PROPOSAL OF A MATHEMATICAL MODEL FOR OPTIMIZING RESOURCES IN MARINE SAR SERVICES

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ABSTRACT

When planners determine the dimensions of a means of transport, for example a regular shipping line that is going to join two or more ports, they estimate numerically the relation between the populations joined. This means that they must study and quantify the people and/or goods that are going to be moved from one point to another in accordance to certain parameters. Consequently, they will indicate to the Shipping Company the number of ships and frequency of sailings that must be established to offer an effective service and make the operation profitable. In the same way, it is possible to establish the relation between accidents and an efficient marine Search and Rescue service, according to a series of parameters determined beforehand. In this work an important population will consist of a zone where many serious accidents take place, and for that reason it will be necessary to give this area suitable coverage. Thus, the resources used for rescue must be located near the demand, considering that the means available are never limitless. This apparently simple problem becomes more complicated when we consider a number of different zones and take into account the different kinds of casualties that occur in each one, as well as the number and nature of the means to be employed. In this paper we propose a mathematical model that allows us to relocate SAR resources following the previous criteria. We have made use of gravity models . These mo dels assess the alternative locations according to their proximity to or distance from the accidents, as well as using corrective coefficients that measure, among other things, the suitability of present infrastructures in the location at issue and the relevance of the casualties.

1. Introduction.

As Lee says, essentially, a model is a representation of the reality. It is usually a simplified and generalized statement of what seems to be the most important characteristics of a real world situation. It is an abstraction from reality which is used to gain conceptual clarity. The value of a model is that it can be used to improve our understanding of the ways in which a system behaves in circumstances where it is not possible to construct or experiment with a real world situation .

To formulate a model it is necessary to reduce a phenomenon to its fundamental lines. That is to say, we realized a simplified representation that, though it does not correspond in its entirety to the reality, allows us to translate the phenomenon into a symbolic - logical language by means of equations or statistical laws.

This way, for example, when a planner determines the dimensions of a regular line of passengers for joining two or more ports, he establishes the interrelationship among the united populations. It means that he is going to study and to establish the number of persons that are going to move every day from each port to the others, according to a few parameters. In consequence, he will indicate to the ship-owner the appropriate ships and schedules adapted to offer an effective service that makes profitable the exploitation of this line.

The same way, it is possible to investigate the interrelationship between the accidents and a SAR service. In this case, a planner must choose among alternative locations for the SAR ships and helicopters. In this model an important population will consist of a zone where place many and severe accidents take place, and for such reason it will be necessary to give her a suitable coverage. This way, SAR resources will be located where the interrelationship (attraction) between the accidents and the rescue resources is maximum, bearing in mind that the available means are never unlimited.

2. Gravity models.

Gravity models have probably been used in planning and transport studies more than any other form of mathematical model. Gravity models have been used during decades to analyze the interaction among several urban areas and they are named this way because the concept of human interaction can be assimilated to Newton's gravity concept. The simplest version of the gravity model can be represented mathematically this way:

$$I_{ij} = G\frac{P_i P_j}{d_{ij}^{b}} \qquad (1)$$

Where:

Iij is the interaction between areas i and j.

Pi, Pj are the sizes of areas i and j.

dij is the distance between areas i and j.

b is a power or exponent applied to the distance between areas.

G is a constant, which is empirically determined, and is used to adjust the relationship to actual conditions. Once calculated, this constant expresses the intensity of the interaction amongst any of the areas in which the region object of study has been divided. This value of G depends on current conditions.

Therefore, gravity models allow estimating the interactions among the different areas in which the region object of study is divided. These models are also applied to the development of indicators that evaluate alternative locations, as the different situations for one bus stop or a station of train and, why not, indicators destined to compare the alternative locations of SAR resources.

3. The gravity models as models of location: problems and limitations.

This paper will center on the following points: Absence of a sound theoretical base; the need for disaggregating; the form of the distance function; the importance of zoning and the problem of calibration.

3.1 Lack of a theoretical solid base

Schneider affirms: There is no real kinship between a gravitational field and a trip generating system . Other authors have developed theoretical explanations of the gravity model using information theory and entropy maximizing methods, but we consider that are not adequate explanations of the gravity model in behavioral terms.

