Readiness Versus Cost Tradeoffs for Additive Manufacturing in a Spare Parts Supply Chain

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Background

- Demand for spare parts is often intermittent, making it difficult for the supply chain to adequately support maintenance operations to remedy equipment failures
- Current spare parts supply chains carry large inventories to combat difficulties in forecasting demand
- Additive Manufacturing (AM) allows locating production downstream in a supply chain to rapidly produce parts with low lead times and higher efficiency, effectively reducing the need for large inventories
- Cost and readiness are two broad metrics of supply chain performance that allow analysts to gauge whether a network is efficient and robust

Objective

- Compare various AM employment strategies in a spare parts supply chain
- Identify a metric for quantifying readiness in a supply chain with uncertain conditions
- Classify spare part demand and assess the effect various demand structures impose on cost and readiness of systems with varying AM capability
- Provide decision makers with options and tradeoffs of AM employment in a supply chain

Demand Classification

- Demand is classified through two parameters:
  - Average Demand Interval (ADI) or average time between nonzero demand periods
  - Squared Coefficient of Variation (CV^2) or variance divided by the squared mean of nonzero demand periods
- Modifying these parameters allows insight into how variance in demand levels and different order intermittency affects network performance

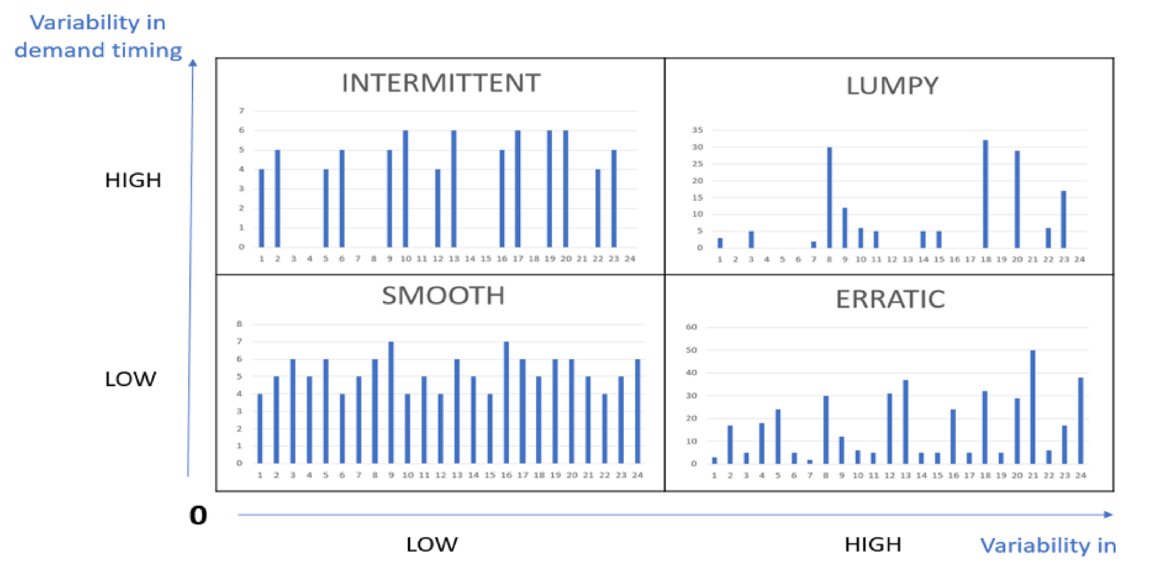

Figure 1: Four different bar graphs depicting what an example demand steam over time would look like given different values for CV² (x-axis) and ADI (y-axis) [1]

Modeling Strategy

- A pilot study assesses the impact of AM by examining three different products flowing through a supply chain with a single manufacturer, three distribution centers (DC), and two service locations (SL) over a 90 day period
- Demand streams are independently generated for each product at each SL
- 32 'Network Designs' of AM Location combinations are ran through a time-staged optimization model to provide insight on how the addition and location of AM affect key performance indicators

