ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

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MSc in Logistics Management

Thesis

“A methodological framework for the allocation of Search and Rescue strategic units”

By Ioannis Parmakis (tml1932)

Supervising Professor: Sofianopoulou Styliani

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TABLE OF CONTENTS

1. INTRODUCTION

This study aspires to develop a theoretical model for the location planning of air Search and Rescue (SAR) units for the optimal level of service using operations research models. Since the term “optimal” has many interpretations depending on the strategy of each organization, we first had to define the strategy a SAR organization should seek to implement and the basic trade – offs this strategy incurs specifically in the SAR environment.

Our approach to this analysis was to use and implement basic supply chain principles (commonly used in the manufacturing industry) to the SAR industry, which is a special case of the service industry, essentially presenting the SAR operations as a large supply chain that delivers the specific service to customers. Then, we narrowed our view down to the location of the air SAR units, which is typically viewed as a facility location problem, that best serves the objectives and satisfies the restrictions of the supply chain. Since the organization was presented as a supply chain, we had to follow a holistic approach, i.e., consider the naval and ground units of the organization.

The air assets are the most responsive in a SAR organization. Their responsiveness is attributed to their capabilities to a) reach an incident at sea and land fast, b) “comb” a large area from an altitude quickly, c) “zoom” in or out to a search area by simply changing altitude, d) operate in adverse weather conditions that might not be conducive to a SAR operation by sea, e) to be quickly repositioned at a different, more suitable base. On the flipside though, the fixed cost of purchasing such units, as well as their variable operational cost can be very high and their capacity to transfer victims is limited.

As a basis of this thesis, we are using the Hellenic SAR organization, and specifically the sea area of responsibility, so the model abides by the specific restrictions and circumstances that apply in the Hellenic SAR environment. However, we believe that this model can be adapted to any SAR organization, since the supply chain and management science principles we apply are global.

Since decisions concerning the procurement of such assets and the respective founding of bases to support and host them entail great costs and affect operations in the long run, they are justifiably considered as strategic ones. However, due to the facts that there are many already found bases (most of them “ready to use”) scattered around the Greek continental and sea terrain, the units have already been procured, their number is satisfying to cover the whole area and they are easily transferrable, the allocation of these resources could also be considered as an inventory allocation problem, depending on whether we deal with the problem in a long-term strategic or short-term (periodic) planning manner. The SAR service is “stored” in the form of assets in different areas and these assets could be conveniently redistributed at relatively low cost based on spatial demand periodization, exactly due to their flexibility

Even though we are dealing with a facility location problem, this approach of viewing the SAR operations as a large supply chain could potentially provide a methodological framework to optimize other aspects (drivers) of the chain, thus contributing to even greater increases in the supply chain surplus - the difference between the service level and the cost.

2. PURPOSE OF STUDY

The purpose of this study is to:

a) Provide a systemic supply chain perspective on the SAR organization and utilize Supply Chain Management (SCM) principles on the asset location problem

b) Identify the major trade-offs in asset location planning

c) Suggest a “customer focused” demand pattern modelling

d) Suggest Operations Research (OR) tools for strategic asset location planning

e) Pinpoint further research areas on the suggested methodology

3. RELATED WORK

SAR units allocation could be considered as a special case of emergency humanitarian logistics facility location problem. Humanitarian logistics (HL) is the process of evacuating people from disaster-stricken areas to safe places and planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, while collecting information from the point of origin to the point of consumption for the purposes of relieving the suffering of vulnerable people(2,6,9). Due to the severity and volume of disasters, research has paid a lot of attention in approaching HL with optimization, decision making and simulation tools.

There is a great volume of disaster research employing modelling and optimization to solve facility location problems in emergency humanitarian logistics. Chawis Boonmee, Mikiharu Arimura, Takumi Asada(2) conducted a survey of research work on the emergency humanitarian logistical facility location optimization model based on data modeling types and problem types, deterministic facility location problems, stochastic facility location problems, dynamic facility location problems, and robust facility location problems. They analyzed and structured each piece of published literature based on the relevant objectives, conditions, disaster types, facility location types, data modeling types, applications, solution methods, categories, and case studies.

Due to the aforementioned survey, in our literature review we will focus on the facility location problem of Search and Rescue problems, and we will zoom in on SAR operations over the Aegean Sea. Afshartous D., Yongtao Guan and Anuj Mehrotra are concerned with the strategic aspect of the emergency distress call response problem, i.e., the determination of the actual locations of Coast Guard stations such that they are adequately located with respect to distress calls that vary over time(1). Their main technical contribution is the development of a spatial statistics model with variable distress call intensity in order to simulate distress call locations. Integer programming models are then used to determine optimal locations for responding stations. Nguyen and Kevin (2000) formulate a goal programming model, which considers Maximal Covering Location Problem (MCLP) and p-Median Problems (p-MP) to evaluate the service level of Canadian SAR operations(7). In addition, they utilize the simulation method with queuing theory to examine the operational performance of SAR aircrafts in accordance with the average time that incidents spend in queue.

At the Aegean Sea area, Razı N. and Karatas M. present the Incident Based-Boat Allocation Model (IB-BAM), a multi-objective model designed to allocate search and rescue resources(8). IB-BAM considers a set of criteria that are unique to the given problem, such as the density and types of incidents responded in the area of interest, resource capabilities, geographical factors and government business rules, and determines optimal boat allocation plans with the objectives of minimizing response time to incidents, fleet operating cost and the mismatch between boats' workload and operation capacity hours.

As far as the SAR helicopters allocation plan is concerned, Karatas M., Razi N. and Murat M. Gunal present an optimization study for their allocation in the area of interest(4). Beyond the conventional formulations for mathematical modelling, they adopt a hybrid methodology to tackle with the challenges of unexpected equipment breakdown and weather conditions changes. Their methodology includes three stages: (a) an Integer Linear Programming (ILP) p-median location analysis model to determine a base SAR helicopter allocation plan with the objective of minimizing total response time to incidents (distress calls), (b) A discrete event simulation (DES) model which tests the performance of the analytic solution under more realistic settings, (c) An alternative resource allocation plan generating and testing practice to evaluate better plans that exist in the vicinity of the ILP model solution.

Finally, Krimizas S presented a multiple scenario ILP set covering model as a decision-making tool for the allocation of SAR helicopters, based on their technical characteristics, the current infrastructure and the desired response time[(5)].

4. SAR OPERATIONS IN GREECE

The Greek government is responsible for conducting SAR operations to the benefit of its citizens, as well foreign citizens and aircrafts and ships in danger that reside within or navigate through its area of responsibility. This area is extended beyond continental Greek territory.

As far as air mishaps and flights in danger are concerned, Greek authorities are accountable for providing SAR assistance, as it has been ratified by the article 25 of Annex 12 of the Chicago Convention (1942) of the International Civil Aviation Organization (ICAO). The area of responsibility of Greek authorities for flights in danger as it has been defined and sanctioned by ICAO coincides to the area of the Flight Information Region – Athens (FIR – Athens), which includes continental Greece and regions over the Agean Sea, Ionian Sea, and international waters, as depicted in Image 1. This area encompasses many islands, most of which can and function as permanent or semi – permanent bases to launch SAR operations from. Most of the islands already host such bases for both naval and air assets, spread mainly across the Aegean Sea area, while more bases for air assets could be found on other islands as well at a very low cost, since the facilities are already developed (Image 2).

