CONFIGURATION OF A SERVICE AND DISTRIBUTION NETWORK IN THE AEROSPACE INDUSTRY

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ABSTRACT
The evaluated company develops, manufactures and supports aircraft for the commercial, executive and military markets, and is developing new products for the executive market. In order to support this fleet in the American market, a new spare parts distribution and maintenance services network is being developed. This work has the objective of defining the quantity and location of service centers and the corresponding distribution center. To do that the spare parts inventory levels in each location were taken in consideration in order to minimize transportation and inventory carrying costs and attend the established service levels in an alignment with the competitive and supply chain strategies. The methods employed were simulation, to evaluate each alternative, and meta-heuristics, to search for the best solutions. The results led to locating the distribution center in Menphis and to a quantity of 7 service centers, much less than the current solution.

Keywords: logistic strategy, distribution network, service network, spare parts in the aerospace industry

1. INTRODUCTION

The problem evaluated in this study is to define the best location for the distribution center and the quantity and best location for the service centers in the U.S. These centers will support the new aircraft fleet, which is currently being built by an executive aircraft industry. The distribution center and the service centers will contain stocks of spare parts and their levels will be taken under consideration for the location decisions. The stocks will be used as source of replacements components for defective ones removed from aircraft, when so is needed. All decisions should be taken so that transportation costs, stock carrying costs and fixed costs of the service centers are minimized, given a minimum level of service required.

The scenario for the problem is an industry characterized as highly cyclical. This led the company to seek in the executive aviation market, among others, a way to soften the impact of unexpected fluctuations in demand in their business. That market was chosen having in mind the predictions that foresee its steadily growth in the coming years, due to factors such as the airports increasingly security procedures for commercial flights, which is leading a number of executives to seek the flexibility, exclusivity and comfort provided by the executive aviation, and the economic globalization, which demands frequent business trips.

This new executive aircraft that are being developed will require a completely different support from the one the company usually provides for civil and military aviation. The aircraft future owners are mainly private executives with no available infrastructure for maintenance, spare parts logistics, pilots training, etc. Furthermore, the market has signaled that a decisive factor for the purchase decision is the perception on the company's ability to provide an adequate support for the fleet in action. To meet this demand it is necessary, among other things, to establish an appropriate network of logistics and services. This article studies the distribution and services network in the U.S., for the new executive aircraft. The network is showed in the following schedule:

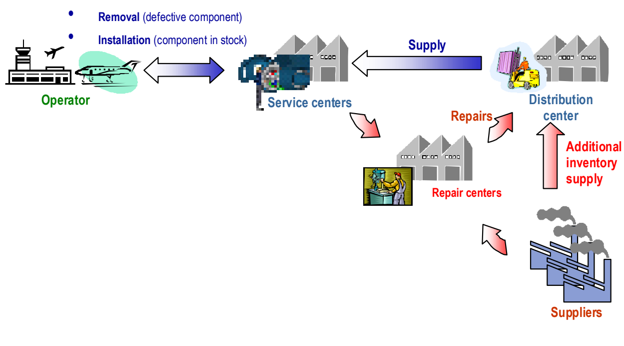


Figure 1: Flow of materials for the support to the aircraft fleet

The process begins when a failure is detected in the aircraft during its operation or during maintenance. When the failure happens during operation, a spare part is obtained from the DC (Distribution Center) or from the SC (Service Center) where maintenance is taking place, after the defective component has been identified and removed. This means that the SCs can also serve regional distribution centers, giving them a very quick response.

If the removed component is a consumable one, (i.e., cannot be repaired), the material sent by the SC is replaced by the DC which, in turn, is restocked by the supplier. If it is a repairable item then it is also replaced by the DC, but only in this case the component removed from the aircraft is sent to a repair center in order for them to be restored and then sent back to the distribution center. This happens when the repairable part cannot be repaired for technical or commercial reasons. It is then discarded and a new one is sent to the DC by the supplier.

2. PROBLEM DEFINITION

The issue covers the following decisions on the distribution network and services:

- The spare parts distribution center location;
- The amount and location of the service centers, which besides providing maintenance services, will also serve as advanced inventories of spare parts;
- The amount of the spare parts stocks (it will be considered a sample of items, to make it possible to take into account the different levels of inventory for each alternative configuration of the DC and the SCs).

