Assessing Risk and Identifying How to Improve Resilience of the Energy Supply Chain in the Pacific Theater: Models, Methods, and Insights

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Naval Postgraduate School (NPS)

America's national security research university

- Facilities of a graduate research university
- Faculty who work for the Navy, with clearances
- Students with fresh operational experience

- Located in Monterey, CA
- 63 master's degree programs
- 18 doctoral degree programs
- 719 faculty
- 1,394 resident students includes
  - 195 international from 42 countries
- 964 distributed learning degree students (60% govt. civilians)

History Highlights	
1909	**Founded at U.S. Naval Academy**
1951	**Moved to Monterey, CA**
	Operations Research launched

Operations Research at NPS

- Operations Research (OR) is the science of helping people and organizations make better decisions using
  - mathematical models, statistical analyses, simulations
  - analytical reasoning and common sense

  to the understanding and improvement of real-world operations.
- OR originated during World War II. The military uses OR at the strategic, operational, and tactical levels.
- Biggest users of OR: modern corporations.
- NPS has the oldest OR instructional program in existence.
- We conduct **analysis** and develop **decision support tools** that are of immediate operational relevance to the decision-maker.
- Often centered around Masters theses.

Faster, Better, Cheaper (FBC)

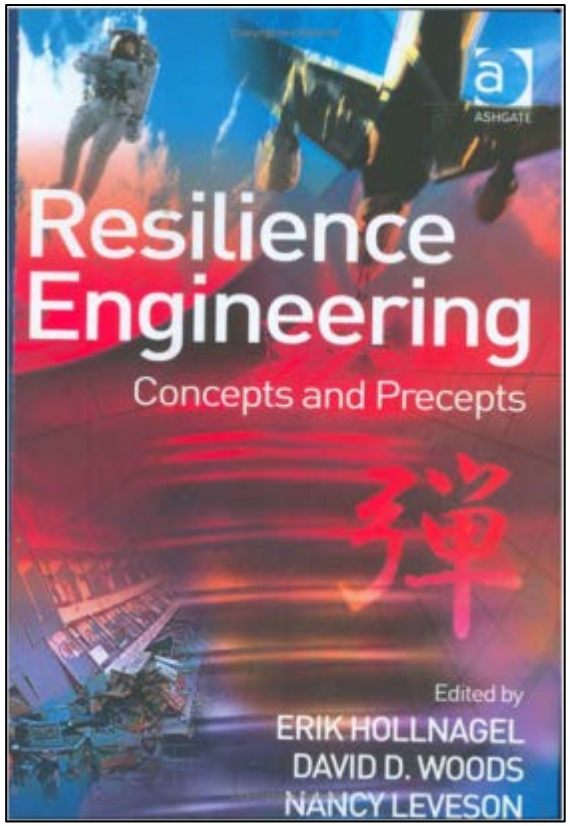
Faster, Better, Cheaper (FBC) is the enemy of resilience!

no “slack” = brittle

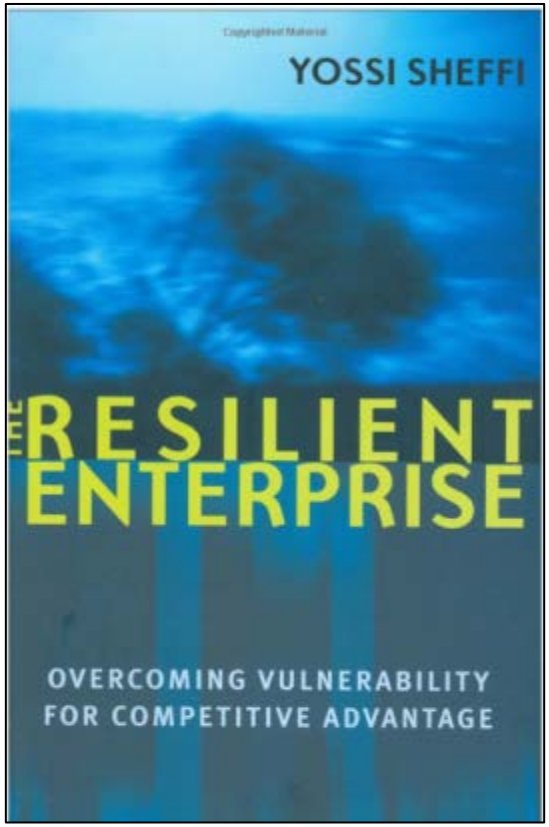
<u>Question</u>: *How to become more efficient in using limited resources while still being able to respond and adapt to surprises?*

- Mission Assurance
- Operational Resilience

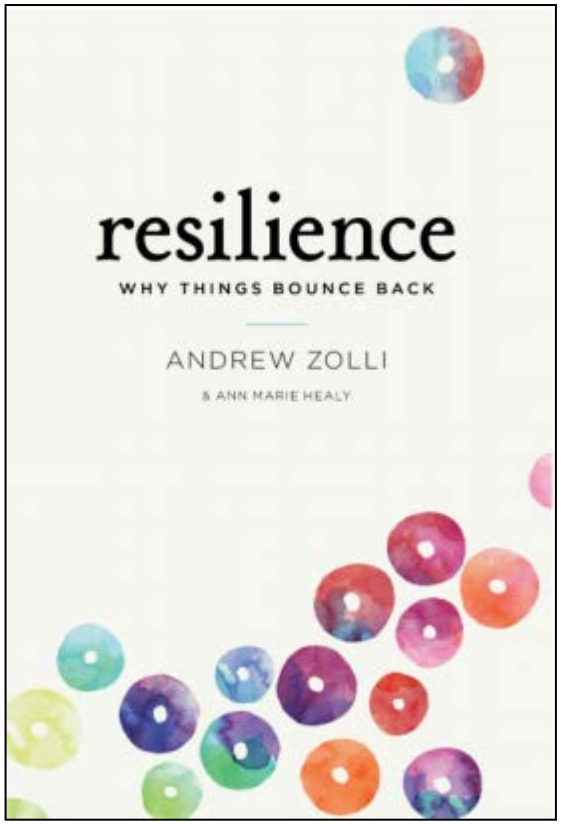
Reading on Resilience



Hollnagel, E., Woods, D.D., Leveson, N. (eds), 2006, *Resilience Engineering: Concepts and Precepts*, Aldershot, UK: Ashgate Press.



Sheffi, Y., 2007, *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage*, The MIT Press, Cambridge, MA.



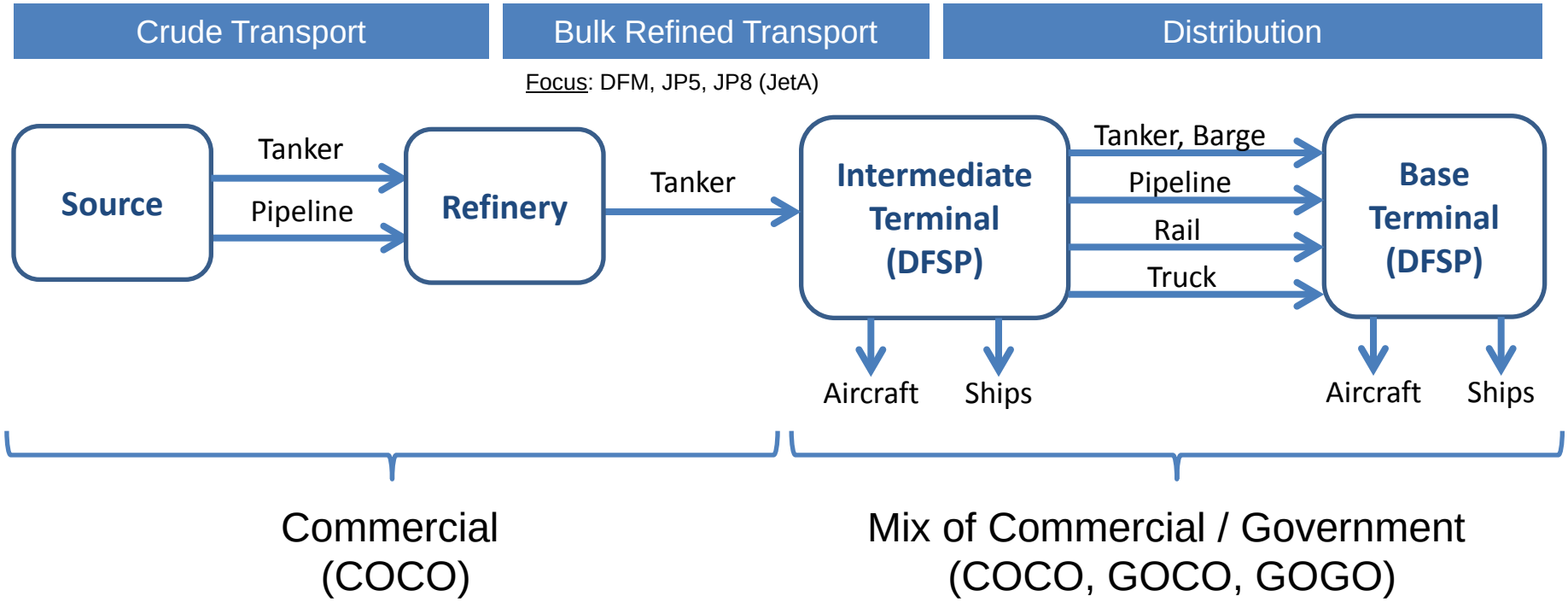
Andrew Zolli and Ann Marie Healy, 2012, *Resilience: Why Things Bounce Back*, The Free Press, New York.