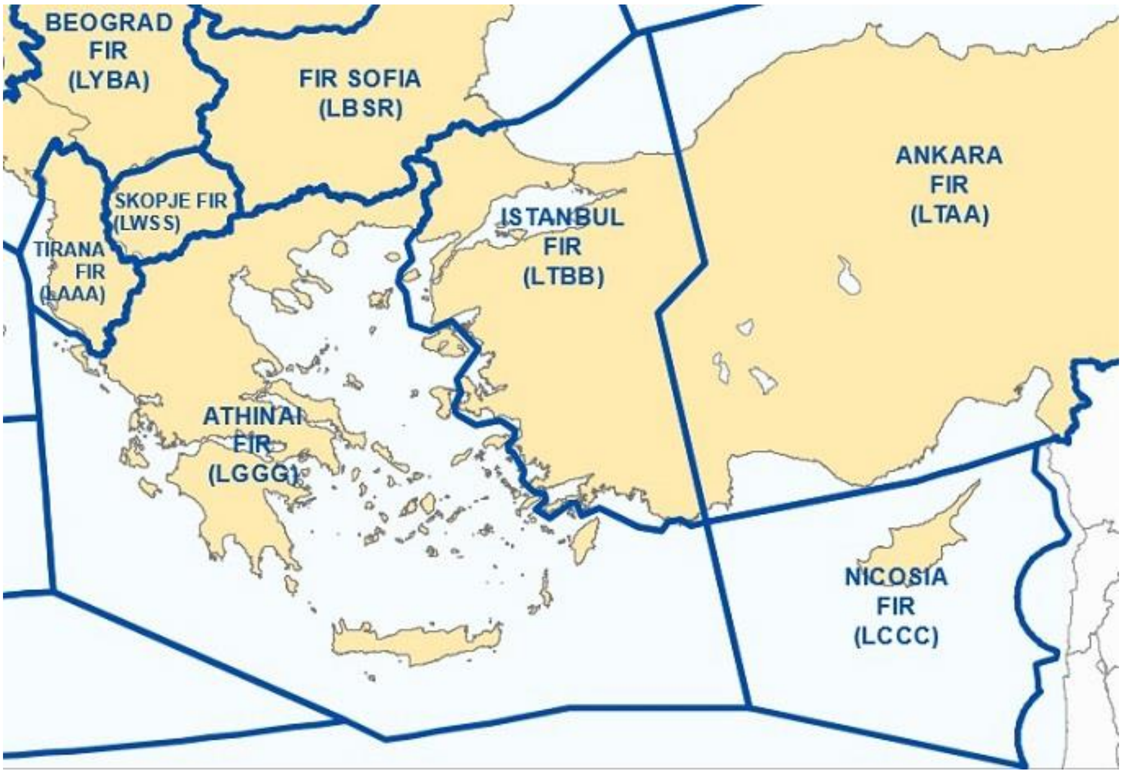

Image 1: FIR - Athens

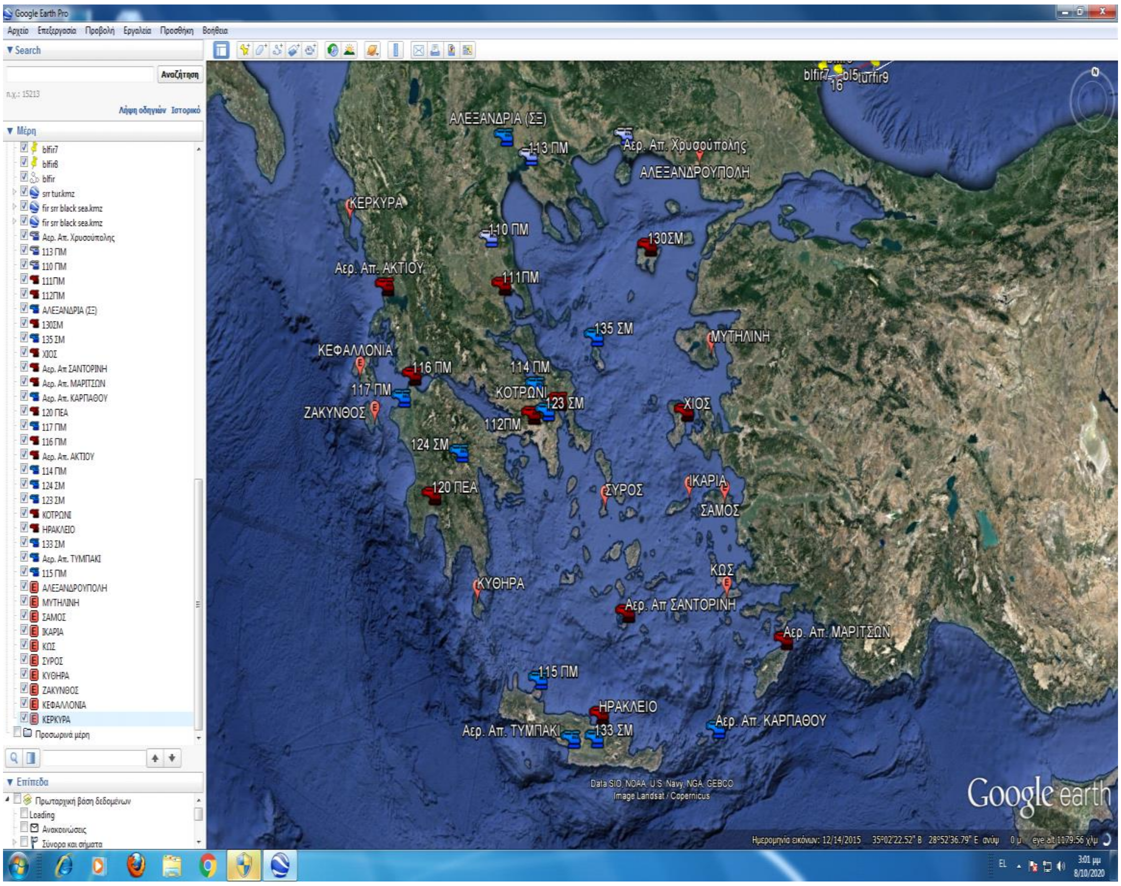

Image 2: Air Assets Bases

Blue helicopters: Functioning Bases

Red helicopters: Potential new Bases

Red pins: Potential new Bases that requires drawing up and signing a contract (with the private company that manages these airports) at a small fee.

Regarding naval accidents and mishaps, Greek authorities are bound by the convention for Naval Search and Rescue (Hamburg, 1979) of the International Maritime Organization (IMO) to support and assist in terms of SAR operations any vessel within Greek waters, as well as the international waters that extend directly beyond territorial waters. The convention does not explicitly designate the area of responsibility on international waters, but rather relegates this issue to be resolved by the countries adjacent to these waters. The Greek government has declared the area that coincides with FIR – Athens as its area of naval SAR responsibility. This statement has been published on the IMO SAR.8/Circ.4/Annex.4.

Apart for the above-mentioned responsibilities, Greek SAR organizations have undertaken the duty to provide Combat SAR (CSAR) services within FIR – Athens region to NATO allied air and naval forces, as it is prescribed by NATO Standardization Agreement (STANAG-3552) and Allied Tactical Publication ATP-10.

On the basis of the aforementioned obligations, the responsibility to provide SAR services within FIR – Athens has been assigned by the Greek government to the following organizations:

a) The Hellenic Military Air Force (HAF), concerning assistance to aircrafts in need or after an air mishap. HAF contributes to SAR operations with the means listed below located at eleven (11) different bases:

a. Four (4) helicopters AS-332, that can operate day and night, even at extreme weather conditions.

b. Six (6) helicopters AB-205, that are limited to day only operations and are subject to weather limitations.

c. Two (2) helicopters S-70B (which are provided by the Military Naval Forces), that can operate day and night.

d. One C-130 and one CL-415 (winter only) aircraft, that can be utilized for search only operations and supply drops.

b) The Hellenic Coastguard, regarding ships and people at sea in danger. The Coastguard employs various means of SAR operations that belong in two major categories:

a. Naval assets, including:

i. OPEN SEA VESSELS (category A-I over 45m)

ii. PATROL SHIPS (category A-I over 28m)

iii. QUICK COAST PATROL BOATS (category A-II over 24m, category A-II over 16m and category A-II over 13m)

iv. SPEED PATROL BOATS (category A-III)

v. LIFEGUARD (category B)

vi. POLLUTION SHIPS (category C)

vii. MULTIPURPOSE SHIPS (category D over 25m)

viii. AUXILIARIES (category E)

ix. INFLATABLE BOATS - SPECIAL PURPOSE

b. Air assets, including:

i. Two (2) single engine Cessna 172-RG

ii. Two (2) single engine Socata TB-20 Trinidad

iii. Three (3) double engine Reims Cessna F-406 Caravan III

iv. Six (6) Helicopters Eurocopter AS365 Aegean Dauphin.

c) The Hellenic Police and Firefighting Forces, regarding SAR operations on land.

Interestingly, even though there is an "umbrella" organization that commands and controls all SAR operations, each organization is responsible for managing its own SAR assets and has to formally request the utilization of assets from another organization, if they happen to be closer to the area of the distress call. Thus, beside the possible inconsistencies in Command-and-Control operations (C&C) that this entails to, it also leads to strategic and planning decisions, namely the allocation of resources / assets, in an isolated / non cooperative way.

Notwithstanding these inconsistencies, the Hellenic SAR organization performs its operations with a quick response time of less than 2 hours. Response time is defined as the time that elapses since the distress call until the appropriate SAR asset reaches the area and provides assistance or performs search operation.

The response time policy is formally established by the nation that is accountable for its Area of Responsibility (AOR). International Aeronautical and Maritime (IAMSAR) Manual Vol 1 recommends the aforementioned response time limit, and the Greek government has adopted this policy. This response time is also considered sufficient for SAR operations by ICAO, IMO and other national organizations. We should bear in mind however that this time includes the asset preparation phase; it is not the net operation time for the assets. Since the readiness time policy for the air assets is set to 30 minutes, the net operation time to reach the distress call is limited to 90 minutes.

Finally, we need to point out that all the SAR means enumerated above have also secondary missions. For example, the HAF air assets are obliged to provide combat SAR. The coastguard assets need to oversee naval border trespassing etc. All these secondary objectives add to the complexity of organizing an effective and responsive SAR system.

5. SAR OPERATIONS MANAGEMENT

When we think of supply chain management, we usually refer to the narrow view of sourcing, storing, and transporting physical material from suppliers to the end customer. Thus, it is easily related to the manufacturing industry. SAR operations on the other hand belong to the service sector of the economy. So, how can these two concepts be correlated?

Well, the first level of correlation has been attained by many businesses involved in the service sector, where the service firm applies logistics concepts to serve its product. Examples can be found in the retailing and the catering sector of the economy. These companies carry out the typical supply chain activities of any manufacturing firm.

However, there are service firms which provide a service without a tangible product (e.g., banking sector). Even though these service – oriented firms distribute an intangible, non-physical product, they still do engage in many physical distribution activities and decisions, such as facility size and location, cash transportation, "staff inventory" etc.(11).