This is a strategic-level issue, and therefore has long-term impacts on the results of the company's operation. The question is how to minimize the cost of supporting the fleet which is ready to fly in the United States, sustaining a given level of service. The cost is composed of three values:

1. The cost of the spare parts stock for defective components of the aircraft.
2. The cost of the spare parts transport.
3. The fixed cost of the service centers.

The restrictions of the problem are:

1. The fleet availability should be equal to or greater than the target set by the company's competitive strategy. The fleet availability will be the indicator to measuring the level of customer service, in the cases of parts that could prevent the aircraft from flying. The fleet availability is measured by the percentage of time that the aircraft are available for flight. An airplane is considered unavailable when undergoing maintenance or being transported to a repair center. In the figure below, the slot of time for obtaining spare parts is represented by the fragment called "Logistic Process", which is part period of time necessary for maintenance. This part can be influenced by the design of the support network.

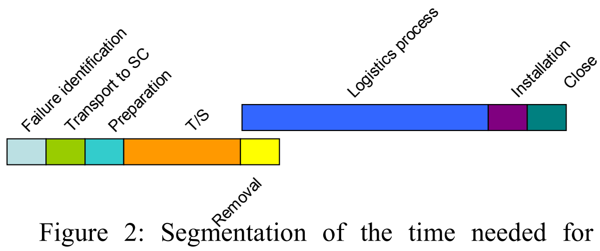


Figure 2: Segmentation of the time needed for aircraft maintenance.

Source: Evaluated company

2. For those parts which do not prevent the aircraft from flying, the fill rate will be used as a service level measure, i.e., the percentage of requests fulfilled within a set time. Despite the fact that those parts do not hinder the flight, the situation may have a strong impact on customer satisfaction. It can impact, for example, in the comforts inside the aircraft, and therefore this kind of maintenance will also be considered as a restriction.

3. Adherence to the standards of service provided to business clients over a maximum distance of a two-hour trip from the customer's base to the nearest service center. This additional restriction on the fleet availability is due to the fact that a medium level of service is taken under consideration when availability is concerned, while our objective here is to establish a maximum distance to prevent any customers from having an inadequate service.

4. The service centers shall contain at least one piece for items classified as "Aircraft On Ground" (AOG), according to what has been disclosed to the market by the company. These are parts that, if defective, can prevent the plane from flying.

5. The support network must contain at least one piece for those ones which are not classified as GBS. Here again, the concern is not the average level of service, but to avoid situations where the service time will be beyond a maximum acceptable level, even if in special situations.

Those are the possible locations that will be evaluated:

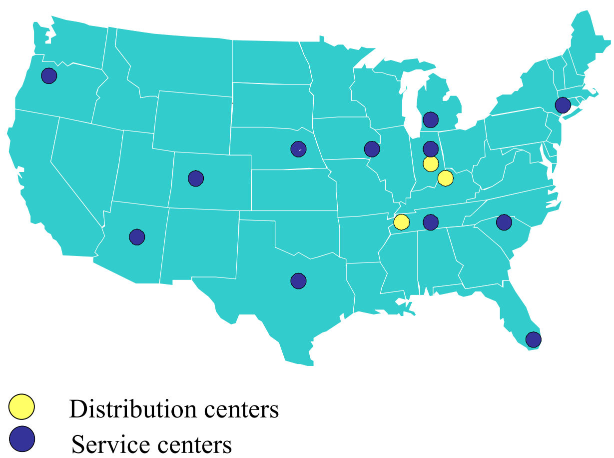


Figure 3: Possible locations for distribution center and service centers.

3. LITERATURE REVIEW

As the main restriction to the problem concerns the service level offered to customers, it is fundamental that the proposed solutions are strongly based on the competitive and functional strategy theories. This will make it possible for us, in an unfolding process, to define in a structured way which values should be a parameter restriction.

To meet the desired alignment between competitive strategy and supply chain strategy, it is necessary to understand the client needs in each one of the competitive strategy target segments, to fully understand the supply chain, and then achieve the alignment between the two. Therefore, we need first to define as attributes, the customers' needs which, in accordance to the competitive strategy, we need to attend. They can be classified by price or by differentiation attributes.