Today's Agenda

- Provide background and history on NPS modeling and analysis efforts on Energy Supply Chain in the Pacific Theater over last 15 years
- Summarize techniques and assumptions
- Highlight current efforts and forthcoming results

- Pointers to lots of references

A Simplified View of Military Fuel Supply Chain

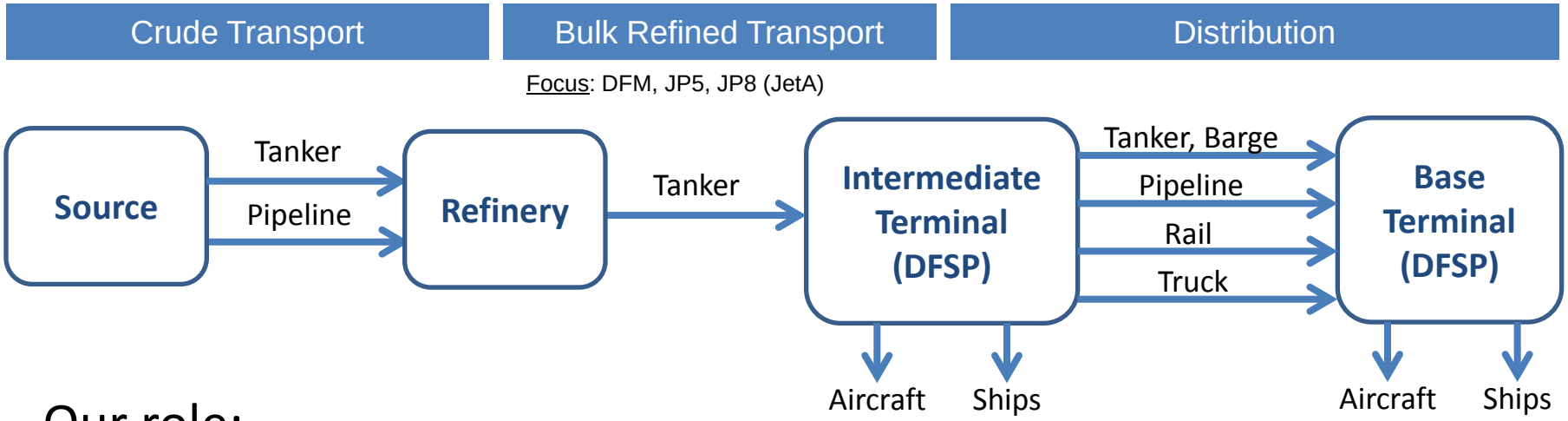


COCO: Commercially Owned, Commercially Operated

GOCO: Government Owned, Commercially Operated

GOGO: Government Owned, Government Operated

A Simplified View of Military Fuel Supply Chain

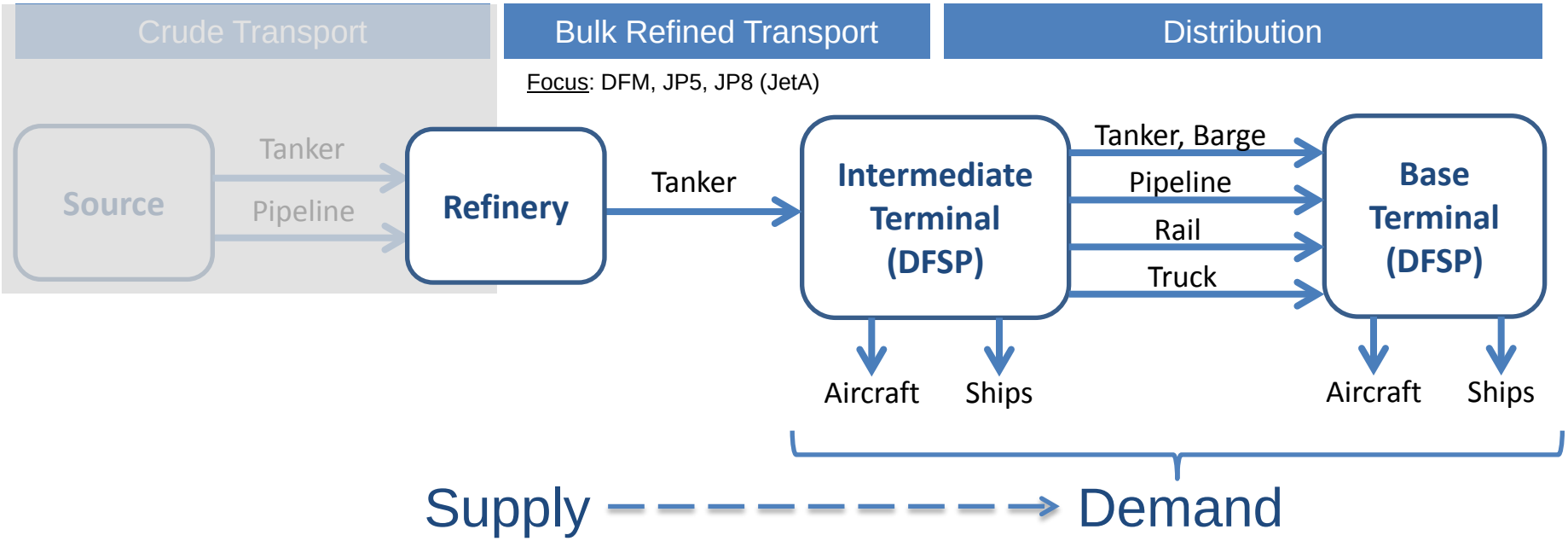


Our role:

- Develop mathematical models that represent the capabilities of the fuel transport & distribution network in Pacific theater
- Exercise these models under various what-if scenarios to assess these capabilities
  - identify vulnerabilities, weaknesses, gaps
  - consider potential mitigations

