of Defense (DoD). Such reliance on overseas capabilities can create vulnerabilities to the supplies of those goods during a crisis or conflict that might not be revealed by traditional analysis of supply of and demand for materials in their raw forms.

This briefing demonstrates the operation of DRAM using the neodymium-iron-boron (NdFeB) magnet supply chain as a test case. It can also serve as a model for analyzing other materials and supply chains of interest to DLA SM. The NdFeB magnet supply chain has characteristics that make it more challenging and ultimately more useful to model than the simplest possible chain: it contains two materials of interest and nodes in multiple countries for most stages of production. NdFeB magnets are also a product type that is important to DoD.

The approach of the DRAM modeling effort was to represent each important production step in the global supply chain for a material and characterize how DRAM operates in terms of production capacity and material feedstock requirements. The fundamental approach is mass flow analysis, from raw material through each step in production. The model must also be able to estimate supply and

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[1] D. Sean Barnett and Jerome Bracken. *Supply Chain Modeling: Downstream Risk Assessment Methodology (DRAM) Demonstration of Capability,* IDA Document D-5347 (Alexandria VA: Institute for Defense Analyses, February 2015).

demand on a time-phased basis under the conditions of the National Defense Stockpile (NDS) planning scenario and any other scenarios of interest. It must be able to represent material shortfall mitigation measures and to reflect longer term changes in technology, the market, and the security environment that may affect the supply chain.

After developing the supply chain model, the study showed how it could be used to assess shortfall risk associated with downstream materials similar to the way that DLA SM and IDA have been assessing shortfall risk associated with raw (upstream) materials. In that approach (i.e., the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM)), risk is taken to be the product of the probability of the shortfall and its consequences. The probability is ordinarily taken to be the probability of the scenario giving rise to the shortfall. Because DRAM looks at downstream supply chains and the goods that these chains produce, the consequences of a downstream shortfall may be taken to be the consequences of the shortage of goods produced with the material(s) in question.

IDA used the DRAM model to demonstrate how shortfalls can be assessed and to show the cost effectiveness of mitigation measures that were evaluated under several different scenarios. The scenarios imposed different effects on material supply and demand and on how potential mitigation measures could or could not work. The scenarios discussed in this briefing to illustrate the capabilities of DRAM are (1) peacetime and (2) no imports (closed economy) with the failure of a sole U.S. source for one material. The longer briefing (see IDA D-5347) covers a broader range of scenarios and demonstrates DRAM's capabilities in more depth. The mitigation measures considered here were (1) government stockpiling, (2) an alternative federal inventory option, (3) spot market purchases, (4) material substitution; and (5) a concerted material production program. The demonstrations for each scenario included an assessment of the product produced by the supply chain, the material flows through the chain, and the shortfalls (if any). The effectiveness of the mitigation measures were shown, with costs estimated where shortfalls were found. The mitigation measures were also evaluated for and prioritized by cost effectiveness.

Although the cases presented were analyzed to demonstrate the capabilities of DRAM, we can draw a few conclusions from them regarding the nature of strategic and critical material supply chains and their potential vulnerabilities. The loss of sources within a supply chain can create shortfalls, depending on the redundancy of the network and the U.S. market share of potential material imports. Different mitigation measures may not be suitable for some material processing nodes and scenarios (e.g., substitution, spot market purchases). The capacities of material production nodes in domestic supply chains may not be balanced for self-sufficiency. For example, shortfall mitigation at multiple nodes may be required to allow the production of the final product at full domestic capacity.

In conclusion, this briefing shows that DRAM is a flexible tool for modeling supply chains. DRAM can represent a wide variety of supply chains for different materials and products. can model a wide range of supply and demand conditions that could arise from

scenarios of interest to DLA-SM and DoD, and can also model a wide range of possible shortfall risk mitigation measures. On the downside, acquiring supply chain data can be difficult because it is frequently considered to be business sensitive and may not be available at all for foreign producers. Nevertheless, the analyses in this demonstration show that DRAM can be useful for gaining an understanding of supply chains important to DoD and potentially uncovering vulnerabilities that are not apparent from analyzing upstream (raw material) supply and demand only.

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1.   Introduction

Supply Chain Modeling: Downstream Risk Assessment Methodology (DRAM) Summary of Development and Application

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October 16, 2014

Institute for Defense Analyses

This briefing summarizes the Institute for Defense Analyses' (IDA) development of the Downstream Risk Assessment Methodology (DRAM). This work was done for Defense Logistics Agency Strategic Materials (DLA SM) to provide the capability to analyze supply chains of strategic and critical materials and their applications. That capability will allow DLA SM to assess and mitigate risks that may arise from supply-chain vulnerabilities that would not be revealed by traditional analysis of the supply of and demand for materials at the raw material level.

The work described in this briefing was performed in the first half of 2013. Thus, it reflects the status of the DRAM analytical capability at that time. It also notes where recommendations for further development or implementation of DRAM have been followed, particularly with regard to IDA's support of the preparation of the *Strategic and Critical Materials 2015 Report on Stockpile Requirements*.[1]

This briefing is a summary of a longer briefing that fully documents the development and use of DRAM (IDA Document D-5347).[2] This summary briefing was presented at the Conference on Diminishing Manufacturing Sources and Material Shortages in December 2013 and at the Military Operations Research Society Workshop: How Risk Assessments Inform National Security Decision Making in October 2014.