As a second step, in order to understand the supply chain, Chopra (2001) proposes a methodology similar to that used to understand the demand: to use a measure of how responsive the supply chain is, in order to provide a consolidated view of how the chain attributes are configured. The major point for attention here is that the more responsive a supply chain is, the less efficient it tends to be. And by efficiency he means the cost incurred to produce and deliver products. Finally, in order to achieve the desired alignment between competitive strategy and supply chain strategy, both of them should aim at the so-called company's zone of strategic alignment. In this zone, the supply chain's responsiveness increases according both to the level of the demand's uncertainty and to the product's life-cycle phase (initial stages require more responsive chains).

Ballou (1998) sustains the hierarchy of decisions concerning the supply chain taking the time frame which they are linked to, as a reference. Decisions at strategic level involve long horizons of time, usually greater than one year, and are based upon aggregate data. Another important point mentioned by Ballou is the trade-offs within the supply chain decisions, both at the same and among different levels of hierarchy such as: the location of deposits, the levels of stock and the size of lots to be used to resupply.

The heuristic and optimization methods are the most commonly used in location and configuration of logistics networks surveys.

Hale et al. (2003) offers a historical perspective on the development of research related to location of facilities. He makes a selection of articles that undoubtedly contributed to its development: Weiszfeld (1937); Weber (1909); Chrystal (1885); Hotelling (1929); Hakimi (1964); Cooper (1963).

Powell (2005) points out advantages and disadvantages in the use of the methods of simulation and optimization via linear programming. On one hand, optimization methods tend to be preferred by scholars due to the intelligence involved in solving problems and the guarantee to find the best solution. Turns out this best solution assumes various factors as previously defined, but they are not always fully known in real world. On the other hand, the simulation methods can represent, with a quite great adhesion, and with the use of rules, the high complexity and the various uncertainties involved in an operation. Since the rules can be adjusted and tested with relative easiness, people directly involved in evaluating operations, tend to prefer the simulation due to this flexibility. The article suggests that both types of methods can be used jointly, in the case of problems involving resources allocation. One should, thus, try to take advantages from both methods.

Several authors, such as Ballou (1984), Goetschalckx et al. (2002), Nozick et al. (2001), Shen et al. (2005), Daskin (2002), Shen et al. (2007), Hinojosa et al. (2008) and Syam (2002) suggest that it is important to consider the inventory levels and its cost, in the location model so that the models in fact consider all the costs involved in the problem. In order to achieve this, the heuristic and simulation models are often pointed out as good alternatives. Keskin et al. (2007) use a heuristic algorithm based on scatter search, including local search and path-relinking routines to solve the problem of finding two stages, with capacity restriction. In comparison to the exact method, there is gap lower than 1%, in relation to the optimal solution, and significant gains in computational performance were obtained. According to the literature search that the author has made, the heuristic methods used in problems of locating the p-median are: heuristics interchange, genetic algorithms, tabu search, simulated annealing, scatter search, greedy randomized adaptive search and a heuristic based on dynamic programming.

According to Glover (2003), the meta-heuristics methods are the ones that organize an interaction between local improvement procedures and high-level strategies in order to create a process which is able to escape from local optimum and to perform a deep search in the solutions area. Lately, these methods have been widely used, in solving various types of complex problems, in particular those of combinatorial nature, for it has proven to be extremely effective in providing near optimal solutions, in a reasonable processing time. Although they do not guarantee as good solutions as in exact models, these last ones often result in processing times which prevent their use. Moreover, some successful applications of exact models have incorporated meta-heuristics strategies.

Muckstadt (2004) puts a great focus onto a type of stock policy called the base stock (s-1, s), in which every time there is any consumption of material, the same amount is resupplied. As the author shows in his book, this is the most suitable model for items of rarefied demand and of high aggregated value, where the order cost is irrelevant when compared to the value of the parts that are being considered.

According to Muckstadt (2004), a safety stock in a stock policy, should be determined both according to the demand's variation and to the resupply time's variation as it has the function of absorbing both of them. As shown by Muckstadt, the definition of the optimum levels of stock in a two-link network with rarefied demand, which behaves as sparse distribution of Poisson probabilities, using exact models is not feasible from a computer. Alternatively, the author suggests using the classic METRIC (Multi-Echelon Technique for Recoverable Item Control) model. The author demonstrates mathematically that the optimal stock of the central deposit is almost always in the interval $[(\lambda iDi, 2 * (\lambda iDi)\ 1\ /\ 2 + \lambda iDi]$, where λi is the rate of demand for item i at the central depot and Di is the time to resupply the central deposit. This is, therefore, the range in which the search method will look for the best solution.

