Optimal Location of Aerial Ports within a Supply Chain: A Case Study

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Abstract

Recent trends in the US Air Force (USAF) including reduction in size of force, closure/consolidation of bases and depots have necessitated a fresh evaluation of the existing transportation structure and the supply chain. Further, the changing nature of redeployment, including an increased role in non-military cargo movement such as that found in disaster relief operations have necessitated a need to readdress the structure of the worldwide cargo supply chain. In this study, a mixed integer program transshipment model is developed to optimally locate the transshipment points (aerial ports) within the supply chain for the USAF. Usually, goods are consolidated at a single point from several supply points (depots and bases) that specialize in the holding of various types of supplies. It is then shipped to the various destination points from the consolidation point, making the transshipment model appropriate. It is shown that the model provides for improvement over the existing structure.

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1. Introduction

This study examines the location of aerial ports as transshipment points within the supply chain needed to effectively manage the worldwide cargo distribution system for the US Air Force. The past trend has been to reduce the size of the force in response to a changing global environment and decreasing budgets. This reduction in both size and number has again been proposed for the near future. Another factor has been the changing role of the USAF, including a greater role in deployments for crisis management in the civilian arena, such as moving humanitarian aid supplies in crises like the recent one in Asia. Redeployment of personnel as well as cargo movement on short notice becomes increasingly important. This will require changes in the supply chain to effectively support the new requirements.

The location of the aerial ports within the supply chain assumes importance in both minimizing costs of transshipment and in reducing the lead times in the supply chain. The original design of the distribution network was based on movement of goods for military deployment, and using aircraft of limited range and capability. Thus the aerial ports were necessarily located on the coasts. With the current long range capability of the aircraft, and the changing nature of many deployments, a new evaluation of the location of the aerial ports is needed to meet the objectives of today' supply chain.

An earlier study of this problem evaluated ten locations [4]. Based on the transshipment requirements at that time, the study concluded that five of those locations be kept open as aerial ports for transshipment of materials. Since that study was completed, there have been several rounds of restructuring in personnel and base infrastructure. This includes closing/realignment of bases and depots from which most of the cargo moved within the supply chain originates. Thus the number of cargo origination points has decreased. At the same time there have also been changes in the location of demand points and demand distribution due to the same reasons. This necessitates a fresh evaluation of the location of the transshipment points (the aerial ports).

Under the recent environment that the USAF operates in, the location of the transshipment points in the supply chain evaluated in this study includes six major ports in existence, as well as three possible locations in the interior, that would not have been considered in earlier designs of the system. Cargo data extracted from the database is used in this study to identify the points of origin (supply) of the cargo and also the points of demand. The data also identifies the total cargo loads moved from each of the origins, and the load delivered (demand met) at each of the destinations. This data is used to determine the optimal number and location of the aerial ports (transshipment points) so as to minimize the total operating costs. The solution is also compared with the costs obtained for the existing set of aerial ports to examine how much improvement the proposed solution could provide.

2. Background

The facility location problem has been extensively studied in the literature. Mirchandani and Francis [5] focus on discrete location decisions, arguing that decision-makers consider a discrete representation to be more realistic and accurate for the location decision.

Ghosh and Harche [3] examine location-allocation models, and cite the most important characteristic of these models as the ability to optimally locate several facilities in a simultaneous manner. In many supply chains, some of the located facilities are used as transshipment points. The multicommodity distribution system design has been studied previously in literature. Geoffrion and Graves [2] solved the problem for a large scale system using Bender's decomposition. The objective was to meet the given demands at minimum total distribution cost subject to the system constraints. A discrete set of possible distribution centers was used to obtain the optimal subset. A customer was assigned to only one distribution center. Bhaskaran [1] developed a transshipment model for an automobile manufacturer. However, this model used a continuous space approach for location, as opposed to a network model. A network model would have only a specified set of facilities to choose from. For the current problem researched here, the network approach is more appropriate, since the set of possible transshipment points is finite and known. The set would include only existing facilities along the coasts and other inland facilities that could be used for that purpose, since the cost of opening a new facility is prohibitive, and unlikely to occur in the current environment.

3. Model

The basic structure of the distribution system within this supply chain is closer to the network distribution system modeled by Geoffrion and Graves [2]. Assigning only one transshipment point to a customer allows for consolidation of the different material (cargo) and therefore favors economies of scale. It is assumed that transportation costs vary linearly with the distance shipped. Operating costs are known for each of the sites evaluated. To reduce the complexity of the study without loss of generality, only the more significant origination and destination points are included in the study. This allows for most of the cargo movement to be modeled in the analysis. A mixed integer programming representation of the aerial port distribution system is presented next. The problem can be stated as:

Minimize $\sum_{jk} (C_{jk}*D_{jk} + V_k)*X_{jk} + \sum_{kl} C_{kl}*D_{kl}*X_{kl} + \sum_k F_k Z_k$ (1)

Subject to:

$\sum_k X_{jk} \leq S_j$ for all j (2)

$\sum_j X_{jk} - \sum_l X_{kl} = 0$ for all k (3)

$\sum_k X_{kl} = D_l$ for all l (4)