Considering this deeper level of analysis, we can view the SAR sector as a service - oriented business with a supply chain that transforms resources (helicopters, naval units, staff) to service. The various stages of this chain could be summarized as follows:

a) Suppliers: The companies that provide assets and materiel for maintenance, as well as the major maintenance facilities.

b) "Operations Center": A link in the chain through which information is distributed appropriately.

c) Distributor: The mother bases.

d) "Retailers": The various bases that act as origin points for all operations.

e) Customers: The people in need, the distress calls positions.

The effectiveness of managing the broad supply chain of the provided service – and not just the logistics of the needed material - will determine the achievement of its objective: high service level at the lowest possible systemic cost.

6. SAR OPERATIONS OBJECTIVES AND STRATEGY

It is generally accepted that the ultimate objective in SAR operations is the exertion of maximum effort to save as many lives as possible, since human life is considered a priceless commodity. This in turn implies that SAR operations competitive strategy should be a very responsive one, i.e. at maximum service level. Achieving that responsiveness level, however, is not as simple as merely employing the most responsive units and the highest number of personnel, since wasting money in such a way could in fact limit the provided service level in a world of scarce resources with alternative uses.

To ensure that the competitive strategy is consistent with the customers' (victims) needs, we should strive to attain and maintain a strategic fit between the supply chain and the competitive strategy. This can be accomplished though the following steps:

a) Understanding the Customer and the Supply Chain Uncertainty: The objective metric that summarizes the customer uncertainty is the implied demand uncertainty, which is affected by the inherent demand uncertainty and the various characteristics of the customers' needs. In the case of SAR the demand uncertainty is high, since this demand can take place anywhere in place and time at our area of coverage. This leads to increasing implied demand uncertainty. Moreover, the attributes of the demand contribute to even larger increases in implied demand uncertainty. We can reach this conclusion just by considering these attributes: variable types of distress calls and accidents, each requiring different means and resources, high response time demanded by victims, high degree of forecasting errors, long idle times or unexpected demand that leads to "stockout" *(Marshall L. Fisher, Harvard Business Review, March–April 1997)*.

On the other hand, the supply chain uncertainty results from the capability of the supply chain. In this instance we can point out to the limited supply capacity (SAR units and personnel), unexpected breakouts and long maintenance downtime, inflexible capacity, especially for naval units (it is difficult and costly to change the location of facilities or replace the units, once established), unexpected adverse weather conditions which limit the conduct (supply) of operations. All these supply characteristics further contribute to an increase in implied uncertainty.

b) Understanding the Supply Chain capabilities: These abilities are linked to many of the characteristics of supply and demand that lead to implied uncertainty. Essentially, in this step we need to identify the ability of our supply chain to respond quickly to distress calls and meet them with short lead time, respond effectively to a high percentage of distress calls, handle different types of distress calls, handle the supply uncertainty through improving maintenance procedures, improving human resources management, renewing the SAR fleet appropriately etc. The more of these abilities the supply chain has, the more responsive it can be.

However, high responsiveness comes at a cost. The more responsive our supply chain is, the less efficient it is. The cost – responsiveness efficient frontier curve is shown in the figure below. This figure is very important to our analysis. Based on that curve we can determine whether our operations take place along the frontier and adjust accordingly. If we are not on the frontier, our supply chain has the potential to improve both in terms of efficiency and responsiveness. If we operate along the curve, we can make adjustments to improve responsiveness, if we find a budget surplus, or even strive to make innovative changes to our processes and make use of new technologies to "press" the curve even lower.

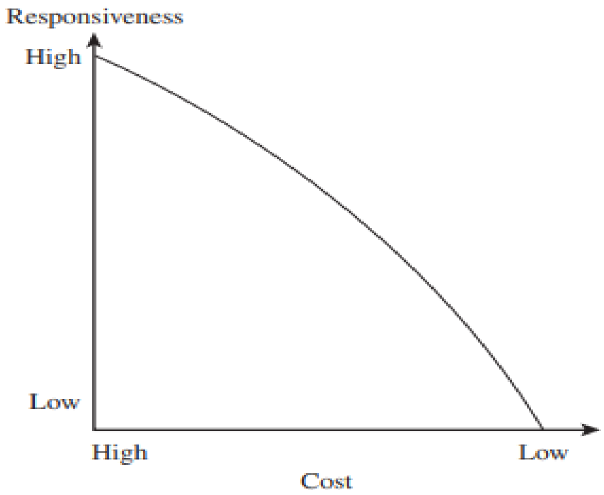

Figure 1: Cost – Responsiveness Frontier Curve (10)

c) Achieving Strategic Fit / Tailoring the Supply Chain: Having acquired an understanding of the implied uncertainty and the capabilities of the supply chain will help us achieve a strategic fit between the supply chain and the demand, i.e., to establish for each stage of the chain the responsiveness level that corresponds to the implied demand uncertainty making the optimal use of available resources.

Furthermore, in our industry specifically it makes sense to achieve strategic fit through tailoring the supply chain. In the first step of our analysis, we can recognize that there are different costumer segments, i.e. types of distress calls, each one with each own implied demand uncertainty. We also identify that our supply chain has different capabilities in terms of efficiency and responsiveness, based on the assets and planning we are implementing. So, we can tailor the way the SAR service is provided to different types of distress calls, by having shared operations for some links through the chain and by having different operations for other links.

The degree to which the fit we established sets our chain on the desired threshold on the cost-responsiveness efficiency frontier curve can be identified by setting and tracking performance metrics across the logistical and cross-functional drivers as they are introduced below.

7. SAR SUPPLY CHAIN DRIVERS OF PERFORMANCE

Having defined the strategic objective of our service supply chain in terms of the balance between the responsiveness to the distress calls and the efficiency (systemic cost), we can improve its performance by examining the logistical and cross – functional drivers of its performance which in the case of our S&R supply chain can be summarized as follows:

a) Facility: the locations where the SAR units (air, naval and ground) are stored and from which they operate.

b) Inventory: the number of the serviceable and unserviceable SAR units at each base, all spare parts necessary for their maintenance and the staff required to operate them. When dealing with optimizing the inventory we should also consider the time - period/operational hours that each asset remains serviceable before requiring maintenance.

c) Transportation: since the final product – the SAR operation – can be delivered by air, naval or ground units that we have "stocked" in a base, it essentially represents which units we mobilize for which type of distress call (outbound transportation). It also represents the means of transportation for the necessary spare parts, operational and maintenance crew or even the costs incurred for relocating units - either for operational or maintenance purposes (inbound transportation).

d) Information: refers to the personnel and activities concerned with identifying distress calls, filing reports and synchronizing SAR operations. Dealing with this driver, we also need to consider whether the processes will be of "push" or "pull" nature and to what degree. By "push" processes we can define the regular "search only" operations, as well as all preparatory processes (designing the network of our chain) in anticipation of a mishap, based on data analysis, time - period demand and experience. By managing to suppress the push/pull boundary closer to the time of the mishap with cost efficient methods we can increase responsiveness and decrease cost.

e) Sourcing: determining who will perform which particular supply chain activity, including, but not limited to, procurement of raw materials and SAR units, maintenance, air/naval or ground operations (delivering the service), determining and reevaluating the active facilities etc., and whether any of these activities should be outsourced.

f) Pricing: This driver has applicability in the private sector businesses, and it is – among else - used to match supply of scarce resources to different kinds of demand. In a government provided service it is commonly accepted that prevention and rescue from life threatening situations should be provided to everyone at all costs. However, this human value cannot ignore the basic principle of economics: demand (distress calls) must be covered by limited resources that have alternative uses (other distress calls). So, even in a publicly setting pricing takes the form of prioritizing.

The above-mentioned drivers do not act independently, but interact with each other, to determine the supply chain performance in terms of responsiveness and efficiency. These interactions often create trade-offs between the elements of those drivers. Hence it is not always efficient to optimize one driver at the expense of the others.

To deal with the optimal location plan of the air SAR units, we need identify the trade-offs that emerge between the facility driver and other elements of the supply chain after having defined the objectives of the SAR supply chain.

8. TRADE – OFFS IN ALLOCATION OF SAR UNITS

The fundamental trade-off when making facilities - related decisions is between the cost, the number, location, capacity, and type of facilities (efficiency) and the level of responsiveness that these facilities provide. Increasing the number of facilities increases facility, inbound transportation and inventory costs, but decreases outbound transportation costs and reduces the response time (increased service level) in general. We need to point out that the increase in service level follows a pattern of diminishing returns which is exacerbated above a certain level, characteristic to each SAR unit.