Traditional Manufacturer

- Origin of all non-AM parts
- Incurs a production cost

Distribution Center

- Supplies all products to the service locations
- Incurs an inventory carrying cost for all products remaining after a time period
- Inventory reorder policy follows a (s,S) policy
- AM-capable location

Service Location

- Location of demand for each product
- Incurs a backorder penalty cost
- AM-capable location

Transport Arc

- Incurs a transportation cost and time (lag)

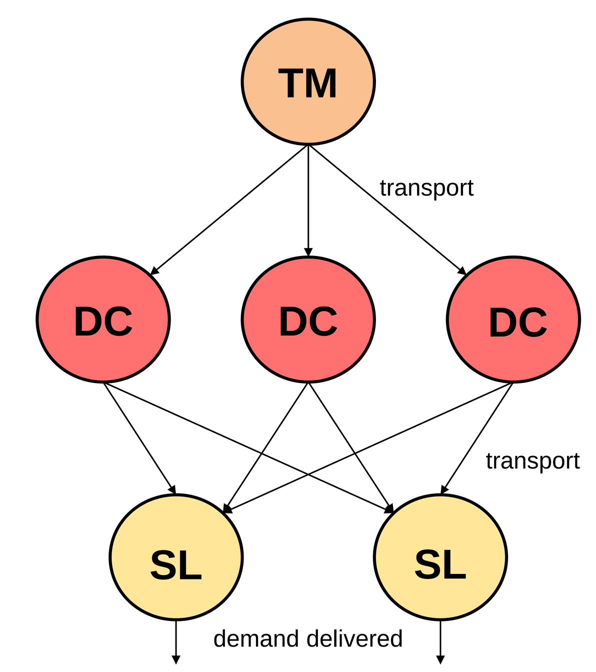

Figure 2: A visual representation of the network with flow of products moving from TM to DCs and exiting the system through the SLs

- Each Network Design is evaluated for performance through an initial min cost Mixed-Integer Linear Program (MILP) model that determines an optimal (s,S) inventory policy for each product at each DC

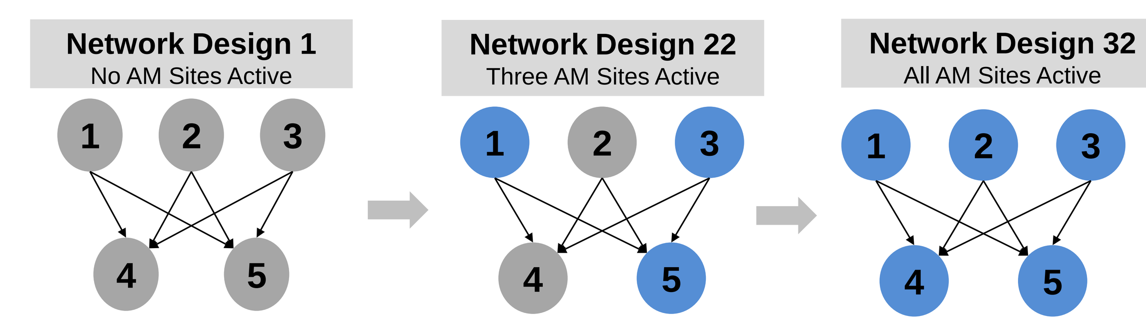

Figure 3: Example layout of 3 different NDs with different combinations of AM Locations at DCs and SLs (AM site indicated by a blue circle)

- The optimal policy for each Network Design is then fixed over a Monte Carlo simulation where multiple demand realizations process through an evaluation model with the same network structure
- Model outputs measure performance of each Network Design for each demand scenario