$\sum_k Y_{kl} = 1$ for all l (5)

$\sum_j X_{jk} - Z_k*M_k \leq 0$ for all k (6)

$X_{jk} - Y_{jk}*M_k \leq 0$ for all j, k (7)

Where:

j is origin point

k is transshipment point

l is demand point

C_{jk} is weighted average shipping cost per ton-mile from any origin j to any transshipment point k

C_{kl} is weighted average shipping cost per ton-mile from any transshipment point k to any demand point l

D_{jk} is Euclidean distance from origin j to transshipment point k

D_{kl} is distance from transshipment point k to demand point l

V_k is transshipment point throughput cost per ton of cargo

X_{jk} is flow in tons per month of cargo shipped from origin j to transshipment point k

X_{kl} is flow in tons per month of cargo shipped from transshipment point k to demand point l

F_k is the monthly operating cost for transshipment point k

Z_k is a 0-1 variable; 1 if transshipment point is established at k, 0 otherwise

Y_{kl} is a 0-1 variable, 1 if transshipment point k serves demand point l, 0 otherwise

S_j is origin point cargo availability

D_l is the total demand at demand point l

M_k is the maximum throughput of transshipment point k in tons per month.

The cargo data has been extracted from the database. The shipments in the database are uniquely identified by a transportation control number. The database is extremely large with over two million entries. Data was extracted and refined to include only cargo data for a fiscal year, and that only transited through the current major transshipment points. Further refining of the data would provide for the largest origin points and also the largest demand points, these would account for more than 85 percent of all cargo shipped.

Similarly, cost data from the database on truckload and less-than-truckload categories was extracted, along

with air cargo transportation costs that are then converted to an average ton-mile basis. Operating costs for the transshipment facilities were also extracted from other sources.

The distance data is taken from the military transportation and travel official table of distances. They are also extracted from the database used at the air mobility command.

Following the data refinement, the model is applied to the data to determine the optimal locations of the transshipment points and to compare the solution against the existing structure. It is expected that the model will lead to improvement over the current system.

The data was extracted for the top points of origin for the cargo. Fifty-three locations accounted for more than 85 percent of all cargo shipped. These are considered in this analysis. Additionally, twenty-two destination points outside the continental United States were evaluated, they accounted for a similar volume of cargo received.

4. Analysis and Results

Since the cost of opening a transshipment facility in this case is prohibitive, indeed none are proposed to be opened we will consider only existing facilities as candidates for transshipment points. Historically because of the distances between overseas destination points and the transshipment points, the transshipment points were located on the coasts to accommodate the range of the transport aircraft. Currently, that issue in no longer of concern as the range of the aircraft has increased. Thus interior transshipment points can also be feasibly evaluated. The six established transshipment points that have been in use along with three interior points that are attractive as possible sites are considered in this study. The interior points either have existing distribution depots in them that are cargo origination points and/or have limited aerial port facilities. It was more difficult to extract the costs for the three interior points also selected as candidates for transshipment points, since they serve other purposes too. Estimates were obtained for these three points, based on the knowledge that their costs were between the highest and lowest operating costs of the existing transshipment points.

Additionally, the throughput capacities of the transshipment points were estimated, based on the current manpower authorized. Other factors such as material handling equipment, ramp space, and storage facilities were also included.

The mixed integer program was applied to the data collected. The results indicate the following. Only three of the six current aerial ports (transshipment points) should remain open. Two of the ports are on the east coast and one on the west coast. One of the ports on the east coast is utilized to its full capacity under this scenario. The other open port has a much larger capacity.

Sensitivity analysis was performed to examine the impact of closing the smaller port and absorbing its throughput into the larger open port. The assumption is that closing a port would provide significant savings and offset increased operating costs. However, under this scenario, total system costs actually increased slightly.

The existing six aerial ports structure was compared against the new three port structure solution provided by the model in this study. While the total freight costs did go up, by almost two percent, the savings in operating costs of maintaining only three aerial ports as opposed to the original six far exceeds the additional freight costs. Operating costs go down by over 45 percent. Overall annual cost saving are in the range of three percent, which is significant, since in real terms it is close to a million dollars. If there was no constraint in the use of existing facilities and new ones could be opened, the savings could be greater over a period of time. It was noticed that at this time, the interior ports did not figure in the final solution, however, as closings of demand points and origin points, as well as transshipment points occur, they could enter the solution.

5. Conclusion

The past and ongoing restructuring process along with declining budgets has forced a new evaluation of the supply chain used by the USAF to move cargo. Additionally, the changing nature of the cargo movement, along with the need for rapid response times requires that the transshipment points (aerial ports) locations be reevaluated. This study considers that issue and shows that the existing structure can be improved on. Only three ports can provide for a more efficient supply chain.

References

References should be listed at the end of the paper. List and number all bibliographical references in 9-point Times and single-spaced. Entries should appear in alphabetical order and should be numbered with the numbers placed in brackets (see example below).

[1] Bhaskaran, S. Identification of Transshipment Center Locations, *European Journal of Operational Research*, 1992, Vol. 63, pp 141-150.

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