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[1] Department of Defense, *Strategic and Critical Materials 2015 Report on Stockpile Requirements* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, to be published).

[2] D. Sean Burnett and Jerome Bracken, *Supply Chain Modeling: Downstream Risk Assessment Methodology (DRAM) Demonstration of Capability,* IDA Document D-5347 (Alexandria VA: Institute for Defense Analyses, February 2015).

Agenda

- **Background**

- **Modeling Objectives**

- **Description of Approach**

  - **Modeling supply chains**
  - **Relating downstream shortfalls to risk**

- **Capability Demonstration Cases**

- **Observations**

- **Conclusions**

This slide presents the Agenda (Outline) that was used for this briefing.

Background

- **Work sponsored by Defense Logistics Agency Strategic Materials (DLA SM)**

- **Build and implement for DLA SM and DoD an analytically rigorous risk-based process that can help DoD set priorities for risk mitigation (preparedness and investments) concerning strategic and critical non-fuel materials**

  - **Process began as raw material shortfall estimation to support National Defense Stockpile (NDS) planning**

  - **The Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) extended shortfall estimation and stockpile planning into risk assessment and mitigation (beyond stockpiling)**

- **The Downstream Risk Assessment Methodology for strategic materials (DRAM) is now extending RAMF-SM into risk assessment and mitigation for *supply chains* downstream of raw material production**

Objective for Today's Presentation

- **Present DRAM capability and demonstrate its operation**

This work was sponsored by DLA SM as part of IDA's broader task supporting DLA SM's strategic materials program.

One goal of the broader task is to provide DLA SM an integrated, analytically sound approach to strategic material risk assessments and analyses of risk mitigation, which will be used by DLA SM to support its planning for and management of the National Defense Stockpile (NDS). To give DLA that risk management capability, IDA developed the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM). RAMF-SM allowed DLA SM to move from its traditional, shortfall-based planning process for the NDS to a new, risk-based process that allows for the consideration of the probabilities and consequences of potential material shortages and provides additional risk mitigation strategies that go beyond stockpiling. DLA SM used RAMF-SM in developing risk mitigation strategies, including stockpile recommendations, for its *Strategic and Critical Materials 2013 Report on Stockpile Requirements*.[3] The goal of this subtask in developing DRAM is to build upon RAMF-SM and allow DLA to perform risk assessments and analyses of risk mitigation for the *supply chains* of strategic and critical materials in addition to the assessments of shortfalls in the materials' raw forms.

The analysis of supply chains is an important addition to DLA SM's capabilities because the supply chains for strategic and critical materials and their applications used by the United States have become increasingly global. Thus, the United States relies on overseas material processing capabilities that are "downstream" from the step of raw material production. This reliance on overseas processing capabilities can create vulnerabilities in the supplies of goods important to the Department of Defense (DoD) and the U.S. economy during a crisis or conflict. Those vulnerabilities might not be revealed by traditional analysis of supply of and demand for materials in their raw forms. DRAM gives DLA SM the ability to identify and mitigate such vulnerabilities and, hence, further its capability to reduce materials-related risk to the nation. DRAM can also help DLA determine the appropriate form of a material to stockpile by ensuring that the material can be processed into final goods in facilities accessible to the United States.

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[3] Department of Defense, *Strategic and Critical Materials 2013 Report on Stockpile Requirements* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, 2013).

2. Modeling

Develop DRAM (Downstream Risk Assessment Methodology) — Objectives

- Represent each important production step in global supply chain

- Estimate supply and demand at each step (node) in each supply chain on time-phased basis under conditions of NDS planning scenario (or others of interest)

- Model response of supply chain nodes to demand for goods, node capacity limits, and quantity of necessary feedstock material available to each node

- Model material shortfall risk mitigation measures applicable at each node of supply chain

- Reflect longer term changes in technology, market, and security environment (alternative futures) in scenario conditions

- Use quantitative approach, which is necessary to assess risk more precisely and to evaluate and support proposed risk mitigation measures

This slide gives the specific objectives of the DRAM modeling effort. The goal is to represent each important production step in the global supply chain and characterize how the supply chain operates in terms of production capacity and material feedstock requirements. The fundamental approach is mass flow analysis, from raw material through each step in production. The model must also be able to estimate supply and demand on a time-phased basis under the conditions of the NDS planning scenario and other scenarios of interest. It must be able to represent material shortfall mitigation measures and to reflect longer term changes in technology, the market, and the security environment that may affect the supply chain. A quantitative approach to the analysis is necessary to assess risk more precisely and to evaluate and support proposed risk mitigation measures.

Develop DRAM—Approach

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- **Use neodymium iron boron (NdFeB) magnet supply chain as basis for prototype**

- **Conduct literature review and canvass experts to identify desirable characteristics of supply chain model, approaches to modeling, and potential challenges**

- **Build model with characteristics to satisfy objectives**
  - **Material flows through nodes and shortfall estimation**
  - **Treatment of shortfall risk mitigation measures**