Lee et al. (2005) propose the use of dynamic simulation to evaluate the inventory policies for repairable spare parts. An optimization model is used to determine the policies to be tested. Zanoni et al. (2005) use the dynamic simulation software ARENA in conjunction with the OptQuest resource within the same tool, in order to find optimal decision variables. According to Kelton et al (2002), besides using whole programming, this resource uses various types of heuristics such as tabu search, scatter search and neural networks, in order to define the values of variables. Dias et al. (1998) proposed the use of dynamic simulation coupled with a search method for determining stock policies for spare parts.

4. LITERATURE DISCUSSION

To start the discussion about the evaluated literature, we can notice it provides the basis for carrying out the work, but in a fragmented way. This means that all the conceptual and methodological elements are present in the literature, but in an ungrouped way, in relation to the set of issues addressed in this article.

The competitive strategy and its deployments to the supply chain functional strategy, has a clearly structured theory. It provides the desired performance parameters to support the company's strategic vision. There has been much research on the strategic role that the service area, with its peculiar supply chain, is currently assuming to companies, due to its potential to provide differentiation and high levels of profitability. Still, the connection among the issues, including the deployment of competitive strategy in the supply chain strategy of specific service, are not yet addressed in an appropriate level of depth. For this research, the entry into a new market, the executive aircraft, aiming at differentiation, is very clearly part of the company's competitive strategy. In such market the products have extremely high added-value, and the quality of after-sales services is crucial to the customer's satisfaction and also to differentiate the company from its competitors. Therefore, it is justified considering as restriction the service levels characteristic of the largest market in the world. Furthermore, we are dealing with a new product in a market which demands great variability. According to Chopra (2001) these two factors suggest the need for a responsive supply chain. Thus, the distribution and services network should be defined in line with the company's strategy.

We have found an extensive literature, most relatively new, on location models which consider logistics costs as costs of inventory loading, transport and applications' processing. By doing so, more results with adherence to the operational scenario of the location problem are expected, thus adding more credibility for the company, among the users of the models. Similarly, the same happens with spare parts planning models, which have received much attention in recent years, due to their inherent complexity, distinctiveness (mainly because of typically sparse and difficult to predict demand) and relevance to the business. However, there was found no article or reference to location models which would take into account levels of spare parts inventory. This, of course, represents a further complexity once, as commented before, the stock levels could not be estimated in the traditional way, even considering non-linearity. Different models for service-provider facilities and materials distribution centers were found in literature, but not for both of them altogether. This is what the present case needs, once the aircraft maintenance centers will also be used as storage facilities.

Thus, from a conceptual and methodological stance, the research was based on a sequence of the evaluated theory on competitive strategy and its deployments for the operational supply chain strategy, the strategic relevance of the service area, the location models which consider logistic costs, and planning models for spare parts.

5. METHOD

The method used to solve the problem was the dynamic simulation, in conjunction with a search heuristic with the objective of achieving, within the highly complex problem scenario, a high level of adherence to the real operation system model, and a processing time able to analyze different alternatives. Such proposal is based on findings from the literature review, as outlined below.

According to the so far the evaluated literature, which addresses the importance of considering the inventory levels while dealing with location problems, the use of methods traditionally applied to location problems, is not adequate to handle the complexity of the interdependence of decisions of location and inventory: Ball (1984); Shen et al. (2005); Shen et al. (2007); Powell (2005); Nozick et al. (2001); Syam (2002); Goetschalckx (2002) and Hinojosa et al. (2008). Among them, the mixed integer programming one has a special place: Owen (1998); Hale (2003) and Klose (2003).

