Designing a Multi-Echelon Inventory Distribution System

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Summary: This thesis examines the flow of raw materials and finished goods through the supply chain of a multinational oilfield services company. Many businesses struggle to optimize the flow of inventory and finished goods through existing plants and facilities. The integration of inventory costs, organizational processes, and changing business dynamics make it difficult to determine the optimal flow. We study a centralized inventory approach, assessed through heuristics, against the existing decentralized approach. We show that demand aggregation and lead time are important factors in determining the upper echelon for a company's internal distribution model.

Before coming to MIT, Patrick Scott worked as a logistics officer in the United States Army for five years. Prior to that, he graduated with a Bachelor's degree from Georgetown University. Upon graduation, Patrick will join General Motors' Global Purchasing and Supply Chain MBA TRACK Program in Warren, MI.

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KEY INSIGHTS

1) **Demand aggregation and lead time are important factors in determining the best upper echelon for a company's internal distribution model.**

2) **Companies often default to normal distributions to describe demand patterns, but occasionally alternative probability distributions yield better results.**

3) **A reduction in safety stock that increase pipeline inventory can actually lead to greater inefficiency.**

Introduction

This thesis examines the performance of multi-echelon inventory systems for an oilfield services company, but the results of the thesis are relevant for any firm that operates globally and has different points of consumption. The sponsor company has facilities, some built organically and others acquired during decades of operations, across the globe. These facilities either hold or consume parts. The best flow of materials through these locations is not clear because the sponsor company is in a period of strategic business adjustment. The company is evaluating its manufacturing footprint and logistic activities. The sponsor company seeks to understand if a consolidation of the logistics activities under the distribution organization would result in improved coordination and financial synergies. In order to determine if the current flow of materials is reasonable and cost effective, we analyzed a proposed alternative. Companies in a variety of industries can use the results of the thesis to reduce inventory holding costs and free working capital through reduction in inventory. Potential safety stock reduction is 2%, which is mainly due to the improved coordination for materials flowing to the final echelon in the supply chain. However, pipeline inventory increases by 12% as a result of longer lead times.

Supply Chain Design

The sponsor company currently has decentralized supply chain flow. Raw materials, components, and parts are sourced and procured by engineering and manufacturing sites (EMS). These locations consolidate inventory. Inventory exists in two buckets: dependent and independent demand. Dependent demand refers to materials used in an assembly or manufacturing process at an EMS location. Independent demand reflects downstream demand from a field location or distribution center (DSC) that is filtered through EMS. Figure 1 depicts the flow for an independent demand part. More than one EMS location could stock the given part just as more than one DSC could stock the given part.