- **Demonstrate prototype DRAM using NdFeB magnets**

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This slide outlines the specific approach taken to develop the DRAM methodology and build a prototype supply chain model for neodymium iron boron (NdFeB) magnets. These magnets were chosen for the prototype because the supply chain has characteristics that make it more challenging and ultimately useful to model as a prototype than a simpler chain: it contains two materials of interest (neodymium (Nd) and dysprosium (Dy)) and nodes in multiple countries for most stages of production. NdFeB magnets are also an important product type to DoD, and IDA has information on the supply chain that it collected from past work.
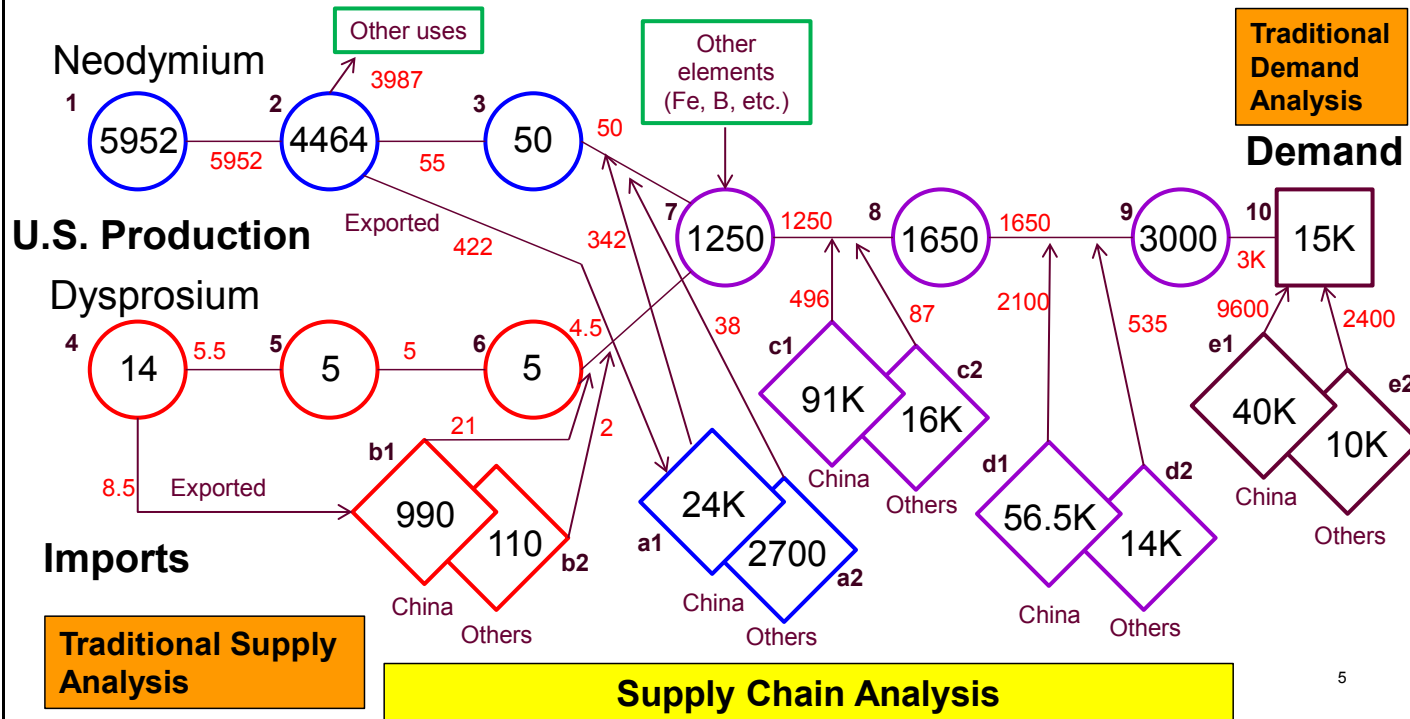
The approach to developing this methodology was to conduct a literature review and canvass experts on supply chain modeling to identify a methodology that would satisfy DLA SM's analytical needs. The development process was iterative. The approach was tried and refined after initial tests to ensure that it met DLA SM's needs.

This production flow diagram for the NdFeB magnet supply chain is used to demonstrate the methodology that IDA developed. The steps of production for NdFeB magnets are set forth at the top of the chart (from Ore Mining through Magnet Fabrication). The nodes of the chain, where the production processes take place, are indicated by large circles for domestic capabilities, and diamonds for foreign capabilities. This diagram focuses on the portion of the supply chain that involves the rare earth elements, Nd (neodymium) and Dy (dysprosium). Nodes involving the processing of Nd are indicated in blue, nodes involving the processing of Dy are indicated in red, and nodes involved in the processing of magnet alloy (formed from Nd, Dy, and other elements) are indicated in purple. The nodes are connected by arcs, which correspond to the flow of materials in the magnet production process (from the beginning step on the left through the final step on the right).

The numbers on the chart represent the production capacities of the nodes and the flow of materials, in tons per year, from one node to another, under the circumstances depicted in this diagram. The large black numbers in each node represent the production capacity of the node in metric tons per year. (Note that some capacity figures are notional and are used to illustrate the working of the methodology and the supply chain model.) The smaller red numbers between nodes indicate the flow of materials—in metric tons per year, from one production step to the next—that allows the supply chain to produce the final product, NdFeB magnets. The relative requirements for each material are based on one NdFeB magnet alloy (used simply for demonstration purposes). The diagram shows that based on the production capacities depicted, material is needed from both domestic and foreign sources at several steps to enable the supply chain to meet the U.S. demand for magnets, which is depicted here as being 15,000 metric tons (MT) per year. As will be discussed later, the model also takes into account the amount of feedstock material required at each node to allow the node to produce its output.