- Note: we are not trying to predict what will actually happen

A Simplified View of Military Fuel Supply Chain



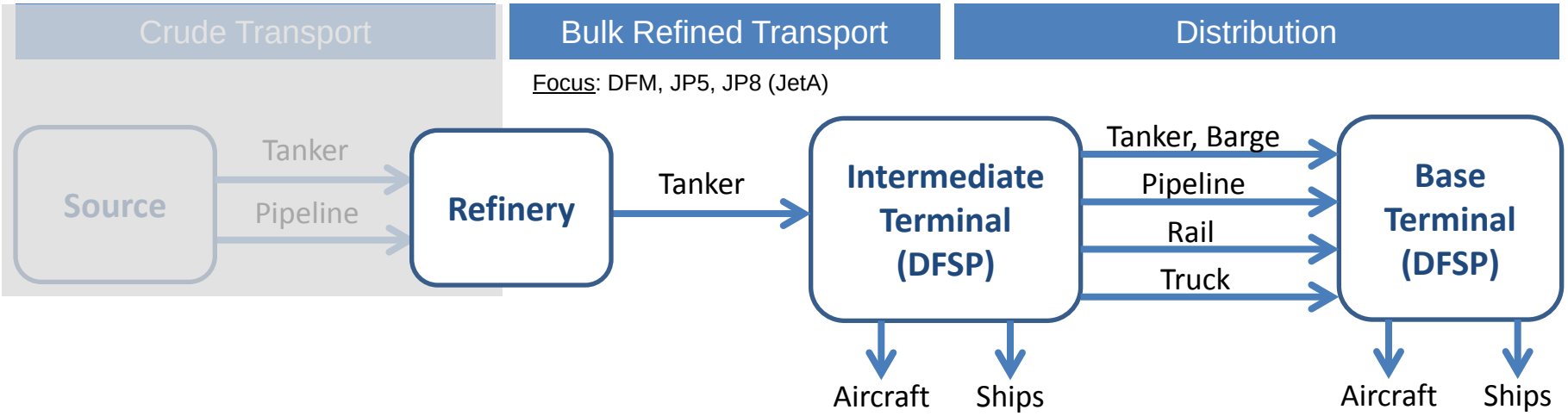
Given available supplies, what is the capability of the fuel transport & distribution network to satisfy the schedule of fuel demands?

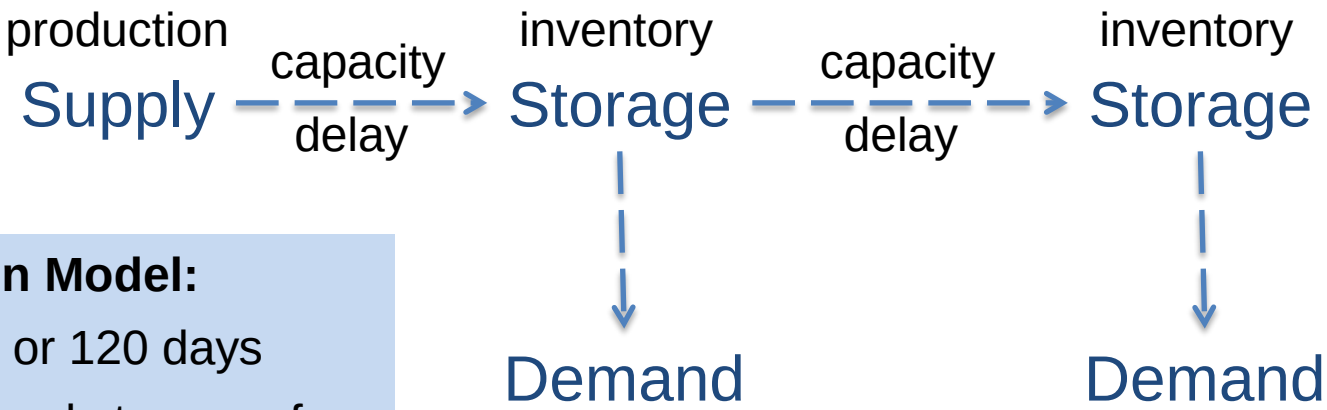
Operational Plans (TPFDD)

Fuel Requirements

- By fuel type
- By location
- By day

A Simplified View of Military Fuel Supply Chain





Prescriptive Decision Model:

Time Horizon: 60, 90, or 120 days

Activities: movement and storage of fuel by type, by location, by day.

Performance: demand shortfalls ("unmet" demand), by location, by day.

Early Work: 1999-2001
Prof. Robert Dell advised four Masters theses sponsored by US Pacific Command (USPACOM)

- LT Tracy Keenan (1999): Distribution Model for Japan; multi-modal network flows from int. DFSPs to base DFSPs
  Title: *Distributing intra-theater wartime POL requirements*
- LCDR Joseph Noble (2000): Scheduling Model for Japan; Individual tanker, railcar, and truck deliveries
  Title: *Scheduling and distributing intra-theater wartime POL requirements*
- LCDR John Harmon (2001): Theater-wide distribution model of 50 DFSPs, including Japan- and Korea-specific models
  Title: *Planning U.S. Pacific Command wartime fuel distribution*
- LCDR David Devlin (2001): Bulk transport model of tanker deliveries into Japan; Pre-planning against attack scenarios
  Title: *Scheduling and distributing intra-theater wartime POL requirements under uncertainty*

System Interdiction Models

- One player is trying to ensure the "operation" of a system.

  We call this player the *operator* or *defender*.
- Another player is trying to *interdict* that operation.

  We call this player the *attacker*.
- Player behavior is a <u>decision</u>, not a random event.
- We can be operator/defender or attacker, based on context.

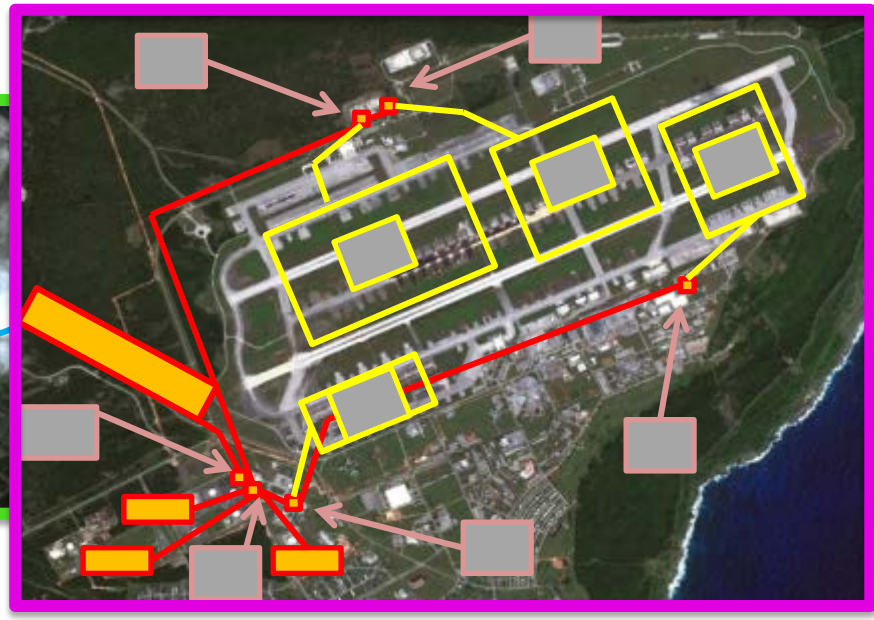
Attacker-Defender (AD)

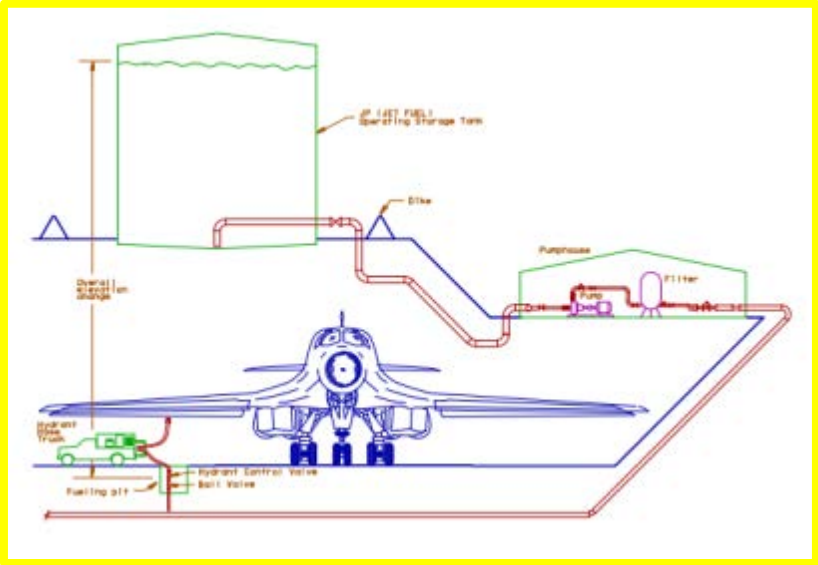
Defender-Attacker-Defender (DAD)

Investments in hardening, redundancy, etc., limited by budget.	Attacks limited by capability of the "attacker" and installed defenses	Optimal operation of the system, even after loss of components

Ref: Alderson, D.L., G.G. Brown, W.M. Carlyle. 2014. "Assessing and Improving Operational Resilience of Critical Infrastructures and Other Systems." A. Newman, J. Leung, eds., *Tutorials in Operations Research: Bridging Data and Decision*. Institute for Operations Research and Management Science, Hanover, MD, 180-215.