As the models of regression, the gravity models are capable of describing satisfactorily the interaction, but they do not explain it. Its attention does not center in what is happening, but in the result of what has happened, summarizing the information to describe the current situation.

Summarizing, it can be said that:

a) The results of the model are not acceptable when changes are produced in the system object of study.
b) Since the laws of the system are unknown, it is not possible to know whether it will change.

3.2 Disaggregating gravity models

It is obvious that these models were designed to account for the behavior of large groups of people, assuming that the behavior of large groups is predictable because the idiosyncrasy of the individuals tends to be cancelled out. The sample to which we apply the model has to be numerous and homogeneous. This way, the behavior of the population can be predictable on the basis of mathematical probability, being diluted the influence of the exceptional behaviors. In other way, the exceptional behaviors do not have to be representative in the set of the sample. When an exceptional behavior is sufficiently representative it is converted into a subgroup of population who must be treated apart from the rest.

When we deal with maritime accidents, it is evident that we must treat separately those fleets with accident rates related to homogeneous circumstances. One initial approximation to this question invites to treating separately the merchant fleet, from pleasure boats and fishing vessels. We can understand better this question with an example: The summer arrival produces an increase in the accidents of the pleasure fleet but not so on the others. Large SAR tugboats are not required to give assistance in incidents related to the pleasure fleet. The treatment of the information related to all three fleets together could lead to trying to keep operative during the summer a number of tugboats greater than necessary.

3.3 The distance function

The distance is used as the impedance variable. Nevertheless, it is evident that simple distance is not a sufficiently accurate measure of the effects of spatial separation. In case of maritime SAR, the time of arrival to the place of the disaster is a more significant variable than distance.

The exponent to be applied to the time factor needs to be changed for different salvage purposes, according to the cause of the assistance (It is not the same thing to be an hour late when human lives are in danger than when they are not). It is easily understood that the exponent not only has to change depending on the cause of the assistance, but also with the distance. This way, for example, we can consider a constant exponent until the radio of action of the SAR vehicle is reached. Once it has been surpassed, the value of the exponent would become infinite.

3.4 Zoning problems.

The use of spatial interaction and location models implies that the region under study has been divided in areas or zones. In practice, zoning systems are generally arbitrary, though the definition of zones is important for model performance.

The maritime accidents taking place in the same zone are grouped together as a unique entity (one weight and one location). That is to say, the model treats equally all the accidents grouped in the same zone.

A large number of zones (small areas) complicate calculations. A small number of zones (large areas) remove precision from the model, provided that it treats equally accidents with very different locations.

3.5 Problems of calibration.

Calibration is the process that allows finding the values of the parameters; it is to say, G and the exponents of the distances or times. These values provide the best adjustment between the model s performance and the fields measurements which gather the behavior of the real world system.

The most common evaluation consists of applying a method of comparisons with different values of the parameter and to select that one that facilitates the better adjustment . Here the problem of the predi ction arises. The parameters are correct for the current situation, but they do not have that to be in the future.

4. Hansen s gravity/potential model.

Hansen developed one of the earliest examples of the use of gravity models in planning situations. His model of location was designed to predict the settlement of population, and was based on the hypothesis that accessibility to employment is the principal factor that determines the above mentioned settlement of population. Hansen considers that the relationship between the increase of the population in the zone i and the present employment in the zone j can be expressed by means of an index of accessibility that would be calculated this way:

$$A_{ij} = \frac{E_j}{d_{ij}^{b}}$$

Where:
Aij is the accessibility index of zone i in relation to zone j.
Ej is the total employment of the zone j.
dij is the distance between zones i and j.
b is an exponent or power of dij.

This one is the expression of the accessibility of the zone i in relation to zone j. The general index for the

$$A_i = \sum_j \frac{E_j}{d_{ij}^b}$$

Hansen admits that, besides the accessibility, a fundamental factor exists in the fixation of the quantity of population who feels attracted by a certain area, this factor is the available area for residential uses. He called this the holding capacity of a zone and thinks that both factors can be combined calculating an index of development potential , which is obtained multiplying the index of accessibility by the hol ding capacity. The resultant index of a zone, Di, is therefore:

$$Di = Ai\ Hi$$

Where: Hi is the holding capacity of zone i. The development potential can considered to be a measurement of the attractiveness of a zone, based on access to employment and in the available area for housings. The population is distributed in zones of agreement with relative development potential of each one of them, that is to say, the development potential of each zone divided by the total potential:

$$\frac{A_i H_i}{\sum_i A_i H_i}$$

Hansen suggested that the share of total population growth, which will be obtained by each zone, is related to how attractive that zone is in relation to all the competing zones. If the total growth in population is Gi, then the amount of that growth going to any zone i will be:

$$G_i = G_t \frac{\left(A_i H_i\right)}{\sum_i A_i H_i}$$

This provides an instrument of assignment of the population which application is relatively easy. It can be used to test the effects of different hypotheses. The figure shows a flowchart that contains the sequence of calculations for the Hansen model..