Finally, the slide shows how this methodology expands the analysis beyond the traditional raw materials analysis used in stockpile planning. In the traditional approach, raw material production capacities are compared to demand to see whether they are sufficient. With this methodology, one can also look downstream of raw material production—to any or all points between raw material and final product production—to see whether the capacities needed along the way are also sufficient to meet demand. Thus, this methodology can enable DLA to uncover potential supply vulnerabilities that would not be revealed by the traditional analysis.

IDA | **Relating Downstream Material Shortfalls to Risk**

- **Risk is defined as possibility of loss or harm:**
  - *Risk = Probability of material shortfall x Consequences*
- **Probability of shortfall is, to first order, probability of scenario**
- **Consequences of shortfall in DRAM are consequences of shortage of final product**
  - **Consequences of "mid-stream" shortages are reflected in shortages of final products**
  - **Potential approaches to assessing consequences of final product shortfalls include the following:**
    - **Expert judgment**
    - **Elasticity of demand**
    - **Long-term price**
    - **Cost of production**

After the supply chain model is built and used to identify potential material or product shortfalls, potentially under different scenario conditions, the analysis moves to assessing the risk created by the potential shortfalls. This approach is consistent with the IDA RAMF-SM approach and DLA SM's use of risk as a metric for assessing possible material shortfalls and for considering mitigation measures that might be adopted to prevent these shortfalls or eliminate their impact.

In the RAMF-SM approach, risk is taken to be the product of the probability of the shortfall and its consequences:

$$\text{Risk} = \text{Probability of material shortfall} \times \text{Consequences}.$$

The probability is ordinarily taken to be the probability of the scenario giving rise to the shortfall.

Because DRAM looks at downstream supply chains and the goods that these supply chains produce, the consequences of a downstream shortfall may be taken to be the consequences of the shortage of goods produced with the material(s) in question. One might assess the consequences of a shortage of goods in several ways, including expert judgment, long-term price, the cost of production, the price elasticity of demand, and the impact of shortages on industrial sector output. Further work in this area was pursued during the preparation of the 2015 Report on Stockpile Requirements and is discussed in the IDA Paper P-5190 that accompanies that report.[1]

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[1] James S. Thomason et al., *Analyses for the 2015 National Defense Stockpile Requirements Report to Congress on Strategic and Critical Materials,* IDA Paper P-5190 (Alexandria VA: Institute for Defense Analyses, to be published), Volume 1, Appendix 20.

3.   Demonstration Cases

Cases Demonstrated

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- *Peacetime supply and demand*
- **Cutoff of imports from China**
- **Cutoff of imports from China with increased demand**
- **No imports (closed economy)**
- *No imports and failure of U.S. sole source*

Demonstrations include product output, material flows, and shortfalls (if any)

Mitigation measures are demonstrated, with costs estimated, where shortfalls are found

Mitigation measure choices can be optimized for cost effectiveness

DRAM quantitative approach enables more precise risk assessment and evaluation and support of proposed risk mitigation measures

Cases Presented in Today's Briefing

DRAM's capabilities will now be demonstrated by showing how the NdFeB magnet supply chain model responds to the two different scenarios indicated in *blue italics*. The scenarios have some elements that may be somewhat similar to those of the NDS "Base Case" planning scenario, but the primary reason for defining them as they are was to cover a range of possible circumstances and show how the model responds to these circumstances. Several scenarios were evaluated in IDA Document D-5347, which presents the development of DRAM in full. In addition to demonstrating the estimation of material shortfalls, this discussion will also demonstrate how the model can be used to evaluate potential shortfall mitigation measures and optimize mitigation measure choices for cost effectiveness.

IDA | **Material Shortfall Mitigation Measures**

- *Traditional government stockpiling*

- *Other federal (or private) inventory options*

- *Spot market purchases*

- **Futures contracts**

- **Reductions in government supply guarantees for exports**

- *Substitution*

- *Concerted material production programs (e.g., Title III)*

- **Enhanced recycling**

- **Security of foreign supply arrangements**
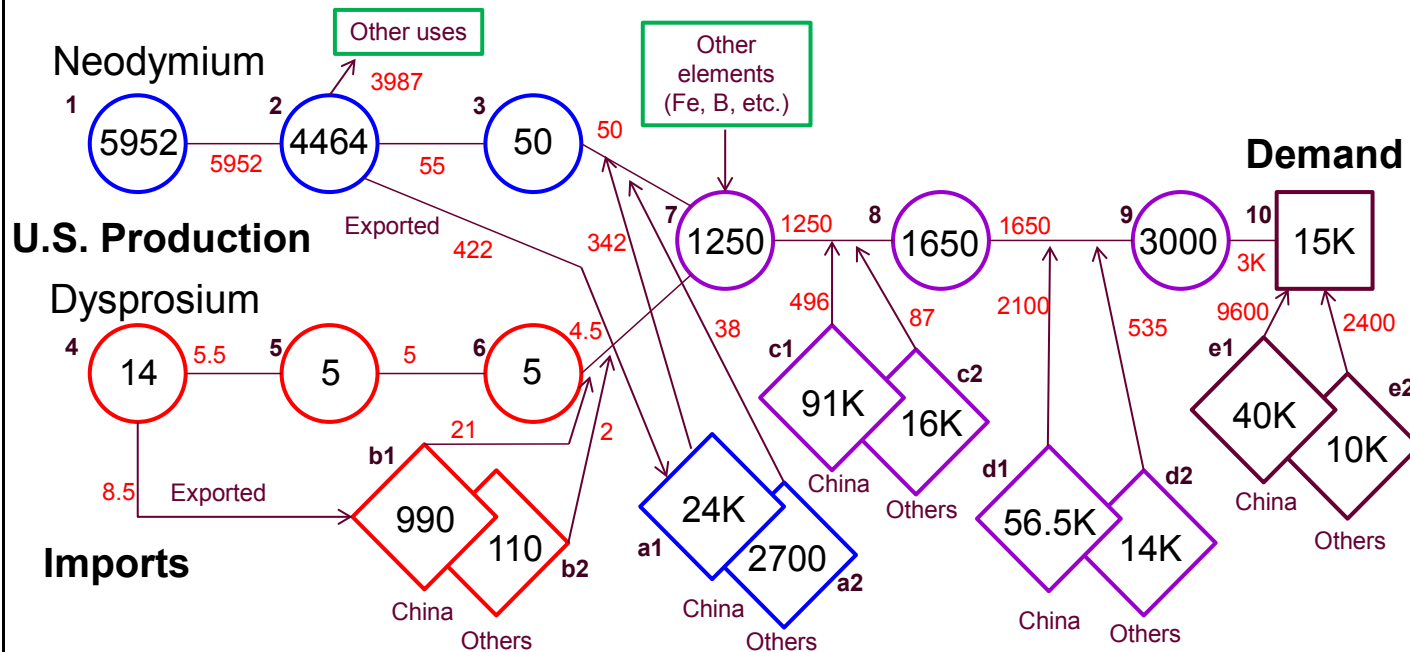
Included in today's briefing