Chankij, Michael K., "Assessing the Resiliency of the JP8 Distribution System on Guam (U)," MS Thesis in OR, June 2012. MORS-Tisdale Winner.





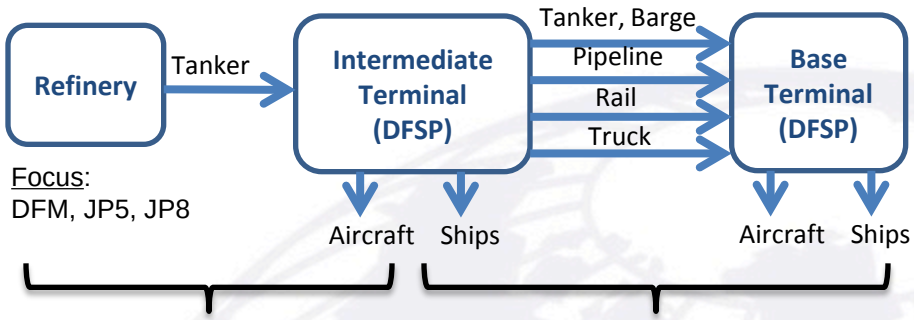
Assessing Risk and Identifying How to Improve Resilience of the Energy Supply Chain in the Pacific Theater

NAVAL POSTGRADUATE SCHOOL

How do disruptions in the ability to deliver fuel affect operations?

Which attack is the worst case scenario for the fuel delivery network?

A Simplified View of the Military Bulk Fuel Supply Chain



Focus:
DFM, JP5, JP8

Bulk Fuel Tanker Transport Into Theater

solved via optimization-based scheduling

Multi-Modal Delivery From DFSP Storage Into Combatants

solved using attacker-defender optimization

Sponsor: Office of the Assistant Secretary of Defense for Operational Energy Plans and Programs (OEPP)

Description: Building on several existing, but related, efforts, we focus on worst-case disruptions and their impact on operations in the US Pacific Command (USPACOM) Area of Operations, along with prioritization, evaluation, and cost of possible mitigations. The project includes the following subtopics: (1) an analysis of the fuel distribution capability on Okinawa; (2) the optimization of prepositioned fuel farm tanks; (3) the resilience of fuel delivery via global sea routes in the presence of deliberate and non-deliberate interdiction; (4) assessing the resilience of the mainland Japan fuel distribution network; and (5) assessing the resilience of the fuel infrastructure on Oahu, Hawaii.

Project Team:

Dr. David Alderson (Operations Research Dept., PI)
Dr. Gerald Brown (Operations Research Dept., Co-PI)
Dr. Javier Salmerón (Operations Research Dept.)
CDR Walter DeGrange (Operations Research Dept.)

Deliverables: 5 MS Theses + 1 Classified Technical Report

- CDR C.W. Burton, USN, "Analyzing the U.S. Military Fuel Distribution Network on Okinawa," M.S. Thesis, OR, Sept. 2013.
- LT A.S. Carline, USN, "Optimization of Prepositioned Fuel at Defense Fuel Support Points in United States Pacific Command Area of Responsibility," M.S. Thesis, OR, Dec. 2013.
- MAJ M.C. Fleischmann, USA, "Resiliency Analysis of the USPACOM Bulk Fuel Delivery Network," M.S. Thesis, OR, June 2013.
- LT C.S. Long, USN, "Analyzing the Resilience of the U.S. Military Fuel Distribution System for Mainland Japan," M.S. Thesis, OR, Sept. 2013.
- LCDR J.S. Montgomery, USN, "Oahu Petroleum Infrastructure Resilience," M.S. Thesis, OR Dept., June 2013.
- **D. Alderson, G. Brown, A. Carline, W. DeGrange, M. Fleischmann, and J. Salmerón, "Assessing Risk and Identifying How to Improve Resilience of the Energy Supply Chain in the Pacific Theater: Bulk Fuel Transport and Prepositioning (U)", NPS Center for Infrastructure Defense Technical Report NPS-OR-14-001R, 2014.**

Analyzing the Fuel Distribution System on Okinawa

LCDR Charles Burton, USN, M.S. Thesis in OR, September 2013

Challenges:

- Time-phased demand (TPFDD)
- Multi-commodity flow network
- Multi-national owners and operators
- Interdependence: electrical grid

Methods:

- Attacker-Defender Formulation
- Component level analysis
- Optimize the operator network
- Worst Case attacker assumed

Sponsorship

- PACOM J81
- OSD OEPP

Goals:

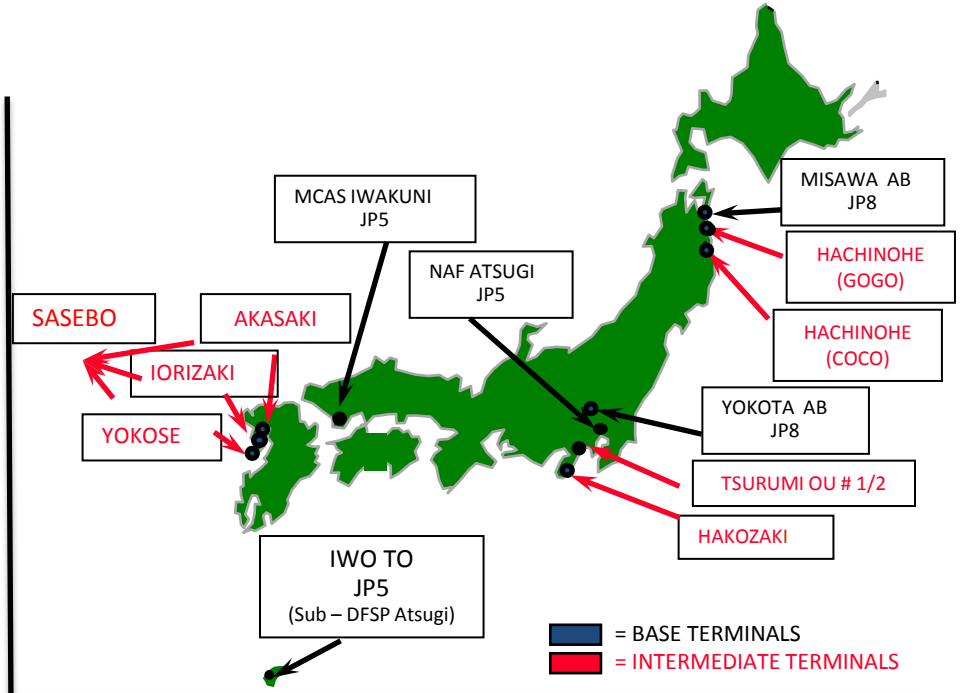
- Identify vulnerable components
- Provide solutions for robust fuel delivery
- A resilient system with the ability to deliver adequate fuel despite disruptions

Analyzing the Resiliency of Fuel Distribution on Mainland Japan

LT Catherine S. Long, USN, M.S. Thesis in OR, September 2013

Technical challenges:

- Military demands require different types of fuel and maximum flexibility for both peacetime and wartime scenarios
- Multi-modal, multi-commodity, multi-time period AD analysis
- In support of real OPLANs



Methods:

- Attacker-Defender Optimization Technique
- Model multi-modal flow of fuel using nodes and arcs
- Deliberate or Non-Deliberate Attack
- Assume worst-case attacker

Goals:

- Identify vulnerable components and worst-case scenarios
- Provide recommendations to make the network more resilient to disruptions

Oahu Petroleum Infrastructure Resilience

LCDR James Montgomery, USN, M.S. Thesis in OR, June 2013

Background:

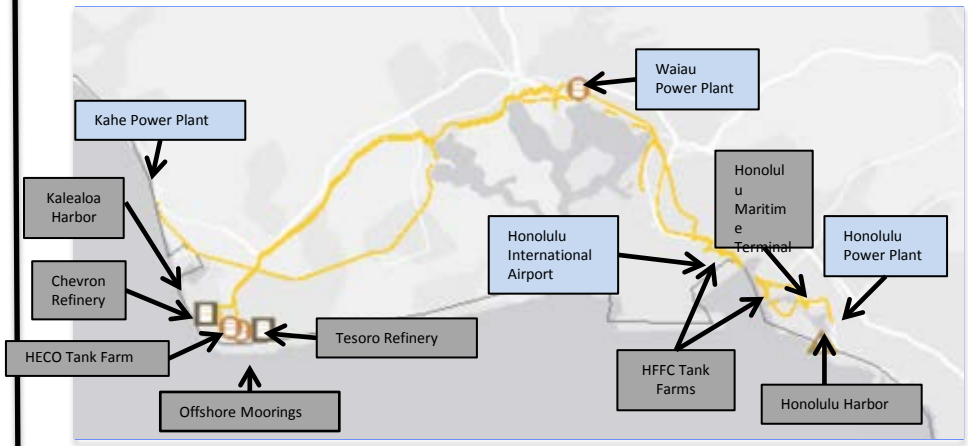
- PACOM has strategic fuel reserves on the island of Oahu, which is connected to and fed by the civilian infrastructure.
- Hawaiian Islands are highly dependent upon the petroleum delivery, refining, storage, and distribution network.

Research Questions

- How resilient is the Oahu fuel network?
- What are the worst-case disruptions?
- How resilient is the combined fuel/electrical system and what are the interdependent vulnerabilities?

Network Model

- 321 nodes:
  - 100 storage tanks
  - 2 refineries
  - 7 end-users
- 457 arcs (37 reverse-flow capable)
- 8-week time horizon
- Penalty for unmet demand
- Penalty for safety stock shortfall

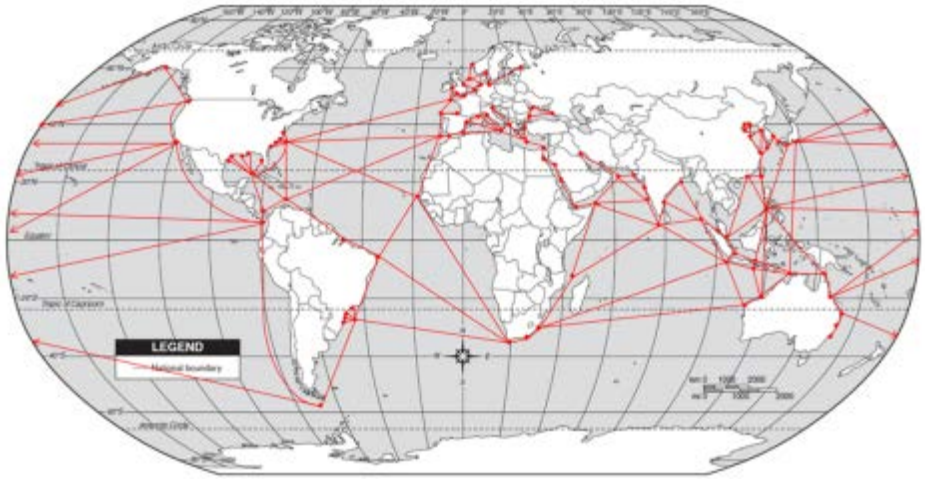


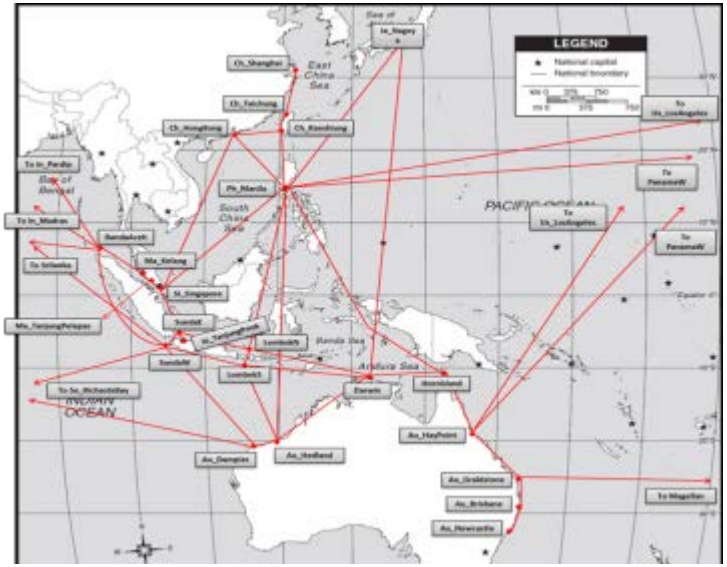
Resiliency Analysis of the USPACOM Bulk Fuel Delivery Network

MAJ Michael Fleischmann, USA, M.S. Thesis in OR, June 2013

Background and Problem:

- Defense Logistics Agency (DLA)-Energy contracts commercial tankers to deliver fuel to PACOM
- Fuel acquired from either government-owned, contractor-operated or contractor-owned and operated fuel depots
- Analysis will focus on:
  - Resiliency of current global sea fuel network, specifically deliveries to the PACOM AOR
  - Ways to improve resiliency of the network





Model and Analysis:

- Mathematical model to represent the day-to-day operations
- Find the minimum cost to deliver fuel from the DLA-Energy providers to the necessary locations in the PACOM AOR.
- Can analyze "what-if" scenarios regarding the loss of individual elements (e.g., tankers, supply points, routes, etc.) of the network.
- Attacker-defender model can identify the worst-case disruptions for the network.

Optimization of Prepositioned Farm Tanks in USPACOM AOR

LT Ashley H. Carline, USN, M.S. Thesis in OR, September 2013

Problem: DoD cannot afford to store enough fuel in each AOR for all scenarios

Solution: Preposition fuel farms to support scenarios across multiple AORs

- Scenario-based demands
- Supply OPLAN fuel demand
- Minimize shortage of supply

Features:

- Scenario-Robust Problem
- Two potential OPLANs
- Maximize quantity of fuel supplied
- Minimize distance to transport fuel from DFSP to customer
- Minimize unmet demand of fuel at a potential gas station location for an OPLAN

Research Questions:

- How many fuel farms?
- Where are the advantaged locations to preposition fuel farms?
- Where to stage refueling operations between fuel farms for each scenario?

FY15 Focus: Fuel Refineries

- **Subtopic 1: Refinery Capacity Analysis**.

  Are global suppliers likely to meet DoD fuel resupply needs of OPLANs?

- **Subtopic 2: Robust prepositioning of fuel and resilience of logistics in support of multiple OPLANs**.

  Do we have enough fuel capacity (i.e. storage, refining and transport) to prosecute given OPLANs?

  Is the infrastructure we have in place now adequate? Do we need it all (i.e. Red Hill)? Is it in the right place?

- **Subtopic 3: Impact of past and anticipated future market changes in the PACOM AOR.**

  What is the impact (positive or negative) of the recent and expected future refinery consolidation and change of ownership across the PACOM AOR on timelines, volumes and sources for our OPLANs?

  What are the trends in terms of consolidation to international locations… And what is the impact on the fitness of PWRS in terms of timelines and sealift needed if closer international suppliers are unwilling or unavailable?

FY15 Focus: Fuel Refineries

- **Subtopic 1: Refinery Capacity Analysis**.

- **Subtopic 2: Robust prepositioning of fuel and resilience of logistics in support of multiple OPLANs**.

  LT Brian Rodgers, 2015, "USPACOM Bulk Fuel Supply Chain Under Multiple Production, Storage, and Demand Scenarios," Master's thesis, Naval Postgraduate School, Monterey, CA.

  Classified technical report (forthcoming) on analysis for OPLAN demands.

- **Subtopic 3: Impact of past and anticipated future market changes in the PACOM AOR.**

  Keenan D. Yoho, David L. Alderson, 2015, "Market Trends for Refined Fuels and Their Implications for Operational Energy in the Pacific Theater," Technical report (forthcoming).