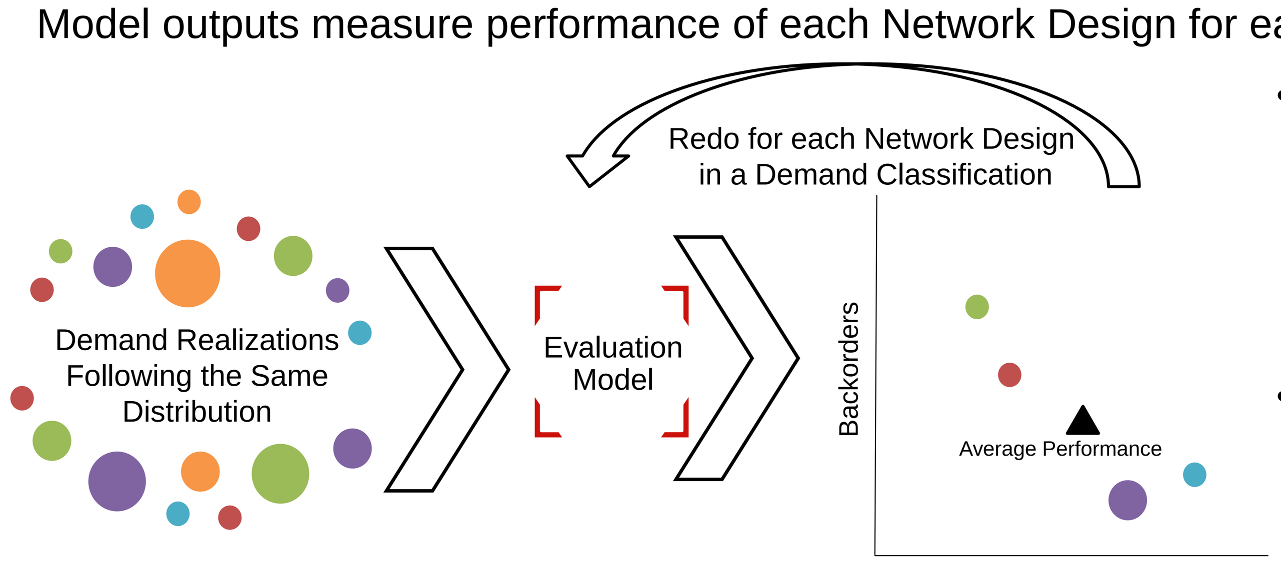

Figure 4: A depiction of the Monte Carlo evaluation process, where a series of different demands streams are sampled from the appropriate demand classification and are used to evaluate network performance over each Network Design

- Backorders are the amount of items not readily available when demand is placed during a time period
- Cost consists of AM fixed cost, production costs, and transportation costs

Results

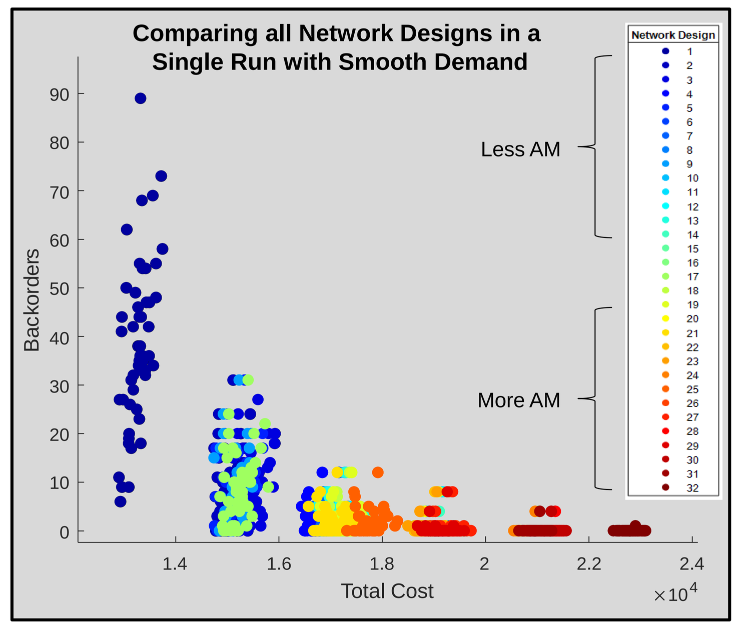

Figure 5: Backorders vs Total Cost for every single evaluation model run using a Smooth Demand Classification

- The addition of AM sites in the system **decreases the amount of backorders** required (increases readiness)
- More AM locations result in **higher total costs**, due to the high fixed cost of setup
- The return for AM decreases as more AM locations are added to the system
- Adding AM capability decreases backorder variability