Moreover, there are several uncertainties involved in the operation, especially regarding the demand behavior. This is intensified by the fact that the spare parts stocks have an erratic and highly unpredictable demand. Therefore, they demand some specific planning models, which are often based on heuristic methods which aim at determining the stocks optimum levels, as suggested by Cohen (2006), Muckstadt (2004), Wong et al. (2005), Sherbrooke (2004), Lee et al. (2005), Batchoun et al. (2003), Zanoni et al. (2005) and Dias et al. (1998). In fact, some of the authors of articles with location models that consider the costs of stock loading, draw attention to the simplifications they had to do to make the model viable and to the specific cases in which such simplifications can be applied: Nozick et al. (2001) and Shen et al. (2007).

To apply the simulation method here described with the heuristic search the ARENA system was used in its 10:00:00 version, property of the U.S. company Rockwell Software. With this program it is possible to model an operation in a very realistic way, considering the fleet size, the levels of inventory, time, costs and their probability distributions for each stage of the process. The results of the simulation can be obtained through the creation of variables.

The operation of the model specifically developed for this work occurs as follows:

1. Each demand for a replacement part represents an entity which is generated within the model. This takes place following specified periods of time, which have been determined in accordance to the rate of defaults in the parts, the probability distribution, the fleet size and the number of parts used in each aircraft.

2. Since the entity has been created, the next step is to characterize the demand for which the part was created, the location, priority and type (scheduled or not scheduled demand).

3. In the case of a demand coming from an airport, the time for sending the piece from the distribution center is simulated (when the piece is not available in stock, the time it takes to arrive there is also added).

4. In the case of a scheduled maintenance, the aircraft flight time to the service center is simulated.

5. When the demand comes from a service center, its consumption is immediate when the piece is in stock. Otherwise, the time taken for the piece to arrive from the DC is added. If the piece is not available in the DC as well, the time it takes until it arrives is equally counted.

6. As soon as each piece is consumed and the demand is met, the replenishment process starts. If the stock is consumed in the SC, it is replenished by the DC, and if it is consumed in the DC, it is replenished by a supplier or a repair center. In the case of repairable parts, a process of sending the defective part to the repair center is also initiated.

7. Throughout the simulation, the transportation costs and the inventory levels are monitored during the periods when the aircraft is unavailable, in order to provide data for a performance assessment for the considered alternative.

Besides the simulation itself, the ARENA system has a module called Optquest that uses, as exposed in Glover (1995), heuristics search, such as “scatter search”, in order to determine some pre-determined parameters, so that an objective is maximized or minimized. The variables that will go through the Optquest seeking process are the opening and closing of the various service centers that can be used in the distribution and services network, as well as the parameters for each and every piece base stock (level below which the stock must be restocked), for the distribution center as well as the service center. The objective is to minimize the total cost composed by the inventory carrying cost, the logistic transport cost (calculated based on the cost per shipment plus the cost per miles of each specific transport) and the fixed cost of each open service center.

To evaluate the three alternatives of location for the distribution center, it will be done different runs of the model with appropriate changes of distance and cost of transport. Since each location is specific to a logistics provider, it is associated with different costs related to each provider. In the parameterization of the model, each simulation will be made for a period of 1 year using the average of 3 replications. For each scenario of the distribution center 500 different simulations will be run within the Optquest for finding the best solution. This number was defined from the observation that there are not significant gains in the results after 300 simulations.

For all parts the distribution center should have inventories inside the interval [(λiDi, 2 * (λiDi) 1 / 2 + λiDi], where λi is the rate of demand for the item i and Di is the time to resupply in the central deposit. As mentioned in the literature review, Muckstadt (2004) showed that the optimum level of stock in the central deposit is almost always in that interval. Inventories bases and centers of service may vary between 0 and the maximum amount set for the distribution center if they are non-critical parts. For critical parts, the minimum quantity in stock is one unit in each service centers. The data used in the simulation obtained from the evaluated company and had to be changed for confidentiality purpose.