LT Brian Rodgers, 2015, "USPACOM Bulk Fuel Supply Chain Under Multiple Production, Storage, and Demand Scenarios," M.S. Thesis, NPS.

Input Data:

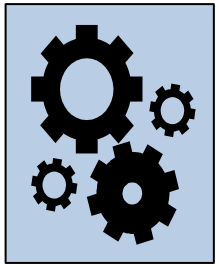
Refineries
- lat/lon
- daily production by fuel type
- % avail. by type
- available (Y/N)

DFSPs
- lat/lon
- storage capacity by fuel type
- initial inventory by fuel type

Transport Network
- origin, destination
- transport mode
- capacity
- distance / time

Scenario Demand
- daily demand
- per DFSP location
- by fuel type

Operator's Model

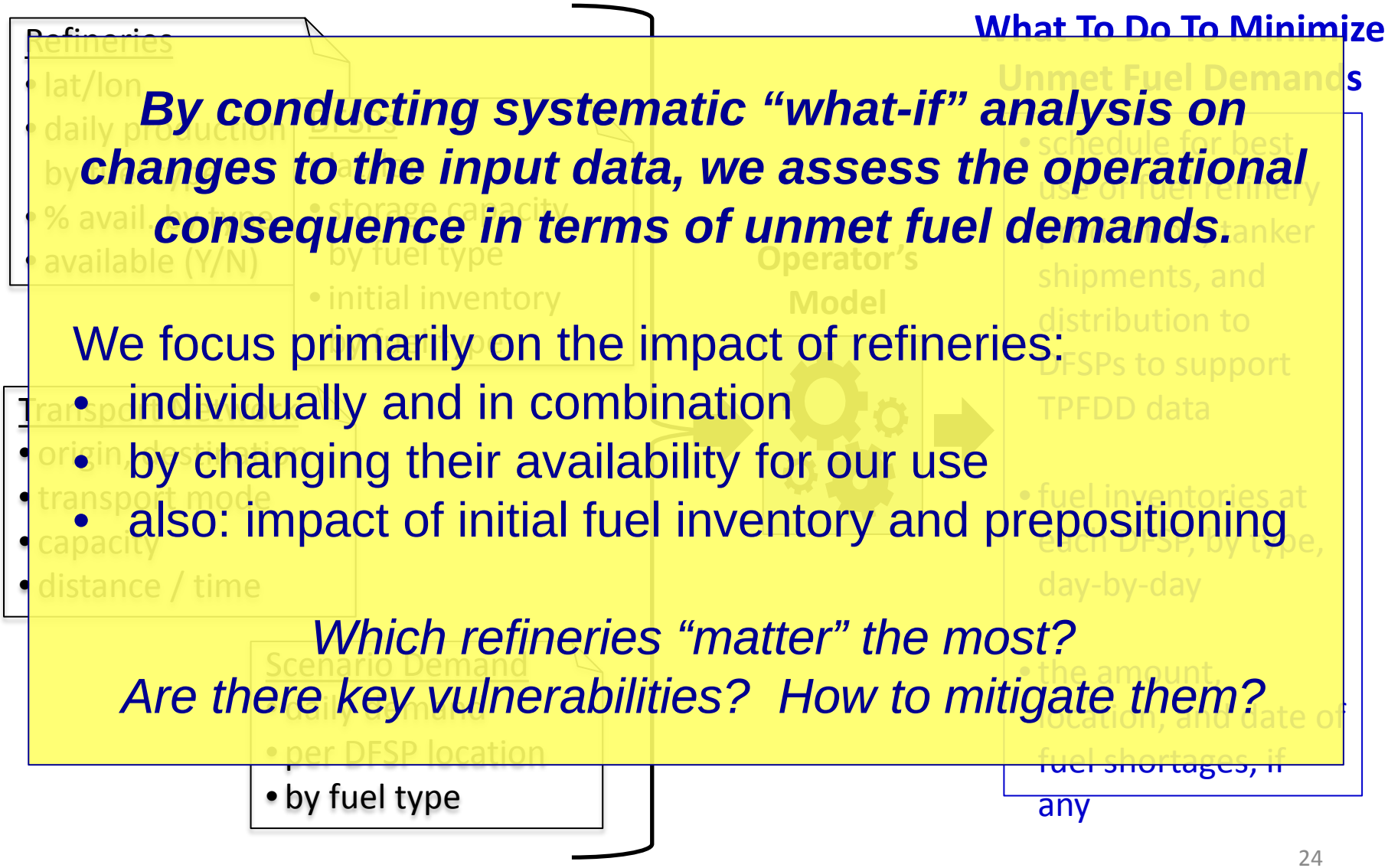


What To Do To Minimize Unmet Fuel Demands

- schedule for best use of fuel refinery production, tanker shipments, and distribution to DFSPs to support TPFDD data
- fuel inventories at each DFSP, by type, day-by-day
- the amount, location, and date of fuel shortages, if any

LT Brian Rodgers, 2015, "USPACOM Bulk Fuel Supply Chain Under Multiple Production, Storage, and Demand Scenarios," M.S. Thesis, NPS.

Input Data:



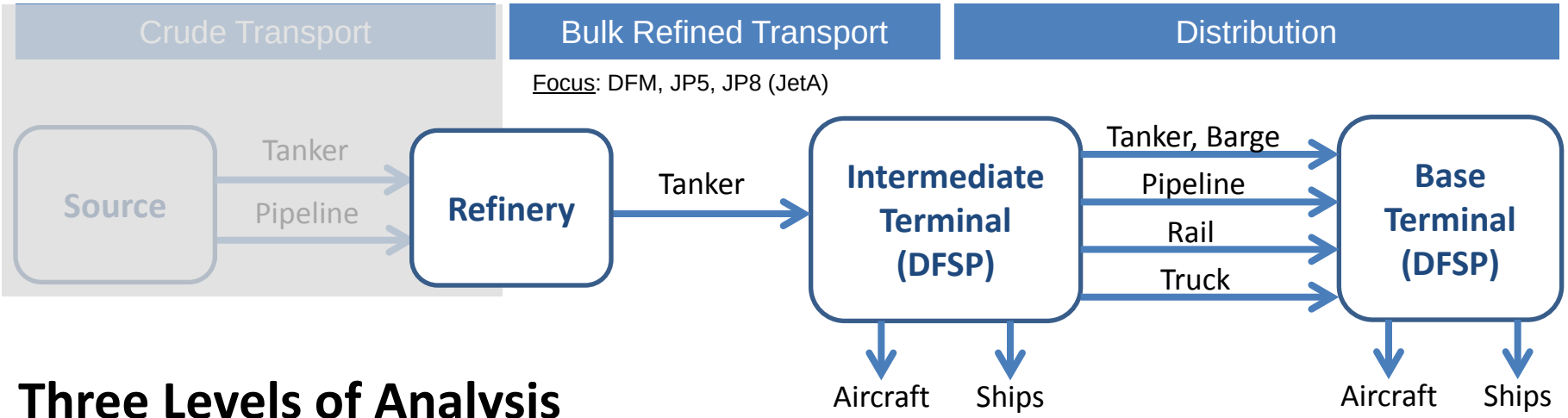
By conducting systematic "what-if" analysis on changes to the input data, we assess the operational consequence in terms of unmet fuel demands.

We focus primarily on the impact of refineries:

- individually and in combination
- by changing their availability for our use
- also: impact of initial fuel inventory and prepositioning

Which refineries "matter" the most?
Are there key vulnerabilities? How to mitigate them?

A Simplified View of Military Fuel Supply Chain



Three Levels of Analysis

- ***Operational***
  - For a given scenario, what does it take to get required fuel to where its demanded?
  - Importance of individual refineries?
- ***Strategic***
  - Will there be enough? Who has it?
  - Producers and consumers?
- ***Political***
  - Which countries will be on our side?
  - What can be done to shape this?