One could apply several different shortfall mitigation measures to prevent or mitigate the effects of a material shortfall. These mitigation measures been assessed or at least considered during the work that IDA has done for DLA SM on managing materials-related risk. The measures in *blue italics* are those that will be considered in the example scenarios used to demonstrate the model.

This slide depicts again the supply chain for NdFeB magnets. It will be used to show how DRAM can model a supply chain and to show its response to different scenarios that affect material supply and demand.

IDA | Peacetime Supply and Demand Observations

- Peacetime case shows material/product flows and production under normal conditions

- Demand met by combination of U.S. production and imports

- Material flows driven by demand for finished goods and requirements for producing upstream products, including process losses

- Imports feed U.S. supply chain at several points

- Imports sufficient to meet U.S. demand as long as U.S. market share is at least 24 percent
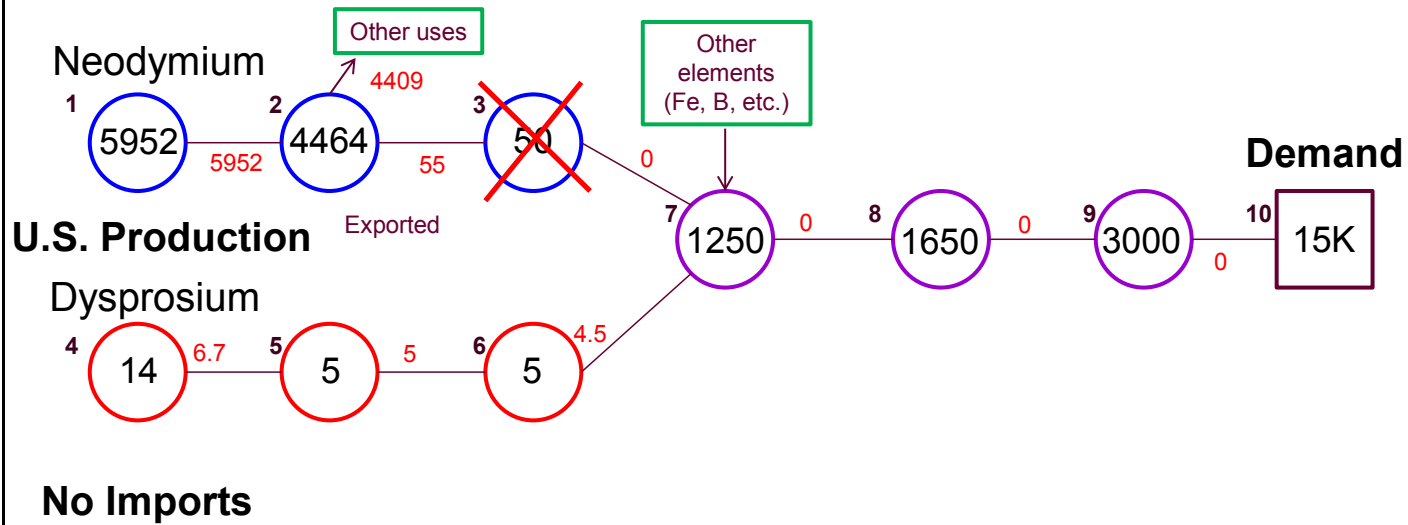
This slide indicates how the supply chain for NdFeB magnets meets U.S. demand under peacetime conditions. The U.S. market share must be at least 24 percent of foreign production to allow the United States to acquire sufficient imports to meet all demands (in this case, the limiting step requiring that fraction is the importation of finished magnets).

This slide models the scenario in which all imports are cut off completely and one supply chain node that is a sole source of one upstream product (Nd metal in this instance) does not operate. This situation is something of an artificial case, but it could be analogous to a DoD supply chain with no qualified alternative suppliers that suffers a failure at one node. The demonstration shows how the supply chain responds to try to meet U.S. demand for magnets under these conditions. The net result of this scenario is that none of the 15,000-MT demand can be met.