The parameters related to the level of service offered to the customers were defined based on the theoretical foundations of competitive strategy and deployment to services and supply chain strategy and the specific settings of the market and the company. The conclusion of the discussion on literature analysis is that the focus of supply chain strategy should be more on differentiation of the service than in reduced costs. The level of service should therefore produce results equal or higher than the best found on the market. On this basis, the parameters to be used as restraints in simulations are:

- Minimum availability of the fleet: 98%
- Minimum Fill rate for non-critical items: 95%
- The percentage of flights to a minimum center services performed in less than 2 hours: 99% (there are specific places as Hawaii and Alaska where the target of 2 hours is not economically feasible, that’s why 100% was not used)

6. RESULTS AND DISCUSSION

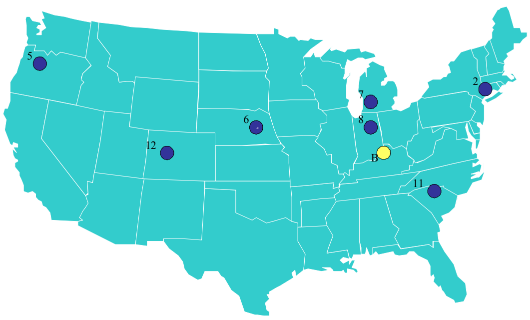
The searches were executed in Optquest for 3 different scenarios, each of them for a distribution center in a different location. Whereas the computer used, a Toshiba Satellite notebook with an Intel Pentium 1.73 GHz and 1 GB of RAM, is default now on the market, the performance can be considered quite satisfactory (times between 32 and 36 minutes). It should be noted, however, that significant simplifications were adopted, such as the inclusion of only 10 pieces in the simulation. To facilitate benchmarking between the 3 scenarios, follows a table with a summary of key results:

Table 1: Main results

Amounts in US$ Millions	Scenario 1	Scenario 2	Scenario 3
Stock carrying cost	2.62	2.56	2.64
Service centers fixed costs	0.6	0.7	0.6
Transport costs	2.46	1.78	2.89
Total cost	5.68	**5.04**	6.13

The final solution to the problem, found after 500 simulations performed in a period of 35 minutes, was the location of distribution center in Memphis and the use of 7 service centers located as below map at:

2 - Windsor Locks (CT)
5 - Hillsboro (OR)
6 - Lincoln (NE)
7 - Battle Creek (MI)
8 - Indianapolis (IN)
11 - Greenville (SC)
12 - Grand Junction (CO)



Distribution centers
Service centers

Figure 4: Selected service centers in the solution of the problem

The restrictions in the level of service (availability of the fleet, fill rate and time of flight to the service center) are all satisfied with this solution. The biggest operational cost is the inventory carrying cost (resulted from an average stock of $ 25.61 million), followed by the cost of transport and finally the fixed cost of service centers.

The fact that the biggest cost is the inventory carrying cost is consistent with the type of problem treated, commonly called asset intensive, where the amount invested in assets, in stocks of spare parts, usually costs more than other operational factors, such as the transport. This result reinforces the need for considering the cost of carrying inventory in such problems.

7. CONCLUSIONS

The solution obtained as a result of the proposed model allows the achievement of the defined levels of service to ensure the company's differentiation in the market, and at the same time minimizing operational costs, taking into account the concept of total logistics cost.

Considering the motivation of this work, we were able to meet the original purpose of proposing a viable, realistic and effective method. The method is feasible because it was demonstrated its use in a specific problem with reasonable processing times. It was possible to make its application to be realistic because, despite the simplifications used, the simulation model reproduced with great fidelity the operational environment to support the aircraft fleet. Its effectiveness comes from both the alignment of the solution with the competitive strategy of the company as well as the correct consideration of the costs and time involved in that, given the level of service defined as a concept that actually reflects what impacts the satisfaction of customers of executive aircraft.

Possible extensions of this research are:

- Research in meta-heuristics that in the case of location problems considering spare parts inventory levels have better performance. This will enable greater performance and subsequent acceptance of the method proposed in this paper for the type of problem here treated.
- Construction of simulation models that result in less than the simplifications adopted in this work. It will always be possible to include new considerations in the simulation model so that it is a better representation of the reality.
- Studies comparing the performance of the method used with traditional methods of optimization. It would require the evaluation of results in real applications of the methods so that the conclusions are not distorted by the various simplifications made in each case.
- Advancement in the study of the concept of fleet availability for measuring the level of service to the market of executive aviation. Currently, this is used mainly for military aircraft, while in other markets fill rate is more common. As a measure of satisfaction from customers of aircraft executives, it seems to make more sense to use the percentage of time the aircraft is available than the percentage of parts that were delivered within a specified period. Also, using the measure of availability allows including the time of flying the aircraft to the centers of service, when the plane is not available to the owner.

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