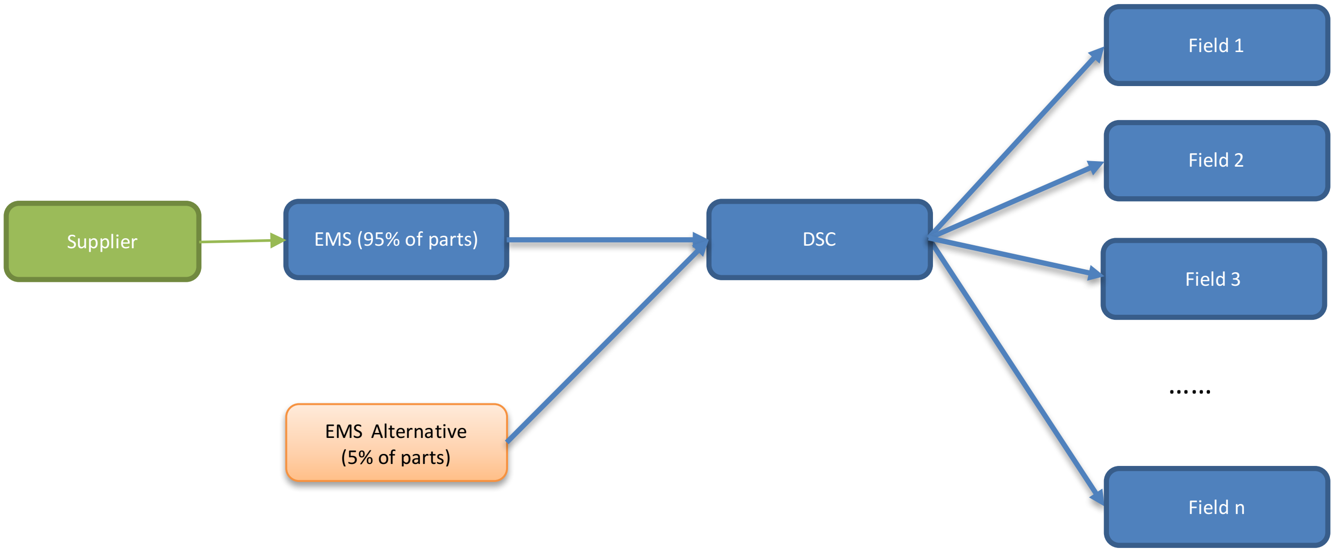


Figure 1 - Current Supply Chain

Our hypothesis was that a centralized inventory model can pool uncertainty and enable a reduction in inventory without impeding service levels. Figure 2 depicts the proposed supply chain.

In the proposed distribution model, inventory flows through a multi-echelon supply chain. The supplier ships the majority of items directly to three global distribution centers. Each of these distribution centers would then provide resupply to field and EMS locations worldwide. Parts that require inspection at an EMS location would be considered out of scope.

The centralized inventory management approach contrasts with the current system's more decentralized organization. Currently, inventory enters the supply chain through more than twenty EMS locations. Demand patterns at the various EMS centers do lead to some natural consolidation. In other words, certain parts tend to concentrate in certain facilities. However, the number of points to the supply chain lead to inventory being spread out over those locations. The future state, however, would concentrate inventory in three global distribution centers.

Data Model

The proposed model uses a base stock policy with an order up-to model. The order up to level is the maximum amount of product the company wants to have in the pipeline. The order up to level for a part is the demand during lead time and review time plus the product of the service level and standard deviation of demand during lead time and review time. The order amount for a given period is the difference between the maximum quantity and the inventory position. The period refers to the review period, which is the fixed interval between orders when managers approve and place replenishment orders.

The maximum quantity, discussed as the order up-to quantity, is defined by service level. Service level refers to the in-stock probability of a given item. If the target service level is 90%, that would indicate an out of stock probability of 10%.