IDA **No Imports with Sole Source Cutoff Case Observations**

- **Imports not available at all and sole source node is cut off**
  - **Severe scenario for demonstrating modeling capability**
- **U.S. supply chain output constrained by lack of upstream capacity at several nodes**
- **One node—Nd metal production—is cut off entirely**
  - **Loss of critical node cuts off all U.S. production of final product**
  - **All but Nd ore and oxide production insufficient to meet final demand**
- **Resulting shortfall = 15,000 MT magnets**
- **Mitigation measure(s) required at one or more nodes**
  - **Stockpiling**
  - **Other Inventory options (e.g., Buffer stock)**
  - **Spot market purchases**
  - **Substitution**
  - **Concerted Program (magnet production and fabrication)**

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When imports are totally cut off and U.S. production of Nd metal is totally halted, the U.S. portion of the supply chain cannot operate at all. This situation causes a complete shortfall of 15,000 MT of magnets. To make up the shortfall in magnets, shortfall mitigation measures must be applied. This discussion will consider the application of the measures listed here and assess which ones would be the most cost effective in this scenario.

IDA | **No Imports with Sole Source Cutoff Case Analytical Assumptions**

Assumptions generally consistent with those used in last NDS Requirements Report

- **One year shortfall in 4-year scenario**
- **Planning horizon = 5 years**
- **U.S. market share = 0 percent (no imports)**
- **Wartime price multiple = 15**
- **Probability of war = 0.0037**
- **Buffer stock rental cost = 15 percent/yr**
- **Cost = budget outlays (no recoupment)**

To assess shortfall mitigation measures for cost effectiveness, certain planning assumptions must be made to put the measures in context and, in particular, allow their costs to be estimated. The necessary assumptions to frame the measures considered in this scenario are set out in the bullet points. These assumptions were also used for the mitigation measures considered in the 2013 NDS Requirements Report.

The shortfall period is used to calculate the size of the shortfall that must be made up using the mitigation measures. The planning horizon is used to estimate the cost of the Inventory option (with the inventory held for the government by a private vendor for an annual fee (buffer stock rental cost)). The U.S. market share determines how much material is available from foreign sources for import to the United States. (In this scenario, it is set equal to zero because all imports are assumed to be cut off.) The wartime price multiple is used to estimate the cost of material or product that is bought on the spot market during the conflict scenario. The probability of war (which was also used to estimate shortfall risk) is used to calculate the expected costs of several mitigation measures that have certain costs that would only be incurred in the event of a conflict. Finally, this assessment considers only budget outlays. Specifically, it ignores any value that that government could recoup from stockpiled material after this material was no longer needed to be held to mitigate shortfall risks.

No Imports with Sole Source Cutoff Case Shortfall Risk Mitigation Options

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Risk mitigation options: indicated below, including inventory sufficient to enable full use of existing U.S. production capacities

Inventory amounts:

- **Nd metal: 430 MT**
- **Dy oxide: 0.5 MT**
- **Dy metal: 22.5 MT**

- **Magnet alloy: 583 MT**
- **Magnet block: 2,635 MT**
- **Fabricated magnets: 12,000 MT**

Mitigation Measure	Amount Provided (MT)	Expected Cost (Budget) ($M)
Stockpiling	Amounts above	3,848
Inventory	Amounts above	2,900
Spot Market	0 (no imports)	0
Substitution	1,500 (magnets)	0
Concerted Program (magnet production)	0*	0

* No extra feedstock available

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This slide shows the results of the analysis of the mitigation measures under one of two possible approaches for mitigating the shortfall under these circumstances: mitigating at the fabricated magnet supply and providing materials to enable the U.S. supply chain to operate at capacity. (The other approach would be simply to focus on the supply of finished magnets without providing for the operation of the U.S. magnet supply chain.)

In this case, under this approach, Substitution is taken, based on a separate assessment, to be able to make up for 10 percent of total demand, or 1,500 MT of magnets. The capacity of Spot Market purchases is zero because imports are cut off. The capacity of the Concerted Program option is zero because no domestic feedstock material is available to use to make magnets. That leaves Stockpiling and Inventory to make up the remainder of the shortfall.

This approach shows how materials needed at several stages of production could be stockpiled or inventoried to allow the U.S. supply chain to operate at capacity, with magnets stockpiled to make up the balance of the shortfall that the U.S. supply chain could not cover. In this case, materials could be held for several succeeding stages of production because the capacity of this chain tends to increase as one moves downstream. It should be noted that because the U.S. Nd metal production capacity is presumed not to operate at all, the output of that node must be entirely made up by stockpiling or inventory. Thus, the amount of Nd metal that would be stockpiled or inventoried is shown as 430 MT. The expected costs of the options are shown with their capacities.

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No Imports with Sole Source Cutoff Optimal Risk Mitigation Solution

- Shortfall mitigation options optimized for cost effectiveness
- Optimal measures under assumptions stated previously
- Mitigation measure priority same as 2013 NDS Requirements Report

Mitigation Measure	Amount Provided (MT)	Expected Cost (Budget) ($M)
Substitution	1,500	0
Inventory (magnets)	10,500	2,074
Inventory (block)	2,635	459
Inventory (alloy)	583	35
Inventory (Dy metal)	22.5	13
Inventory (Dy oxide)	0.5	0.3
Inventory (Nd metal)	430	23
Total	**15,000 (magnets)**	**2,604**

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This slide shows the result when the shortfall mitigation measures presented on slide 14 are prioritized using the same priorities that were used in the 2013 NDS Requirements Report. In this approach, the highest priority measures were applied first, followed by succeedingly lower priority measures. Consistent with the 2013 Report, the Spot Market and Concerted Program measures would be the first priority because these measures would provide the high performance (magnets) desired by users. However, these measures are not available under the specific circumstances of this scenario. The next priority was assigned to Substitution (because it provides substitute goods rather than the goods in question). The last priority was assigned to Inventory and Stockpiling (because of their relatively high cost), and Inventory was selected (to make up the balance of the shortfall) because it is less expensive (in dollars per ton) than Stockpiling.