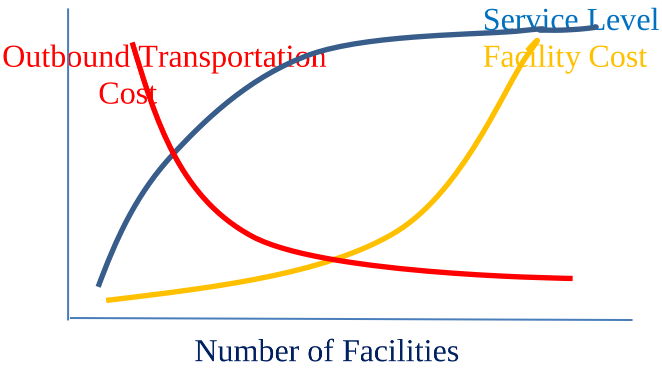

Figure 2: Fundamental trade-offs between number of facilities, costs and service level:

Increasing the flexibility of a facility (by combining different types of assets in one facility – mixed types of facilities) increases the cost of each facility but may consolidate the number of facilities and contribute to economies of scale and scope, especially when considering missions that demand coordination between different types of assets. As a result, it could decrease total inventory and inbound transportation, but poses a danger of increasing outbound transportation costs and response time. Thus, an optimal selection of a mixture between mixed assets and exclusive assets facilities should be considered.

Increasing the capacity of each facility, namely the number of units, leads to increased facility and inventory costs but contributes to response time reduction and quick adjustments to fluctuating demand (agility), making the chain more capable to deal with surges in demand due to periodicity, unforeseen events or urgent mishaps.

Changing the type of the facility actually refers to the type of units employed at each facility (air, naval, ground and mixed). The chosen type essentially entails to different transportation, both inbound and outbound, inventory and facility costs. The increase in responsiveness level and transportation costs that follows the increase in the number of air units is obvious. There is also a trade-off between number of air assets and inventory holding costs, namely the costs for supporting and maintaining the SAR units within a specific time - period. Opting for air units (high transportation costs) may reduce other types and facilities of SAR units required (less inventory and facility costs), considering the fact that less air assets are capable of dealing with more mishaps of high priority/low capacity effectively, since they rarely take place at the same time within the effective operational radius of units.

However, this relationship between number of air assets and inventory and outbound transportation costs is not one-sided. Below a certain number of units, their inventory turnover rate – the rate at which they require maintenance – may increase dramatically and thus their holding cost as well. This is denoted by the slight "bathtub" light green curve in the relationships Figure 3 below. This relationship holds true for air units because the high service level required renders the mobilization of air units as the only option in high priority mishaps. For the same reason we also observe an increase in total transportation costs, since below a certain level of air units, these units will have to be transferred more regularly and will also be burdened with the task to travel longer distances to satisfy the same level of urgent demand. Note that this does not apply for other types of units though, since the demand satisfied by these assets can be also satisfied by air units, even though in higher numbers. So, given a certain service level, decreasing other units will increase the number of air units and thus both total inventory costs for air units and, at an even higher rate, total transportation costs.

Finally, we should also point out that above a certain level of utilized air units diminishing returns in the service level commence. Increasing the air units too much will not have a huge impact on the improvement of the service level, especially considering that there are mishaps that can be dealt with other units both efficiently and effectively (e.g. high - capacity incidents, incidents by the shores). In a nutshell, employing too few air units will increase costs in the form of “inventory” (high maintenance rate of air units, increased number of other type of assets) and transportation costs and could potentially have a negative impact on the service level (naval and ground assets cannot entirely replace air units, even though the opposite could hold true), but employing too many air units can also lead to dramatic cost increases (operation/transportation/maintenance costs) and on top of that may not contribute to commensurate improvements in the service level.

We conclude that, given a required service level, there is an underlying trade-off between the location and number of air units in relation to the location and number of naval and ground units. Increasing the air units reduces facility and inventory costs for other types of units but increases inventory and facility costs for air units and total transportation costs. Furthermore, reducing the number of air units below a certain level, will have the opposite effect to the one expected on the inventory and transportation costs (leading thus to a bathtub curve); due to the increased asset turnover rate required to maintain the desired service level. Given all these trade-offs the need for a holistic approach seems really appealing.

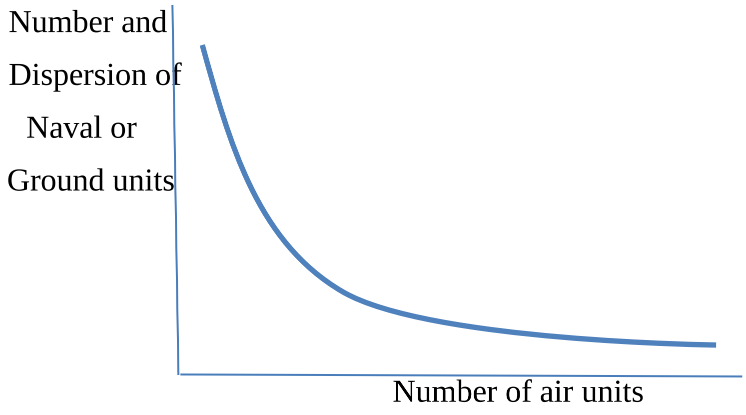

Figure 3: Relationship between the required air and naval or ground units to achieve a specific service level

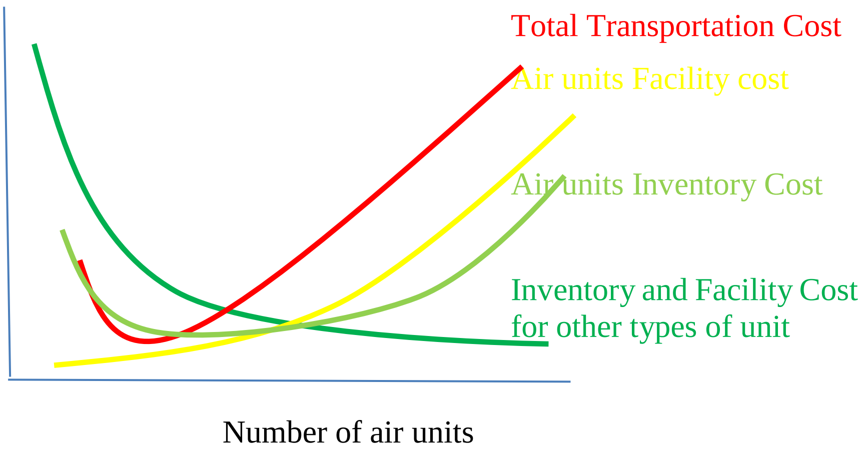

Figure 4: Relationship between costs and the number of air units considering a fixed service level and the relationship with other type of units

Of the above-described trade-offs the one mainly considered for the current facility location is the one between number of facilities and service level, with the most important criterion being the coverage of the whole area of responsibility. All the above trade-offs are taken into account however, on an ad-hoc basis, whenever a distress call takes place, especially when there is a choice between different types of assets to be mobilized. However, this ad hoc basis, even though it might allow for a high service level, does not guarantee the most efficient and effective utilization of the means available.

Thus, we will attempt to reevaluate the approach to facility location taking into account all of the above trade-offs, especially the ones that emerge between different types of units. To do that, we must first look a little deeper into the demand patterns of the distress calls and how these can be linked to the SAR capabilities.

9. SERVICECHAIN DEMAND PATTERNS

When examining the demand patterns, we are mainly concerned with two variables: the type of the mishaps and their spatio-temporal appearance. Identifying the type of the accident will help us tailor the chain appropriately. The analysis of the second variable will help us in crafting a model for the problem and solving it using OR tools.

As far as the first variable is concerned, there has been some analysis of the types of mishaps, especially in the Aegean Sea, as it was mentioned in the related work. The Hellenic Coastguard uses standard categories for the mishaps, which cover a broad range of accidents, such as:

a) Medical evacuation from ship (MEDEVAC)
b) Medical transfer from a local hospital
c) Missing ship/boat
d) Human who fell in the sea from ship
e) Water inflow to ship
f) Collision of ships
g) Missing swimmer, fisher, boat
h) Mechanical failure
i) Fire on deck
j) Shipwreck findings
k) Illegal trespassers
l) Ship in dire situation
m) Sinking

On top of their variety, we are also facing a large quantity of mishaps; there have been reported approximately 2.000 incidents last year. Approximately 150 of those were handled by air assets. This adds to the uncertainty of the system, since not only it makes it difficult to forecast them, but also impedes the location planning.

However, we are not really concerned with the type of the mishap per se, but rather with two dimensions of the mishap: its criticality and the number of lives involved. The criticality can be defined by the combination of two factors:

a) Urgency for response to save life/lives.

b) Accessibility to/from the distress call and the rescue center, which in turn is affected by distance and weather conditions.

Thus, all types of mishaps could be positioned graphically along a straight line in ascending order based on the two factors above. A MEDEVAC at long distance is more critical than one that takes place at short distance. Equivalently, a MEDEVAC due to an immediate life-threatening situation is more critical than a mishap of water inflow that has not yet been manifested excessively.