Independent of the demand distribution, the key

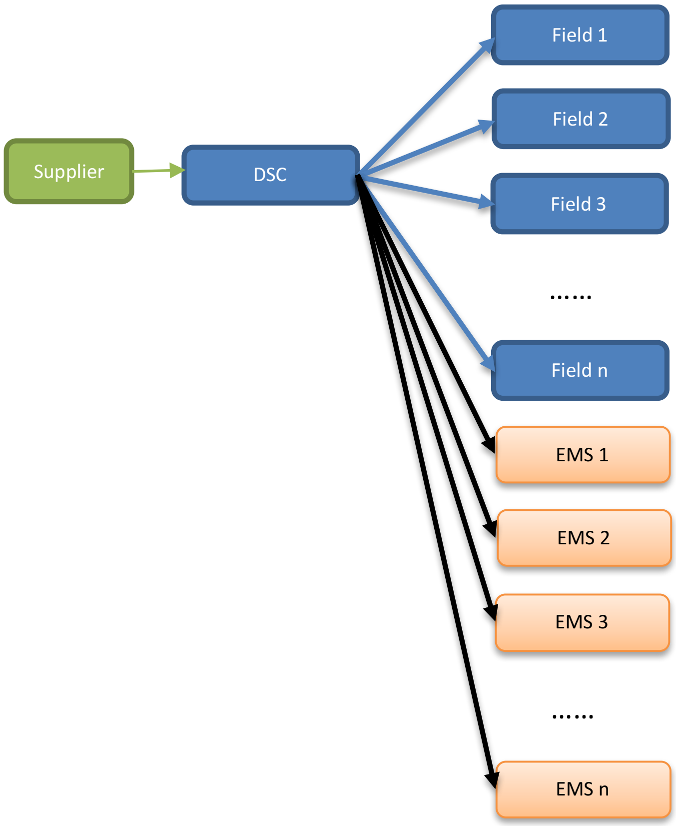


Figure 2 - Proposed Supply Chain

metric for establishing inventory levels in the model is the service level. In practice, the sponsor firm segments SKUs into three categories that carry a unique service level. Managing thousands of SKUs that each have a distinct service level would be impractical to implement using the firms current structure and information technology systems.

The three categories for service levels are high runners, runners, and strangers. High runners use an 85% service level, runners use a 70% service level, and strangers do not hold safety stock. Poisson distribution applies for parts with a demand frequency of less than 10 months per year. High runner candidates comprise only five percent of the overall quantity of parts demanded. Runner candidates consist of nineteen percent of part demand at EMS locations.

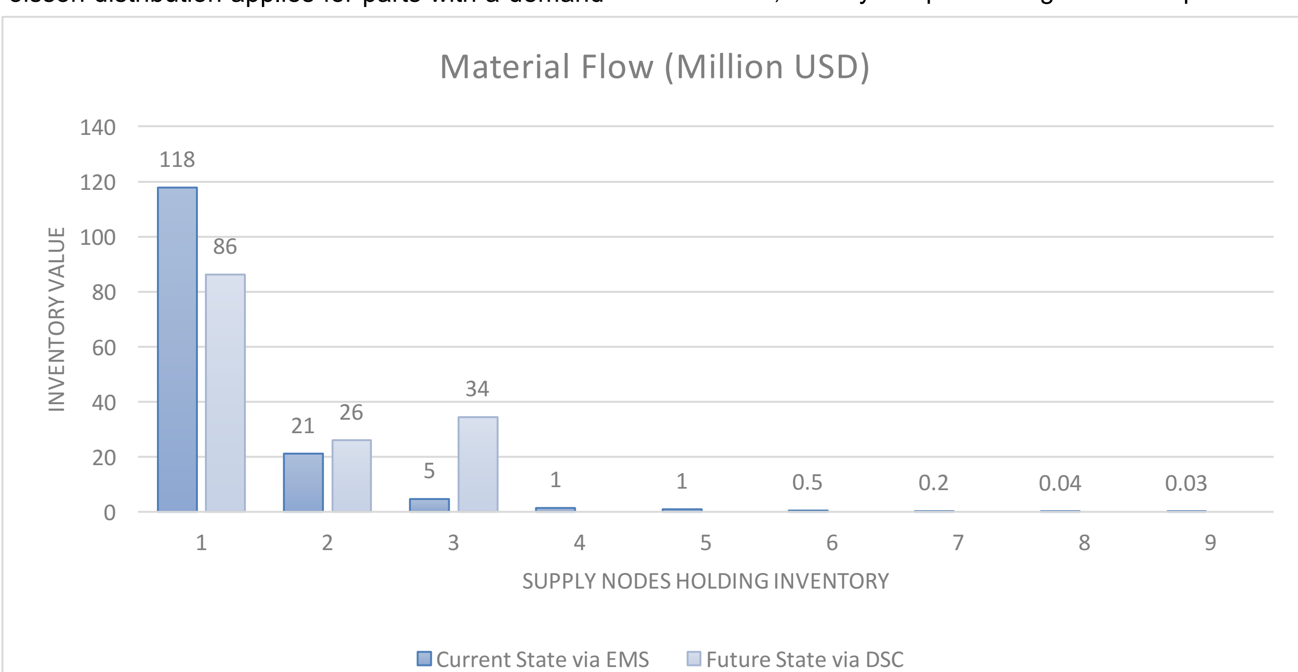
Results

Figure 3 demonstrates a key reason why the proposed model does not actually lead to a significant inventory reduction. The chart depicts the level of aggregation at the first echelon (upper echelon). Figure 3 shows the number of locations, for the upper echelon, at which an item is stocked during twelve months of demand. The current state actually has a greater level of aggregation than does the proposed model. These results suggest that there is no substantial risk pooling effect in the proposed model.