Stockpiling and Inventory include all of the upstream materials needed to enable the U.S. supply chain to operate at capacity—including all of the Nd metal needed to make up for the absence of that supply chain node—plus the magnets needed to make up the balance of the shortfall. When the costs of acquiring and holding all of the materials indicated are calculated, Inventory remains the less costly approach, and it is selected.

In this case, with this mitigation approach, the total shortfall could be mitigated for a cost of $2.604 billion. While the results are not presented here, this approach costs slightly less than the cost of maintaining an inventory of finished magnets only. This further shows the ability of DRAM to address different material shortfall scenarios—in this case an import cutoff combined with a U.S. supply chain failure.

4.   Observations and Conclusions

Modeling Observations

- **Loss of sources within supply chain can create shortfalls, depending on redundancy of network and U.S. market share of imports**
  - **Loss of single node could prevent production of final product**
- **Different mitigation measures may not be suitable for some nodes and scenarios (e.g., Substitution, Spot Market)**
- **Capacities of nodes in domestic supply chains may not be balanced for self-sufficiency**
  - **Shortfall mitigation at multiple nodes may be required to allow production of final product at full domestic capacity**
  - **Options for shortfall mitigation may exist at multiple mid-stream nodes and at the final downstream node**
  - **Relative costs of shortfall mitigation at different nodes (e.g., mid-stream, downstream) may vary depending on material and nature of production process**

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Although these cases were analyzed to demonstrate the capabilities of DRAM to model supply chains, we can draw some conclusions from them—stated on this slide—regarding the nature of strategic and critical material supply chains and their potential vulnerabilities.

IDA | **Conclusions**

- **Modeling capabilities demonstrated**
  - **Supply chains with material flows for multiple materials and multiple material suppliers**
  - **Multiple scenario conditions**
    - **Peacetime material flows**
    - **Increased demand**
    - **Cutoffs of material supplies from specified sources or all sources, including domestic**
  - **Shortfall risk mitigation measures evaluated**
    - **Applicable node by node and material by material**
    - **Effects on individual material flows, production of goods, and mitigation costs calculable**
    - **Can be optimized using specified priorities or to minimize cost or risk**
- **DRAM will be used to assess risk and evaluate mitigation measures for supply chains for FY 2015 NDS Requirements Report**

This slide notes that this presentation demonstrates the supply chain modeling capabilities of DRAM. The capabilities are very flexible and can represent a wide variety of supply chains for different materials and products. They can also model a wide range of supply and demand conditions that could arise from scenarios of interest to DLA-SM and DoD and a wide range of possible shortfall risk mitigation measures—those included in the 2013 Stockpile Requirements Report and others.