Considering also the other dimension, the number of lives involved, we can depict the mishaps on an orthogonal two-axis system. We can easily deduce that four distinct zones are created, as it can also be observed in Figure 5 below:

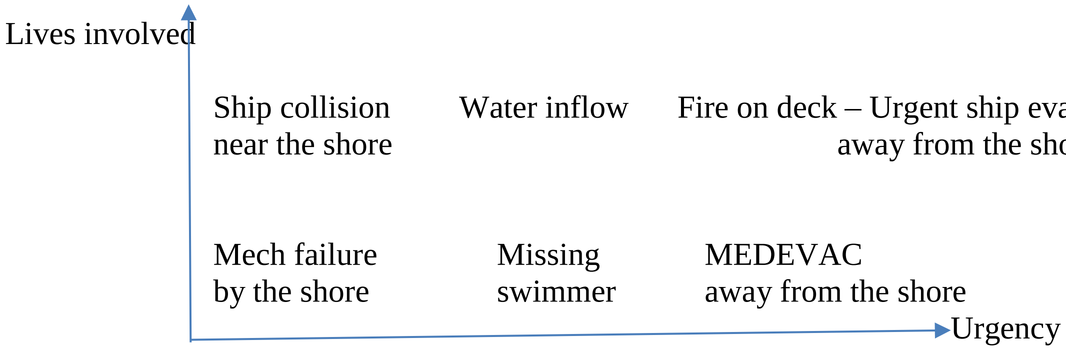

Figure 5: Criticality of incidents

a) On the bottom left side, we have mishaps of low criticality and few or zero lives involved, such as a routine survey or a mechanical failure, usually near the shore.

b) On the bottom right side, we have mishaps of high criticality usually accompanied with difficulty in accessibility. These types of incidents include

MEDEVACs located mainly along naval vessel routes at the southern part of the Aegean and Ionian sea and the area between Crete and the rest islands in the Aegean, as well as urgent hospital transfers from any island to the mainland (usually Athens and Thessaloniki).

c) The upper left zone includes incidents where many people are involved, but the urgency to respond is low, e.g., ship collision near the shore with the evacuation situation under control.

d) Lastly, on the upper right zone we come across the most demanding incidents that require great responsiveness and capacity of SAR means.

This categorization determines the priority given, as well as the type of assets devoted to each type of mishap; fast air units for mishaps on the right side and cheaper naval units for incidents on the left side of the spectrum. This prioritization takes place on an ad hoc basis. However, we could use this finding along with the spatial model suggested below to make strategic decisions on the location of the assets.

The variety of the types of mishaps established above, as well as their huge number and the irregular frequency contribute to the high variation in the spatial appearance of the incidents. Due to this variation, I would suggest refraining from using a determined set of values (e.g., spatial arrangement at a specific year). On the other hand, using stochastic models based on demand pattern distributions (9) could lead to very complicated calculations, considering also that there are both fixed and variable costs involved.

I would therefore suggest calculating and using expected values for the spatial arrangement of the incidents. This preference is also attributed to the fact that mapping out the mishaps and categorizing them has led to noticing patterns in their spatial arrangement. Specifically, we noticed that the majority of the incidents take place along ship routes, as well as the coastline, with coasts by touristic places bearing a higher density. Their frequency also happens to vary with season; some types of mishaps appear more frequently during summer (e.g., missing swimmers), whereas others during the winter (missing fisherman, capsize etc.). Therefore, we can deduct a correlation between type of incident, population density (both local and touristic), ship itineraries and demand spatial and temporal arrangement. Since we are concerned with the strategic location of resources, we do not need to take into account the temporal arrangement. Temporal patterns, however, could be very useful, when dealing with the asset allocation problem in a short-term operational manner.

So far there is no data available concerning the frequency of each type of accident. We could however rely on worldwide statistical averages for each type of mishap per thousand of capita per day or per mile of ship route per ship (note that the "per ship" condition can easily be converted to "per day"), whichever is applicable. We could then mark small hexagons[(a)] with a side size of 2.5-mile[(b)] over the coastline, the ship routes and on the islands (for the urgent hospital transfers) and estimate the expected values of each type of incident per day based on the peak number of residents and peak number of ship density (peak number of ships simultaneously passing through each small hexagon at a given time). Peak numbers are suggested, since we are committed to providing a high service level. On top of that, erring on the side of higher numbers could lead to inefficiencies, which are welcome in a responsive supply chain, such as the one involving the SAR helicopters, since they eliminate any shortage costs. However, national policy could opt for any other demand "density".

[(a)] Hexagons were picked because they approximate a circle and can completely cover an area with no overlaps

[(b)] The side dimension was picked arbitrarily depict areas sufficiently small that can be searched fast by any available mean. A trade off exists; small areas simulate single points of destination more effectively in our calculations, but they also increase the number of required calculations.

It should be highlighted at this point that the spatial model for the appearance of the incidents is not an attempt to forecast accurately the place and number of the incidents, but merely a simplified process to provide us with input for our objective function and constraints. We thus abide by the quote “A good model is better than a perfect model”. Even though the expected values for each type of incident may be very different compared to their actual numbers, they still provide a statistically reliable basis for reaching a long - term optimal solution for the strategic asset location planning.

10. TAILORING OUR SERVICE CHAIN

Having established knowledge on the demand patterns and supply capabilities we can tailor our chain. Before we continue with our analysis of the segmentation of the demand patterns, as it appears in the “criticality of incidents” figure, we need to note the meaning of the marginal area close to the intersection of the axes; low criticality and no lives involved. This depicts “Search Only” operations. These operations are characterized as a continuous process (contrary to the rescue operations, which are discrete), which can contribute to the whole efficiency and responsiveness of the chain by shifting the push/pull limit of the processes further down to the customer side; early spotting of incidents can prevent waste of resources and time and contribute to the employment of the appropriate asset for each distress call (postponement).

As such an effective tool of postponement, these operations play an important role, but they should be conducted in the most efficient way possible. Right now, these operations are conducted by wastefully employing valuable, scarce and expensive air and naval assets, which limits the continuous flow of the process and may interfere with their responsive employment to distress calls. It should be noted that continuous efficient search operations do not preclude other means of searching (e.g. naval patrols, safeguards outposts etc.). They rather upgrade the output environment in a “lean” way.

The rest of the zones depicted by Figure 5 (“criticality” of incidents) could be served by our supply chain in the following three ways:

a) The bottom right zone can be served effectively only by fast-moving helicopters. Hence this zone should be our primary focus when utilizing these assets. A special subcase of interest in this zone are incidents that take place at night. These incidents cannot be dealt with any type of helicopter. Specifically, for HAF only SUPER PUMA and S-70 can execute SAR operations at night.

b) The two zones on the left side of the diagram require efficient use of resources and could be served effectively by naval assets located nearby. Air assets could potentially contribute to SAR operations (especially if the situation starts shifting to the right), but this zone is not their top priority. They should be used only if there exists a positive trade-off against using naval assets.

c) The upper right zone demands the employment of a robust and reactive system of high-capacity naval assets. However, the combined utilization of other assets, such as nearby ships and especially air SAR units could ameliorate the high urgency encountered. In this case air assets that do not directly collect victims, such as airplanes, are also useful, since they can airdrop essential life - saving/sustaining resources.

Each of these four supply chain zones defined requires its own approach to model the problem and determine the optimal location planning of its matching assets.

11. ASSUMPTIONS

Before we delve into the four different approaches, it is appropriate to summarize and enumerate our assumptions below:

a) Each type of incident “g” is covered by a specific range of types of units “u”. Also, vice-versa: each type of unit “u” can only deal with a specific range of types of incidents “g”.

b) All hexagonal incident areas “j” should be covered by at least one appropriate type of unit. The required number of this type of unit is estimated by the capacity required for the specific type of incident “g”.

c) All units have a maximum number of missions they can execute daily.

d) All units must reach their matching distress calls within the required timeframe discussed in chapter 4. To ensure that, circles are drawn around each facility with the facility placed at the center and a radius of 1 to 1,5 hour distance based on the respective unit travel speed. We then consider only the area S_{iu} within that circle as “served” by the type “u” asset stationed at the respective facility “i” in the objective functions. The OR models can be solved using different maximum response times to calculate the effective radius for each facility and the solution that offers the desired mixture of service level (based on national policy) and quantity of required resources (budget constraints) can be selected.

e) Incidents that require the intervention of a specific unit within its effective range from a specific base, S_{iu}, do not take place simultaneously. However, we consider multiple accidents taking place within the S_{iu} during the day.

f) We do not consider any procurement decisions for new SAR assets, except for drones for the Search only operations. Thus, we have a constraint for the existing quantities of assets. We can still use the same OR approach if we want to renew our fleet of assets, but we will suggest how the objective functions and constraints can be tweaked to support such decision in a holistic manner.

g) Since there could be budget available, but not sufficient to support a holistic renewal of fleet, we could consider renting air units – deployment and withdrawal of which is easy and fast - to support peak demands operations. We will introduce a simple tweak in the constraints to accommodate that concept.

h) We do not differentiate between night and day distress calls, in order not to increase the complexity of the demand patterns. This issue is dealt with prioritizing the assignment of helicopters capable of night operations to highly critical incidents.

i) We need to prioritize; allocate first the necessary quantity of air assets to the highly critical incidents that can be "served" by air units only (preferably SUPER PUMA and S-70 helicopters, that support night operations). Then we assign the rest of the air units or budget (if any) to the highly critical incidents that require a combination of resources (top right zone of the diagram in Figure 5) and lastly to the left side incidents after examining the trade – offs with the utilization of naval assets. This prioritization is the reason that we introduce different OR models gradually, essentially building up the deployment of SAR assets considering the solutions of the previous step as constants.

j) One operational drone maximum per facility.

k) Peak demand is considered only due to the strategic nature of our planning process.

l) We use two types of costs as coefficients in the objective function; overhead costs for each facility activated, which are further analyzed to fixed and variable for both units and facilities, and direct variable costs for the units travelling to and from the incidents.

m) Overhead fixed costs include costs for activating and equipping the base (including the costs for transferring units and personnel to the base) and renting costs for the required air units.

n) Overhead variable costs include depreciation, periodic personnel and asset transfers between each facility and its mother base, wages and maintenance (facility only) costs. These costs (except for the maintenance costs, which are regarded as direct variable costs) apply to both facility and assets. To turn these costs into a "fixed" number that will help us model the problem, we could calculate the present value of the total of the above costs during the lifecycle of each facility and unit.

o) Direct variable costs for each asset refer to fuel consumption per mile and the proportion of maintenance required based on operation hours.

p) Inability to provide "supply" of service due to weather conditions is not considered. This issue can be tackled with the use of simulation and better resolved at operational level planning based on weather seasonal variations and forecasts.

q) All units are assumed to be operational at any moment. To satisfy that condition, we might need extra "inventory" of units. This can be calculated afterwards based on the maintenance cycle of each unit.

r) Support from nearby ships that are not part of the SAR organization is not considered. This is an extreme case scenario, especially during peak demand seasons. However, it is studied for academic purposes.