Thank You

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21 OCT 2015

MINI-GRIDS AND SMALL POWER PRODUCERS IN EMERGING MARKETS

IFC | International Finance Corporation
WORLD BANK GROUP

WORLD BANK GROUP

IFC: A MEMBER OF THE WORLD BANK GROUP*

IBRD	IDA	IFC	MIGA	ICSID
International Bank for Reconstruction and Development	International Development Association	**International Finance Corporation**	Multilateral Investment and Guarantee Agency	International Centre for Settlement of Investment Disputes
Loans to middle-income and credit-worthy low-income country governments	Interest-free loans and grants to governments of poorest countries	**Solutions in private sector development**	Guarantees of foreign direct investment's non-commercial risks	Conciliation and arbitration of investment disputes

***Owned by 184 governments.**

IFC International Finance Corporation WORLD BANK GROUP

The U.S. Government is IFC's

Biggest Shareholder

INVESTMENT TOOLS for EMERGING MARKETS

LOANS

- Project and corporate financing
- On-lending through intermediary institutions

EQUITY

- Direct equity investments (up to 20% of company's equity)
- Private equity funds

TRADE FINANCE AND SUPPLY CHAIN

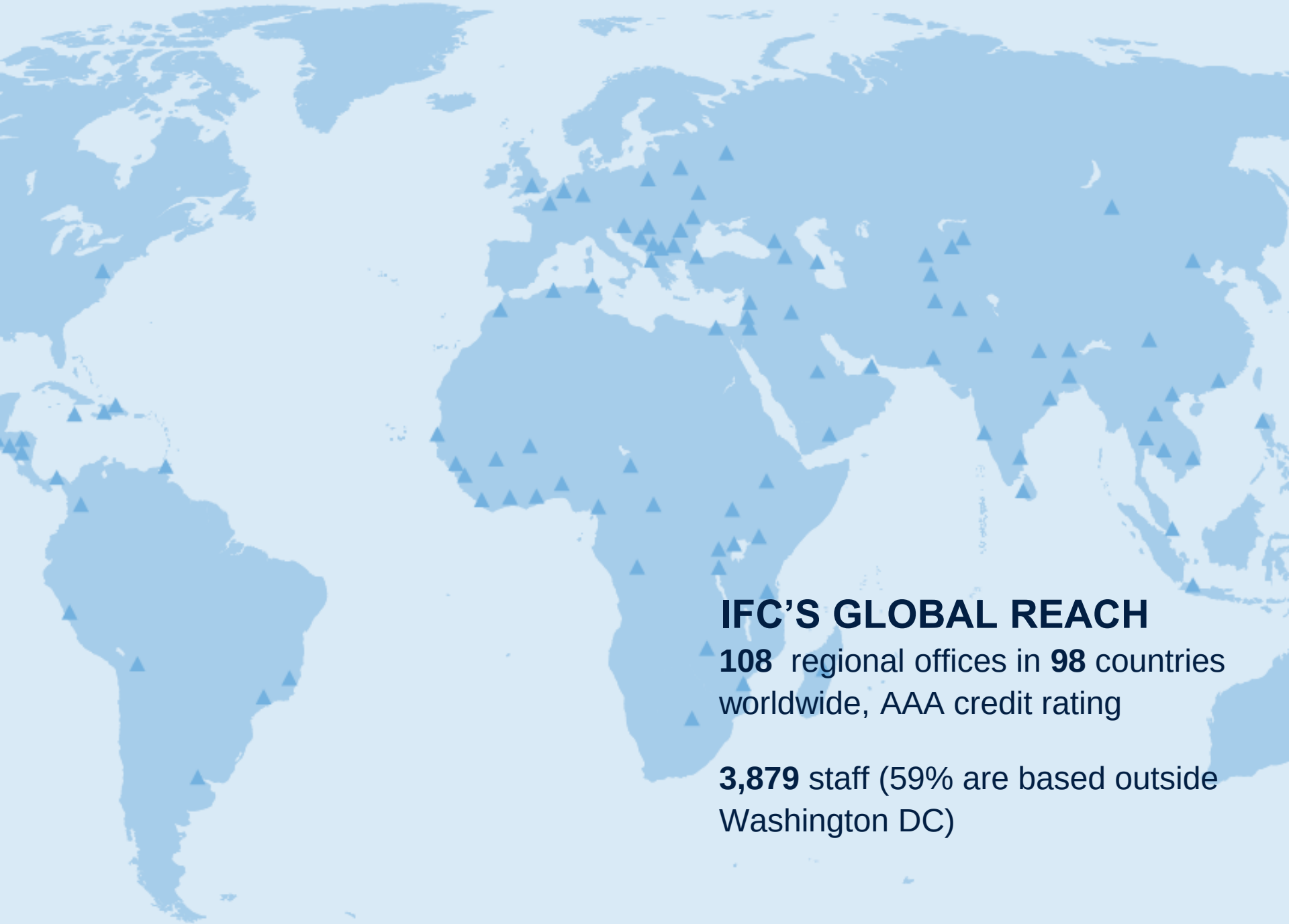
Guarantee of trade-related payment obligations of approved financial institutions

SYNDICATIONS

- Capital mobilization to serve developmental needs
- Over 60 co-financiers: commercial banks, fund, and DFIs

RISK MANAGEMENT SERVICES

Derivative products to hedge interest rate, currency, or commodity-price exposures of IFC clients



IFC'S GLOBAL REACH

108 regional offices in **98** countries worldwide, AAA credit rating

3,879 staff (59% are based outside Washington DC)

Renewable power: IFC has financed some 2,500 megawatts of wind power and 650 megawatts of solar power in emerging markets, often as first-movers helping develop viable new markets.

Costs have fallen dramatically for renewable energy

- Typical generation costs for wind projects = **6 to 12 cents/kWh**
- Typical generation costs for solar PV, grid tied = **9 to 20 cents/kWh**

Hybrid technology has evolved significantly:

- Wind-solar-diesel integrated systems can provide reliable power
  - Systems are well-understood and have a good track record
- Renewables can displace anywhere from 10% to 90% of fuel use

This is not a technical problem … it is a problem of financial structuring.

What is a mini-grid?

1. An isolated SPP* that sells at retail
2. An isolated SPP that sells at wholesale to a utility
3. Grid-connected SPP that sells at retail
4. Grid-connected SPP that sells wholesale to utility
5. Some combination of 1—4

*SPP = Small Power Producer, 1 – 50MW

Conditions for Success

1. Commercial viability is required – most mini-grids need an anchor customer to justify expense of local distribution system; householders not enough
2. Bilateral/Multilateral/Government-subsidized or donor financing is fickle – here today, gone tomorrow
3. Lenders/Investors must see a solid business case – interest rate and tenor are key
4. Regulatory environment must be sound

IFC Mini-Grid Program in Tanzania

IFC launched a $5 million program to increase access to energy in Tanzania by developing a market for mini-grids. The initiative aims to bring affordable, off-grid renewable energy to households and businesses in rural Tanzania.

IFC will work with project developers in Tanzania to promote commercially viable mini-grid business models, and will advise banks and financial institutions on how to extend long term finance to mini-grid developers.

Mali Scatec Segou Solar

IFC and Scatec Solar will develop a $55 million solar power project in Mali with local developer Africa Power 1.

- 33MW greenfield solar photovoltaic plant in Segou, 240 km from Bamako
- IFC takes a 20 percent equity stake in the project company for $2.5 million, provides additional $12.5 in loans for own account, and will mobilize additional parallel loans of up to $15.2 million Euros
- Scatec Solar is a Norwegian independent power producer. Signed MOU with IFC in 2012 to develop, design, finance, construct and operate solar plants in Africa.

Jordan One Solar

Jordan One Solar is a 20 MW solar PV power plant located in Al Mafraq, north of the Jordanian capital, Amman, with an estimated project cost of US$70 million.