Finally, the slide notes that DRAM will be used (where data are available) to assess risk and evaluate mitigation measures for supply chains for the 2015 NDS Requirements Report. In fact, DRAM was used to evaluate several downstream material forms for the 2015 Report, and those evaluations served as the basis for potential DLA SM stockpile recommendations.[1]
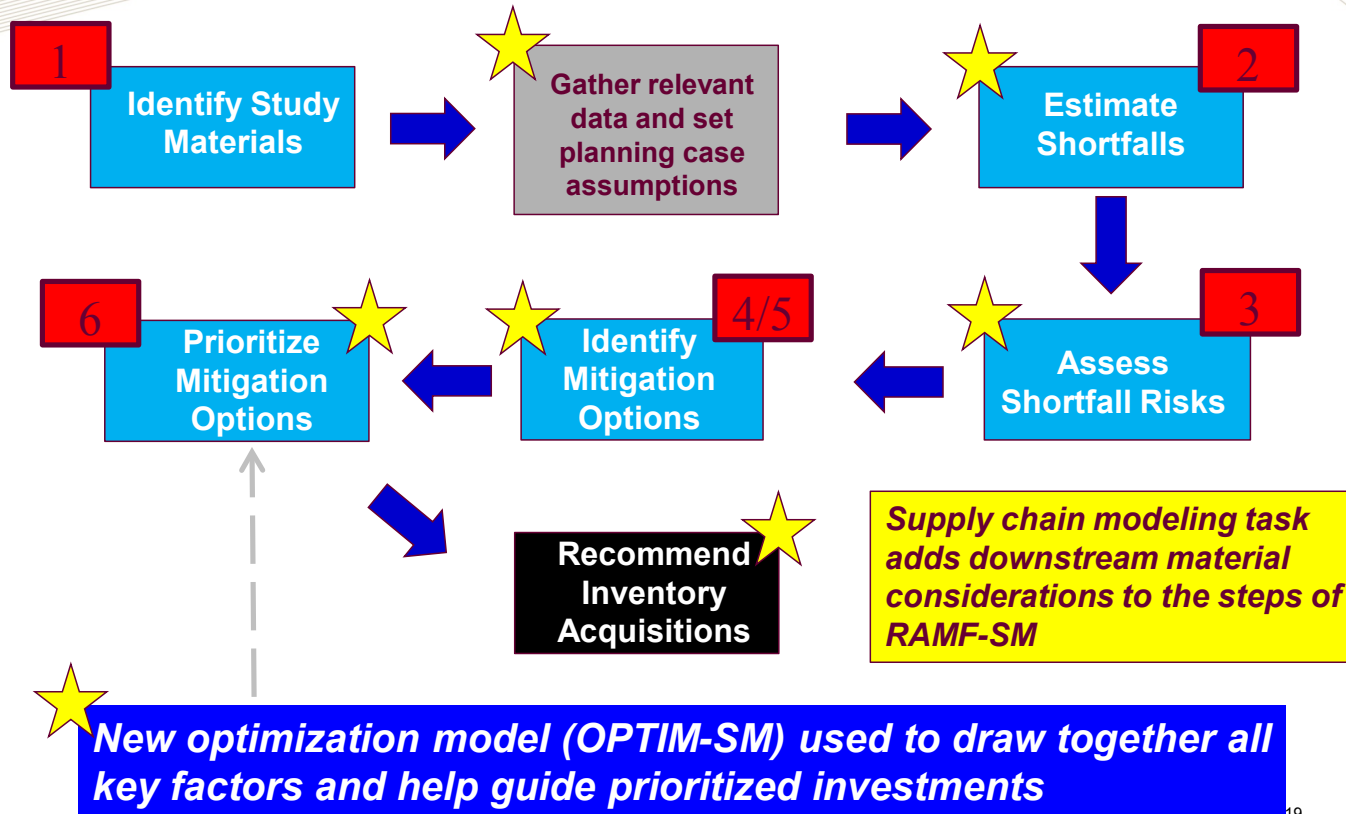
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[1] Thomason et al., *Analyses for the 2015 National Defense Stockpile Requirements Report to Congress on Strategic and Critical Materials,* IDA Paper P-5190 (Alexandria VA: Institute for Defense Analyses, to be published), Volume 1, Chapter 6; Volume 3, Appendix 9; Volume 4, Appendix 14; Volume 1, Appendix 22.

5. Backup Slides

BACK-UP

The slide in this section is backup material.

RAMF-SM Process and Steps

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1 Identify Study Materials

→

Gather relevant data and set planning case assumptions

→

2 Estimate Shortfalls

↓

3 Assess Shortfall Risks

←

4/5 Identify Mitigation Options

←

6 Prioritize Mitigation Options

→ Recommend Inventory Acquisitions

Supply chain modeling task adds downstream material considerations to the steps of RAMF-SM

New optimization model (OPTIM-SM) used to draw together all key factors and help guide prioritized investments

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This slide presents RAMF-SM (introduced on slide 2), which is used to assess and plan the mitigation of material shortfall risks for DLA SM. RAMF-SM follows six steps in assessing and planning the mitigation of shortfall risks:

- identifying (and selecting for study) materials of concern to the U.S. national security community;

- assessing whether any significant problems could arise in meeting critical demands for materials, given supplies likely to be available to the United States;

- assessing the importance of overcoming (or the risks to the United States of not overcoming) those shortfalls by deliberate government mitigation actions;

- identifying various plausible/promising government mitigation options to address any important shortfalls;

- assessing and comparing the specific costs and mitigation effects of these various promising government mitigations options, both individually and together; and

- identifying priorities among the materials for investments of taxpayer dollars, whether through stockpiling or other government investments, to mitigate important potential shortfalls.

RAMF-SM was developed for the assessment and mitigation of risks related to raw materials. However, if the analytical techniques of DRAM are applied within each of the RAMF-SM steps, RAMF-SM can also be used to evaluate and mitigate the risks from potential shortages of materials in their downstream forms.

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Appendix B
Abbreviations

DLA SM	Defense Logistics Agency Strategic Materials
DoD	Department of Defense
DRAM	Downstream Risk Assessment Methodology
Dy	dysprosium
IDA	Institute for Defense Analyses
MT	metric ton
Nd	neodymium
NdFeB	neodymium iron boron
NDS	National Defense Stockpile
RAMF-SM	Risk Assessment and Mitigation Framework for Strategic Materials
U.S.	United States

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14. ABSTRACT

The Institute for Defense Analyses developed the Downstream Risk Assessment Methodology (DRAM), for the Defense Logistics Agency Strategic Materials, to analyze supply chains of strategic and critical materials and the applications in which they are used. DRAM allows the assessment and mitigation of risks arising from vulnerabilities in supply chains that would not be revealed by analysis of the supply of and demand for raw materials alone.

DRAM represents each important production step in the supply chain for a material and characterizes how it operates in terms of production capacity and material feedstock requirements. The approach is mass flow analysis, from raw material through each step in production. DRAM can also estimate supply and demand on a time-phased basis under the conditions of the National Defense Stockpile planning scenario and others of interest. It can represent material shortfall mitigation measures.

DRAM's operation is demonstrated using the neodymium-iron-boron magnet supply chain. This document is a summary of IDA Document D-5347, which presents DRAM in more depth. This briefing was presented at the conference on Diminishing Manufacturing Sources and Material Shortages (December 2013) and at the Military Operations Research Society Workshop, How Risk Assessments Inform National Security Decision Making (October 2014).

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