12. OR APPROACHES

Moving on with our OR analysis, we can discern the following approaches:

a) Case of Search only operations with drones: This appears to be a procurement problem. OR integer programming could be very useful after purchasing the assets to locate them to optimal locations. However, the same modelling approach could be utilized to facilitate procurement decisions. During the procurement process a selection of prospective types of units will be suggested based on their attributes and capabilities and service level targets. Since we are dealing with a "continuous flow" service process (searching), our goal is to maximize efficiency, after selecting the appropriate prospect types of units that satisfy our service level needs, such as range, sweeping speed, ease of deployment and handling etc. It should be noted that range and sweeping speed is correlated with the number of units required. So, these capabilities could entail benefits in efficiency.

The efficiency objective is satisfied, if we manage to deploy the minimum number of units to cover the area of interest. So, we are dealing with a set covering problem, if not strict constraint in the maximum number of units is set, or a maximum coverage problem, if there is a strict budget constraint. The efficiency criterion could be assessed by calculating the lifecycle cost of each type, multiplying it with the OR problem solution obtained and comparing them with each other.

Before we model the problem, we need to draw circles with each potential base "i" at their center and with a radius that ensures "sweeping" of the area of interest S_i within a specified timeframe. This depends on the capabilities of each type of drone and is subject to national policy. The mathematical formulation for the first case (lenient budget policy) is:

$$Min \sum \quad Y_i \qquad (1)$$

(Minimize the number of bases “i” selecting from all possible locations)

Subject to constraints (s.t.):

$$\sum_{i \triangleq j} Y_i \geq 1, \forall \text{ j} \qquad (1.1)$$

(Every potential incident point “j” should be enclosed within at least one S_i)

(≙: means “that corresponds to” – we sum all the Y_i that correspond to each incident “j”)

$$Y_i \in \{0,1\}$$

and in the case of maximum coverage with limitation of k bases (=number of units that can be purchased) we need to add the constraint:

$$\sum Y_i \leq k \qquad (1.2)$$

The prospective locations should not be limited to the air bases, but they should include all facilities that could be supported by the SAR organization, such as naval bases. Obviously, the limitation k varies between different types of units that are considered for purchase, based on their purchase cost.

b) The second case refers to the highly critical incidents (lower right and upper far right zone of Figure 5) that are addressed by air units (including the ones that require high capacity, since air units can play an auxiliary role in those). The objective in this case is high responsiveness, which is translated to proximity to distress calls and sufficiently large number of units. The first goal could be achieved by inserting in the objective function the minimization of distance between distress calls and the air units. Sufficiency of units is achieved by tailoring the service chain, which leads to efficient allocation of the responsive assets. Also, moving closer to the efficiency – responsiveness curve boundary, by aiming for less operational flight hours, could produce the same effect, by allowing higher expenditure towards the acquisition and support of responsive assets. Thus, an objective function that seeks the minimization of variable costs of the air units could satisfy the objective of responsiveness.

To formulate the model, large circles need to be drawn around each potential air facility as in case (a) to establish the area S_{iu} described in assumption (d). As we have already described, the average number of distress calls $(ANDC)_j$ is calculated statistically based on the respective “traffic” (ship routes, population density) within a small hexagonal area. Each distress call within that small hexagon is considered to take place at the center of each hexagon “j”.

Therefore, the following mathematical formulation of the model is suggested:

$$Min \sum_j \sum_{i,u \triangleq j} (ANDC)_j \cdot d_{ij} \cdot Y_{iu} \tag{2}$$

s.t.:

$$\sum_{i,u \triangleq j} X_{iu} \geq 1, \forall \text{ j} \tag{2.1}$$

(we sum all the X_{iu} that correspond to (serve) each incident “j”)

$$\sum_i X_{iu} \leq AH_u \left(+\frac{B}{C_R}\right)^*, \forall \text{ u} \tag{2.2}$$

$$X_{iu} \geq Y_{iu} \cdot \frac{\sum_{j \in S_{iu}} (ANDC)_j}{\frac{MMu}{D}}, \forall S_{iu} \tag{2.3}$$

$$X_{iu} \leq M \cdot Y_{iu}, \forall \text{ i,u} \tag{2.4}$$

$$Y_{iu} \in \{0,1\}, X_{iu} \in N$$

<u>Where</u>

X_{iu}: number of helicopters of type “u” stationed at base “i”

Y_{iu}: decision binary variable that represents whether a base “i” is activated and loaded with unit of type “u”

M: A sufficiently large number, way larger than the minimum number of units required ($\frac{\sum_{j \in S_{iu}} (ANDC)_j}{\frac{MMu}{D}}$).

AH_u: Available helicopters of each type "u"

$(ANDC)_j$: Average Number of distress calls within each small hexagonal area "j"

d_{ij}: Distance from base "i" to the center of each area "j" and back or, in the case of incidents that require transfer to a major hospital, it represents the above-described distance plus the distance between "j" and the one of the major cities, Athens or Thessaloniki, whichever is closer.

MM_u/D: Maximum Missions per Day. This calculation depends on the setup time of each type of asset, its capabilities, as well as factors such as the crew rest time.

B: Available Budget (in case there is one)

C_{Ru}: Renting cost for each type "u" asset

Constraint (2.1) ensures that all incident areas "j" are supported by at least one unit "u" from at least one location "i". Constraint (2.2) considers the maximum available number of units. Constraint (2.3) and (2.4) ensure that the number of stationed helicopters of type "u" at each location "i" will be sufficient to satisfy daily demand within the area S_{iu}, only if the base "i" is selected for activation.

If inequality (2.2) cannot be satisfied, it means that the existing air assets and our budget are not sufficient to cover the demand. In that case we need to consider the demand that can be satisfied by air assets only (low capacity – right left side of Figure 5).

If, on the other hand, the total number of helicopters is less than the number of night operating ones (AS-332 and S-70), we will solve the same models again considering only these types in the objective function and constraints, in order to be consistent with assumption (i).

We observe that this model provides the minimum number of helicopters to deal with daily operations. Also, it does not consider the requirement for a higher number of helicopters to deal with high - capacity incidents; we just receive a solution to utilize air assets in an auxiliary role only.

c) The third case refers to the upper right zone in Figure 5. Both the remaining helicopters and the high-capacity naval units are utilized. Since we are dealing with incidents that require assets of different capacities, we are introducing a new parameter for the Average Number of Distress Calls: $(ANDC)_{gj}$, which refers not only to a specific incident area "j", but also to specific types of incidents "g" that require the similar capacity. So, more than one parameter $(ANDC)_{gj}$ correspond to each incident area "j".

We have already considered the far upper right zone incidents to assign at least one helicopter to those in an auxiliary role. However, now we can consider stationing and employing more than one helicopter per base to deal with those incidents, even exclusively with air units, if the trade-off of employing them against high-capacity naval units is positive.

Since we are appreciating the trade-offs between establishing different types of bases, we need to include binary variables in the objective function, $Y'_{i,} \in \{0,1\}$ that represent the activation or not of a new facility "i" only and are multiplied with the facility overhead costs. In the same respect we also need to sum the product of the Y'_{iu} variables with their respective overhead variable costs. To formulate the model, we need to draw circles similar to the previous case.