While risk pooling effect is limited, the proposed model does improve inventory levels at EMS facilities and distribution center locations when compared to the actual current state data. Field sites are unaffected in terms of safety stock required. The proposed model not only reduces inventory at EMS locations, but also reduces the required safety stock at DSC locations.

The model of the current system assumes that all materials are supplied through EMS facilities. The model assumes that only materials demanded by field locations will go through DSC locations. This analysis shows an safety stock reduction of only 2%, valued at approximately $200 thousand.

Sensitivity analysis revealed that the proposed supply chain increased pipeline inventory by 12%. The increase in pipeline inventory is due to the material processing time at the upper echelon. In the current mode, 7 days of processing time take place at the upper stream echelon (EMS). In the proposed model, 15 days of processing time take place at the



upper stream echelon (DSC). However, even if the DSC maintains the 7-day processing time of the current state, the pipeline inventory still increases. In this case, the current model has pipeline inventory of $6.5 million and the proposed model has pipeline inventory of $7.3 million. The increase is due to the fact that the majority of demand by value belongs to EMS locations. 63% of demand by value belongs to EMS locations. The proposed mode increases the transit time to satisfy demanded value when EMS facilities are no longer the upper echelon.

In order to demonstrate the impact of the Poisson distribution in the proposed model, we conduct a second scenario analysis using normal distribution. This sensitivity analysis uses normal distribution for all types of demand, regardless of frequency. In the proposed model, Poisson distribution was used when the average demand over lead time was less than 10. Safety stock increases 34% from $8.7 million to $11.7 million in the proposed model with a normal distribution. These findings reveal that the use of a Poisson distribution provides a better fit for the demand pattern and reduces inventory. The company currently does not use a Poisson distribution, so the use of the Poisson distribution skews the analysis. On the other hand, these findings reveal that a Poisson distribution can improve the current system.

Further Insights

Potential safety stock reduction is 2%, which is mainly due to the improved coordination for materials flowing to the final echelon in the supply chain. However, pipeline inventory increases by 12% as a result of longer lead times.

The findings do not support a change to the proposed model because the proposed model does not aggregate demand enough to offset increases in pipeline inventory. The models suggest reductions in inventory levels and cost are due to the use of a model against actual data and the use of a Poisson distribution instead in exclusive use of a normal distribution. The thesis reveals that lead time reduction is critical. Pipeline inventory can be larger than safety stock. A reduction in safety stock with an increase in pipeline inventory can lead to a more inefficient supply chain. A company can determine if this is the case by examining where the majority of value is consumed. For the oilfield services company, the EMS facilities consume the majority of value even though those parts are slow moving. As a result, the EMS facilities are strong candidate as the upper echelon in the company's supply chain. We recommend the company use a Poisson distribution to more accurately match demand patterns. The Poisson distribution would enable a better inventory policy for slow and infrequent demand.

The thesis demonstrates importance of aggregation in order to support reductions in inventory across a supply chain. However, reductions in lead-time could also serve to reduce pipeline inventory. The cost impact of using increased airfreight could serve as a next step in the analysis for the company. Additionally, increased forecast accuracy could also enable inventory reductions. If the oilfield services company were to improve forecast accuracy, they could dynamically adjust service levels by part as opposed to segment. This could enable a more robust inventory management plan. However, this approach could increase management and information technology costs. Further analysis could help the company assess the inventory impact of these approaches.