- The characteristics of the demand distribution greatly affect network performance
- **CV^2 is the greatest indicator of backorder quantity** with the greater the value, the more backorders required
- A larger ADI results in more costly solutions, but negligible differences in backorders and readiness
- **AM adds the most value when** the level of demand varies greatly from one period to the next

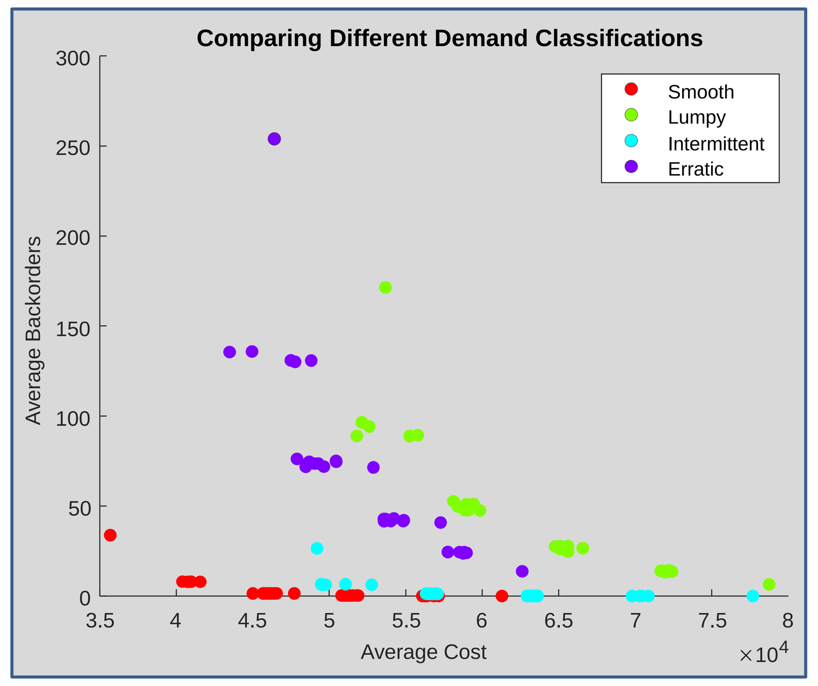

Figure 6: Average Backorders vs Average Cost (normalized for demand volume) for different Demand Classifications

Future Work

- Design of a network that models a deployed environment with significant lead times and multiple intermediate distributors
- Scale model to include a larger variety of actual military spare parts
- Factor in an increased risk of military readiness
- Assess best value-added options for integration of Additive Manufacturing into military supply chains

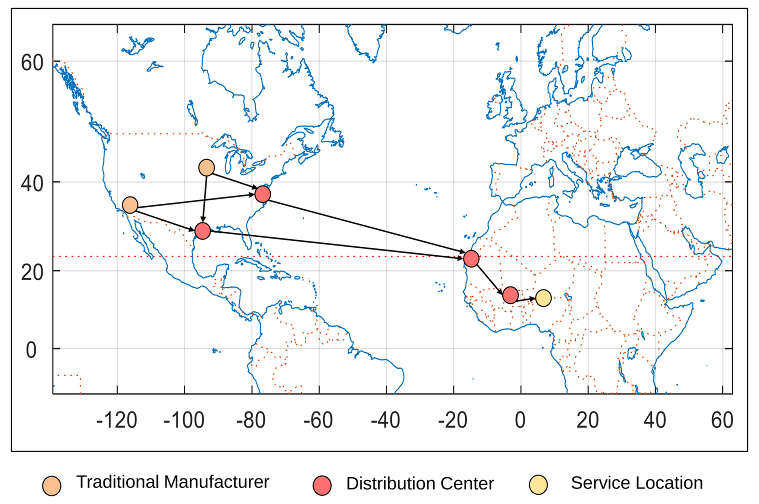

Figure 7: Notional example of a supply chain to a deployed environment in Africa, with manufacturers in the US and both domestic and overseas Distribution Centers supplying an overseas Service Location

[1]: Used with permission, FrePPLe, https://frepple.com/blog/demand-classification/