The model that captures the above-mentioned constraints and assumptions is the following:

$$Min \sum_j \sum_{i,u \triangleq j} ((OC_i) \cdot Y'_i + (OC_u) \cdot X'_{iu} + (ANDC)_j \cdot d_{ij} \cdot Y'_{iu} \cdot (VC_u) \cdot \sum_{u,g} (RC_{ug})) \quad (3)$$

s.t.:

$$\sum \ X'_{iu} - \sum_{i:existing\ facilities} X_{iu} \geq AA, \forall \text{ u} \quad (3.1)$$

$$X'_{i,u} \leq M \cdot Y'_{iu} \quad (3.2)$$

$$\sum_{i,u\triangleq g \in S_{iu}} (X'_{iu} + X_{iu})/Max\{RC_{ug}\} \geq 1, \forall \ S_{iu} \quad (3.3)$$

$$X'_{iu} \geq Y'_{iu} \cdot \frac{\sum_{j \in S_{iu}}((ANDC)_{gj} \cdot RC_{ug})}{\frac{MMu}{D}}, \forall \text{ S}_{\text{iu}} \quad (3.4)$$

$$Y'_{iu} \leq \ Y'_{i}, \forall \text{ i,u} \quad (3.5)$$

$$Y'_{iu} \in \{0,1\}, Y'_{i} \in \{0,1\}, X'_{iu} \in N$$

<u>Where</u>

X'_{iu}: new types of stationed units of type “u” (naval and/or air) at the activated facilities “i”

Y'_{iu}: a binary variable that takes the value of 1, if a new type unit of type “u” is stationed at base “i”, 0 otherwise.

OC_i: Overhead Costs for activating base “i”

OC_u: Overhead variable costs for operating unit type “u”

VC_u: Direct variable operating Costs of type “u” asset per mile

AA_u: Available Assets of (naval or air) type “u”

M: a sufficiently large number – larger than the number of the appropriate type “u” unit required to handle the daily average number of type “g” distress calls within their effective area S_{iu} around base “i”

RC_{ug}: Required Capacity of type “u” asset to deal with the type “g” incident

$Max\{RC_{ug}\}$: Required Capacity of type “u” asset to deal with the type “g” incident within S_{iu} with the highest capacity requirement

Constraint (1) sets the limit for the available assets. In the case of helicopters, it refers to the ones assigned to each facility on top of the ones assigned with resolving the previous model. So, for constraints (3.1) that refer to air assets, we need to subtract the number of the helicopters we assigned to each base based on the previous model. Constraint (3.2) ensures that we don't assign any new units to inactive bases. Constraint (3.3) and (3.4) ensure that all incident areas "j" within the S_{iu} are supported by at least the required number of at least one type "u" asset (based on the type of incident "g" that has the maximum capacity requirement for the specific asset) stationed at any location "i". For this constraint and for the air units only we need to take into account even the units X_{iu} we calculated from the previous model. Constraint (3.5) correlates the binary variables Y'_{iu} and Y'_{i}.

d) Last, we have the case of the incidents of lower criticality that can be dealt with effectively by not responsive assets, such as naval units. We are still considering the already located air and naval assets from the above models and we place new naval units, only if there is a positive trade-off in utilizing new naval units. The positive trade-off can still be estimated by the distance to the demand point and the variable cost (direct and overhead) of utilizing each asset. We are inserting binary variables Y''_{i} and variable X''_{iu} for only the new potential facilities and types of units respectively. If there are helicopters available, we can consider them in the model in the same way as in the previous model. Thus, the model follows a similar formulation:

$$\sum_j \sum_{i,u \triangleq j} ((OC_i) \cdot Y_i'' + (OC_u) \cdot X''_{iu} + (ANDC)_j \cdot d_{ij} \cdot Y''_{iu} \cdot (VC_u) \cdot \sum_{u,g} (RC_{ug})) \quad (4)$$

s.t.:

$$\sum X''_{iu} - \sum_{i: facilities\ from\ case\ (C)} X'_{iu} - \sum_{i:\ facilities\ from\ case\ (B) only, u: air} X_{iu} \geq RA_u$$

$\forall$ u (4.1)

$$X''_{i,u} \leq M \cdot Y_{iu}'' \tag{4.2}$$

$$\sum_{i,u \triangleq g \in S_{iu}} (X''_{iu} + X'_{iu} + X_{iu}) / Max\{RC_{ug}\} \geq 1, \forall \; S_{iu} \tag{4.3}$$

$$X''_{iu} \geq Y''_{iu} \cdot \frac{\sum_{j \in S_{iu}} (ANDC)_{gj} \cdot RC_{ug}}{\frac{MMu}{D}}, \forall \; S_{iu} \tag{4.4}$$

$$X''_{i,u} \leq M \cdot Y''_{iu} \tag{4.5}$$

$$Y''_{iu} \leq \; Y''_{i} \; , \forall \; i,u \tag{4.6}$$

$$Y''_{iu} \in \{0,1\}, Y''_{i} \in \{0,1\}, X''_{iu} \in N$$

Where

RA_u: Remaining Assets of (naval or air) type “u”

13. A SPECIAL CASE SCENARIO: BUILDING THE SAR ORGANIZATION FROM THE BEGINNING

In the first part of this thesis the importance of viewing the SAR organization holistically and discussing the various trade-offs involved was presented and analyzed. However, in the above models the existence of several constraints (maximum available number of assets, types and capabilities of existing assets etc.) may prevent these trade-offs from appearing vividly and are limiting us from reaching the "optimal" solution. So, for academic reason, it is appropriate to consider what the optimal location would have been in the case of building the organization from scratch, without any budget constraints.

Even though this appears to be a fictitious scenario, it is more than an academic interest. Seeking out this "optimal" solution could equip us with a guide; a benchmark case against which we can compare our current plan and deployment. This provides potential benefits, as we will discuss in the "performance metrics" chapter.

Case (a) already follows this scenario, so it will not be further analyzed. For the remaining cases, we need to include the purchase cost of each unit in the objective function and add new binary variables Y_j for the activation of each facility as we did in case (c) in the previous chapter (the case that refers to the upper right corner of the criticality diagram in Figure 5). The purchase cost of each unit is added to the rest of the overhead costs and used as coefficient. The constraint of the availability of units is also removed.

As a sidenote we need to mention that all objective functions discussed deal with costs now. Even the distance coefficient in case (b) needs to be converted to variable costs coefficient. This does not interfere with the objective of responsiveness, since lower direct variable costs and proximity to demand are highly correlated. Thus, the formulations are adjusted in the following ways:

(b) $Min \sum_j \sum_{i,u \triangleq j}((OC_i) \cdot Y_i + (OC_u) \cdot X_{iu} + (ANDC)_j \cdot d_{ij} \cdot Y_{iu} \cdot (VC_u))$ (5)

s.t.:

$\sum_{i,u \triangleq j} X_{iu} \geq 1, \forall$ j (5.1)

$X_{iu} \geq Y_{iu} \cdot \frac{\sum_{j \in S_{iu}}(ANDC)_j}{\frac{MMu}{D}}$, ∀ S_{iu} (5.2)

$X_{i,u} \leq M \cdot Y_{iu}$ (5.3)

$$Y_{iu} \in \{0,1\}, X_{iu} \in N$$

(c) Min $\sum_j \sum_{ji,u \triangleq j}((OC_i) \cdot Y_i' + (OC_u) \cdot X'_{iu} + (ANDC)_j \cdot d_{ij} \cdot X'_{iu} \cdot (VC_u))$ (6)

s.t.:

$X'_{i,u} \leq M \cdot Y'_i$ (6.1)

$\sum_{i,u \triangleq g \in S_{iu}}(X'_{iu} + X_{iu})/Max\{RC_{ug}\} \geq 1$, ∀ S_{iu} (6.2)

$X'_{iu} \geq Y'_{iu} \cdot \frac{\sum_{j \in S_{iu}}((ANDC)_{gj} \cdot RC_{ug}))}{\frac{MMu}{D}}$, ∀ S_{iu} (6.3)

$Y'_{iu} \leq Y'_i$, ∀ i,u (6.4)

$$Y'_{iu} \in \{0,1\}, Y'_i \in \{0,1\}, X'_{iu} \in N$$

(d) $\sum_j \sum_{i,u \triangleq j}((OC_i) \cdot Y_i'' + (OC_u) \cdot X''_{iu} + (ANDC)_j \cdot d_{ij} \cdot X''_{iu} \cdot (VC_u))$ (7)

s.t.:

$X''_{i,u} \leq M \cdot Y_i''$ (7.1)

$$\sum_{i,u \triangleq g \in S_{iu}} (X''_{iu} + X''_{iu} + X_{iu})/Max\{RC_{ug}\} \geq 1, \forall S_{iu} \quad (7.2)$$

$$X''_{iu} \geq Y''_{iu} \cdot \frac{\sum_{j \in S_i} (ANDC)_{gj} \cdot RC_{ug}}{\frac{MMu}{D}}, \forall S_{iu} \quad (7.3)$$

$$Y''_{iu} \leq Y''_{i}, \forall i,u \quad (7.4)$$

$$Y''_{iu} \in \{0,1\}, Y''_{i} \in \{0,1\}, X''_{iu} \in N$$

The above models, being linear, can be resolved on excel solver. Attached with the thesis the solution of a conceptual version of model (2). The parameters of distance and the expected number of incidents at each area are conceptualized due to lack of statistical data and due to security reasons. The attached spreadsheet is included to show that the models have been tested and verified. In the attached model a matrix is included that helps define which "j" areas are supported by which combinations of bases "i" and units "u". This matrix helps us define the summations $\sum_{i,u \triangleq j}$

Taking into consideration all the models introduced in this and the previous chapter, we would like to point out that there is a variable that is not explicitly expressed in the objective function, but it certainly plays a role on the solutions: the operational speed of each unit. This speed defines the area S_{iu}, which results in adding more terms in the objective functions (more "d_{ij} terms introduced), in changing the existing parameters in the objective function (since it affects the variable costs in cases (c) and (d)) and also in changing the right - hand side of some constraints.