- 20 year PPA with NEPCO
- Total Project cost $70 million
- AMP Solar Group of Ontario is 67% shareholder, BOO of utility scale plants for on-grid and off-grid use
- Evolution Solar of Santa Clara is 17% shareholder and is a market leader in thin film PV manufacturing
- RAI Energy Int'l of California is 13% shareholder

David Fulton

Head

USA & Canada Relationship Management

International Finance Corporation

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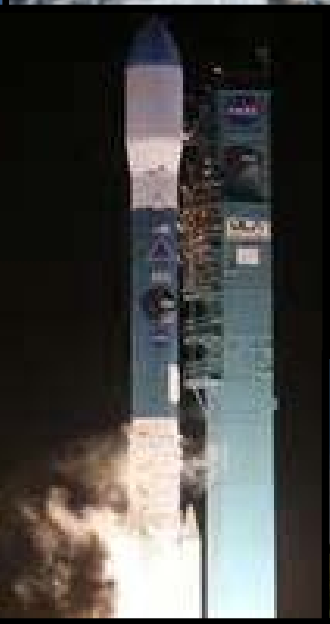
DEFENSE LOGISTICS AGENCY ENERGY

AMERICA'S COMBAT FUEL SUPPORT LOGISTICS AGENCY



Resilience in the USPACOM AOR

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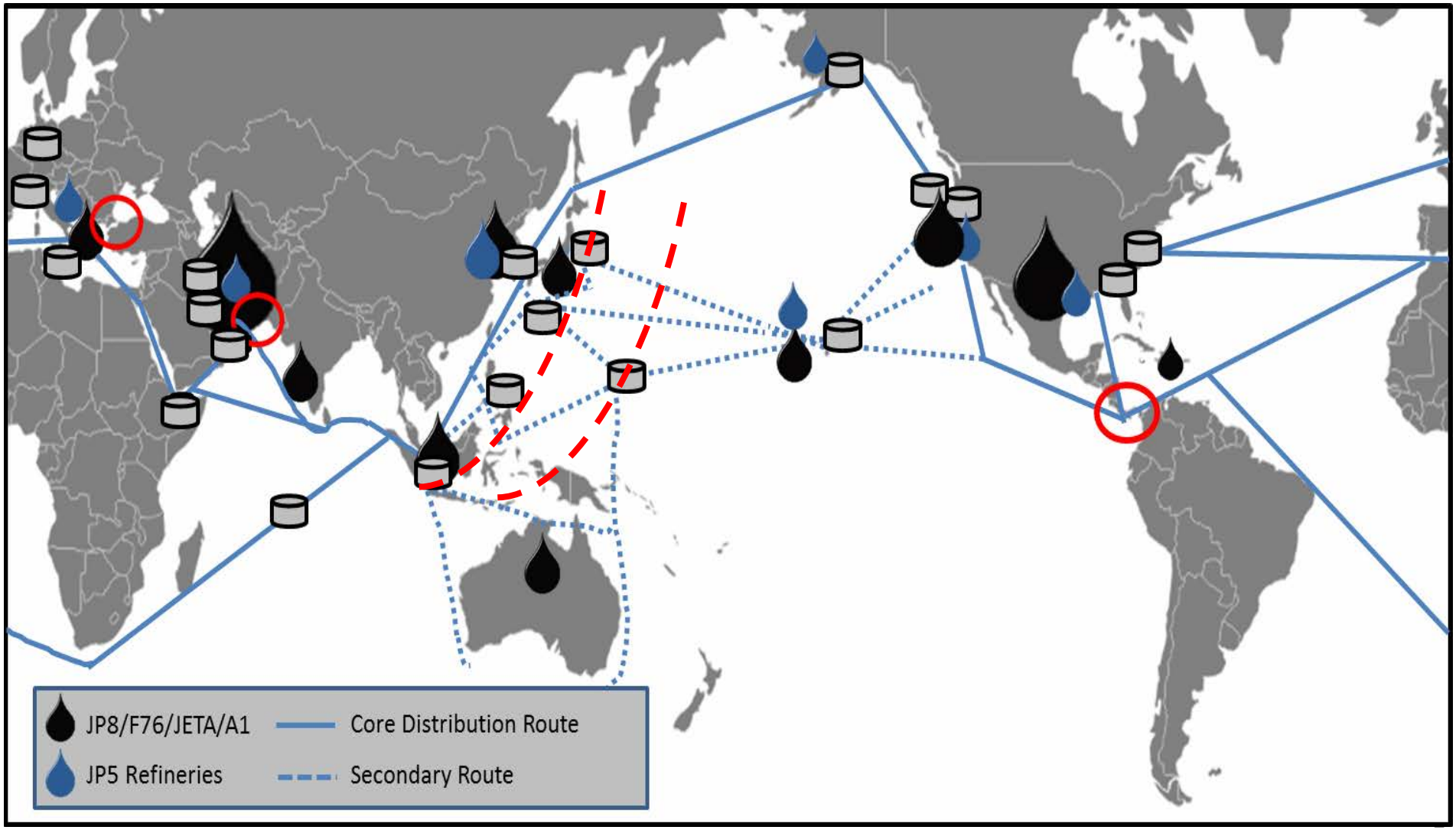
WARFIGHTER FIRST - PEOPLE & CULTURE - STRATEGIC ENGAGEMENT - FINANCIAL STEWARDSHIP - PROCESS EXCELLENCE

Global Energy Supply Chain

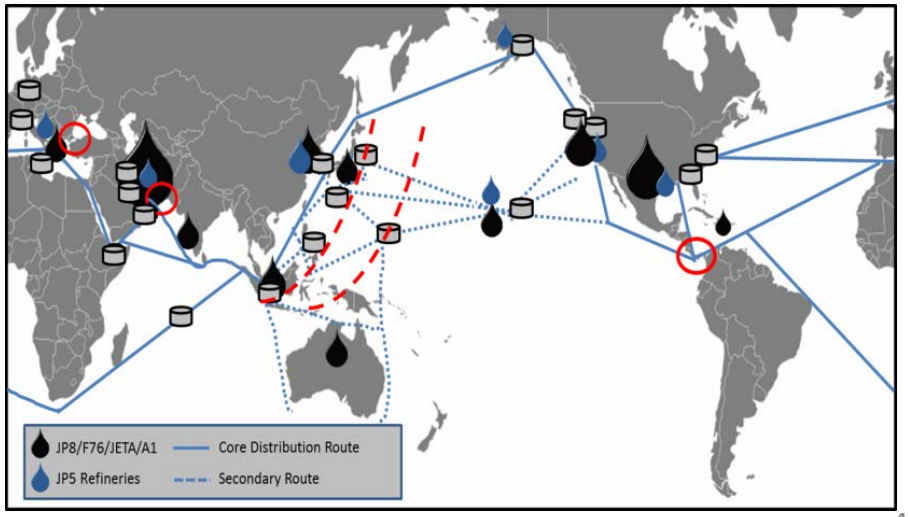


What is the Paradigm?

- Doctrine: War Reserve Stocks to commercial
- Must own it to control it
- MILSPEC fuels
- Fight from fixed infrastructure
- Unfettered access (ports, suppliers, supplies)
- Long but reliable LOC's

Vulnerabilities of the Paradigm

- Mal-positioned products
- Infrastructure interdiction and distribution disruption (direct attack/cyber)
- Aging infrastructure / Environmental risk
- Shrinking MILSPEC supplier base
- Political/commercial influence
- Limited US-flagged carriers
- Access and agreements
- Lack of Critical enablers
- Fuel additives supply chain
- Fuel quality
- Downward fiscal pressure



Enhancing Resilience

- **Lower Warfighter Risk -- build a better mousetrap**
  - **Diversify locations/sourcing**
  - **Leverage of commercial infrastructure**
  - **Transition to commercial-spec fuels (test/certify)**
  - **Supply Chain velocity**
  - **Critical enablers (strategic to tactical employment)**
  - **Expanding cooperation with Partners**
- **Change the doctrine (pivot point?)**
- **Velocity and $: selectively decommission infrastructure**
- **Velocity of Repair: Commercial best practices**
- **Reduce Supply Class XI!**
- **OE 'supply chain' strategy: more capability / less cost**

DEFENSE LOGISTICS AGENCY

AMERICA' S COMBAT LOGISTICS SUPPORT AGENCY

WARFIGHTER FIRST - PEOPLE & CULTURE - STRATEGIC ENGAGEMENT - FINANCIAL STEWARDSHIP - PROCESS EXCELLENCE

THIS CONCLUDES OUR PRESENTATION FOR TODAY.

Please join us tomorrow from <u>1100-1230</u> as we talk about Alternative Resourcing of Energy Capabilities.

Joining us will be Chris O'Donnell from the Joint Rapid Acquisition Cell and Sophia Kim from the National Security Technology Accelerator.