Therefore, parametric analysis is required. The models could be resolved several times to determine the best operational speed for each unit. This can be accomplished with the help of sensitivity analysis based on duality. As it was already mentioned, by modifying the area S_{iu}, more terms are added in the objective function and the values of existing ones change. Also, this change along with potential changes in the processes (such as changing the capacity of the available units, their maximum number of missions per day etc) and the expected number of incidents also affect the matrix and right hand side of inequalities/constraints. Sensitivity analysis could provide us with the allowable changes range. Reduced cost and dual prices help estimate how much the objective function will be improved based on each change. Solving the models for each allowable change range could provide us with a mixture of potential solutions based on our parameters assumptions and it will help us focus on modifying the parameters that provide the largest benefit at the lowest cost.

14. METRICS AND KEY PERFORMANCE INDICATORS

"All models are wrong, but some are useful" George Box

We need to highlight that we did not aspire to come up with the perfect models for demand forecasting and the location of assets. Such pursuit is unrealistic and a waste of time. But the above – prescribed models can set the foundations for continuously improved decisions on the location of the assets for our service chain. Having recognized that it is impossible and impractical to predict all the variables and prescribe the perfect model, we need to establish both metrics and Key Performance Indicators (KPIs) related to the location of the assets.

We need to bear in mind that metrics should be set sparingly, only if they provide value, since they come at a cost and might overwhelm the decision process. Metrics track and provide data on the facility - related processes of the SAR organization and thus, help us feed our models with correct input, as well as identify areas where process improvements could lead to gains, based on our models. KPIs help us evaluate whether our model - based decisions lead to efficient improvements on the service level (along the efficiency – responsiveness curve), the strategic objective of our organization, and provide us with feedback to reevaluate and improve our models.

According to the American Production and Inventory Control Society (APICS), the association for supply chain management, five attributes of the Supply Chain Operations Reference (SCOR) model are most important to success[14], all of which are affected by the location of assets:

a) Reliability: The ability to perform tasks as expected. Reliability focuses on the predictability of the outcome of a process.

b) Responsiveness: The speed at which tasks are performed and at which a supply chain provides products to the customer.

c) Agility: The ability to respond to external influences and respond to marketplace changes to gain or maintain competitive advantage.

d) Cost: The cost of operating the supply chain processes.

e) Assets: The ability to use assets efficiently

Out of these attributes reliability could be characterized as the most important one and can be measured with a single metric: the percentage of missions that were dealt with the most appropriate asset effectively within the required timeframe. This metric is equivalent to the "Perfect Order Fulfillment (POF)" metric. Even though this metric can really depict the effectiveness of our chain, it is complex and challenging to collect and connect the appropriate data.

So, we need to break it down to its different component metrics, which coincide with other important attributes: responsiveness and asset utilization. Essentially, we are calculating the percentage of incidents that happened within the effective radius of an active asset and the percentage of these assets that corresponded to the criticality of that incident. Then we multiply both. We need to point out that as far as the performance metric for the facilities is concerned, we are not calculating the incidents that were reached within the required timeframe, but the ones that are within the effective radius.

In terms of asset utilization, we need to measure the naval capacity utilization; the percentage of active naval assets (not undergoing maintenance) that are being underutilized over the year. This can be an indicator for overcapacity for routine and low criticality incidents. We notice that we do not need to concern ourselves with this metric for helicopters, since inefficiencies for such high-service level assets are not only unavoidable, but also welcome.

As far as the agility is concerned, we are concerned with the effectiveness of our chain in case of suboptimal weather conditions either at a facility or at the area of an incident (which upgrades the criticality of the incident) and in case of emergency failure. We could run simulations with such cases and check the percentage of the effectiveness of the solutions to our OR models. We could even compare these effectiveness rates with the ones achieved by the “optimal” solution described in the previous chapter.

When it comes to costs, we could use the same comparison could be applied when checking the cost attribute. Specifically, we could compare the cost of operating our chain within one year with the costs incurred in case we had used the “optimal” solution. These comparisons could help us make decisions about developing our service chain towards the “optimal” solution. Apart from these comparisons, we can also keep track of the incidents that were dealt with a most costly asset than necessary (helicopter). We then need to examine the reasons for such response. If it was due to a lack of an activated naval facility nearby, we might need to reevaluate our models.

As far as other metrics are concerned, we need to focus on the ones that have input in our models. In fact, performing a sensitivity analysis on our models can guide us to focus on the binding constraints and on the coefficients that can have an impact on the solution, if changed. These in turn, can be translated to the appropriate metrics to focus on. Such metrics could refer to costs, such as calculating the overhead costs, lifecycle costs etc. Other metrics refer to time, such as the setup, idle time, maintenance cycle time, or the effective range of the assets and thus their coverage area. All these metrics change the right - hand side of the constraints and the objective functions parameters, but not all influence the optimal solution. By determining the binding constraints and focusing on the corresponding metrics can lead us to improving the necessary processes.

Finally, and most importantly, we need to keep track of the various types of demand patterns, their distribution and variation.

15. CONCLUSIONS – SUGGESTIONS

From our analysis the following conclusions can be drawn, which can in turn act as fundamental suggestions for further improvements in our modelling approaches:

a) The demand pattern model may appear complicated, but its power does not lie in its ability to predict the location of the incidents accurately, but rather in the fact that takes into account correlation and causation of incidents. Further cooperation with other organizations (tourism bureau, health organizations, shipping companies etc) and use of analytics tools will be necessary to improve the modelling approach and its output.

b) It was implied that we use average numbers for peak demand. This was a simplification. Each type of accident follows a unique distribution and has its own variation. Instead of picking the average number for each type of accident, we could pick the number that covers the desired number of standard deviations from the average, based on the desired service level. We could even create scenarios for different service levels, solve the OR models for each one, run simulations based on the demand type distributions, as well as weather conditions, and then make decisions on our planning. Our decisions would have to balance out the desired service level for each type of incident, the capacity inefficiencies (based on the variation and criticality of each type of incident), the maintenance cycle of the assets (having extra capacity could contribute to lean maintenance processes) and available budget.

c) Correspondingly, the OR models for the facility location problem may appear simple, but each one serves a different objective, since its input is different, based on our customer – centric demand modelling. Also, applying tailoring and prioritization ensures that responsiveness and efficiency are satisfied appropriately.

d) Additionally, we need to consider demand fluctuation over time. The solutions to the models prescribed above can be considered as our baseline strategic planning. We need to periodically review our models and reallocate our assets using dynamic programming models. This medium-term planning process can effectively be aligned with maintenance planning and allocation of assets in such way that streamlines asset utilization. For these short and mid-term planning, we do not consider lifecycle costs and costs for activating the facilities. We could consider costs for transferring the assets, if applicable (remember: for the allocation of the air assets we do not consider fixed costs for the activation of facilities, since we are mainly concerned with maximum responsiveness and optimal utilization).

e) Resolving the OR models could in fact be time consuming and cumbersome; there is a lot of data involved. Investment in supply chain modelling and business intelligence software is strongly encouraged. We need to highlight at this point that these advanced types of software do not render our work vain. The framework suggested can constitute the foundation upon which AI software builds on.

f) Sensitivity analysis and the dual problems can help us focus on the appropriate metrics. The suggested metrics in turn and our KPIs can guide us through the whole process of revisiting, re-evaluating and improving our models and also focus on improving the necessary processes.

g) Similar trade-offs exist between air and ground forces SAR assets. So, the same principles apply, and the same approach can be followed to deploy air assets in alignment with ground forces assets.

16. FURTHER RECOMMENDATIONS

We notice that the models receive improved input and can in turn provide improved feedback, when we expand the scope of our chain to include not only the whole SAR organization functions, but other organizations as well. Other organizations can thus be considered as part of our service chain, as suppliers of information. This information encompasses not only demand patterns, but also:

a) Lifecycle costs of the assets, such as the fixed costs they impose on the organization, their variable costs, their residual value, as well as renting costs.

b) Maintenance schedule and times.

c) Human resources capabilities and needs.

This systemic approach could benefit our analysis of the SAR organizations as a service supply chain.

The OR tools and Supply Chain Management principles can in turn contribute to decision making in a variety of issues, including but not limited to:

a) (Re)designing the network of the chain: where should mother-bases and maintenance centers be located, what their roles should be, whether we should establish mixed bases and where. These are some of the decisions concerning the network design.

b) Process optimization: whether and how applying lean management and theory of constraint could lead us to focus on the processes that need improvement, as well as establish the appropriate KPIs.

c) Whether we should expand our chain to embody insurance companies: such addition could provide both financial resources and improved information flow to the chain and contribute to its efficient management. Any changes to the priorities of distress calls that this modification might incur could be counterbalanced by the increased capacity achieved by the increase in resources, as well as by the increased management efficiency.

d) Maintenance planning

e) Reallocation, purchasing and disposal of assets

f) Asset inventory optimization based on economical inventory quantity of repairable items.

Establishing the afore mentioned decision - making processes and incorporating a broad spectrum of organizations in such processes is not an easy task. For an organization such as HAF, it might require radical changes through disruptive change management.

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