5. Formulation of the model.

The problem dealt with by the authors of this paper tried to evaluate the spatial distribution of the maritime SAR resources which cover the coasts of Northern Spain. Therefore, we faced a wide maritime region and a large number of ports and alternative airports.

We elaborated a database with the location of the maritime accidents, information about the implied vessels, the type of incident, their causes, meteorological conditions, human and material loses, together with the means of salvage that were used, whether they belonged to the Spanish SAR Service (SASEMAR) or to neighbor countries.

Our work aimed to redistributing SAR means in an optimum way. To achieve this task, we evaluated different alternative locations.

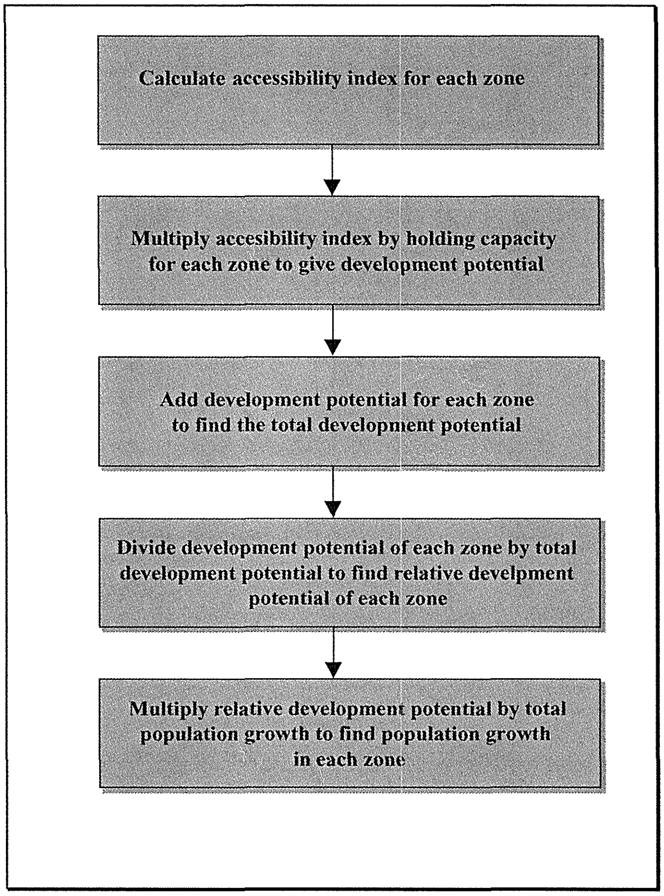

Fig. 1 - Flowchart for Hansen model

The model we propose is a modification of Hansen's model. Our model evaluates each of the resources separately (fast rescue boats, rescue tugboats and helicopters). This point of view is due to the fact that we can use different ports for the location of the different resources.

5.1 Assignment of weight

Maritime accidents were classified as belonging to four different types attending to their relevance: very serious, serious, moderate and slight. This information was stored in the database as an integer ranging from 1 to 5.

Relevance = f(no. deceased, no. injured, no. rescued, vessel value, cargo value)

In terms of gravity models, we assigned some weight to the accidents. Said otherwise, we are thinking that the intervention of the means of salvage is more valuable in some cases that in others.

The weight of the accidents has in our model a role equivalent to which the employment has in Hansen's model. The assignment of weight to the different accidents is carried out by means of an expression which arguments are included in the different fields of the database. In this article we do not include the detailed formula provided that we do not try to enter into such levels of concretion and, besides, we are quite sure that any reader will be able to obtain a number of different algorithms for such formula.

When every accident has been assigned a weight, we must distribute such weight between the different SAR resources: helicopters, tugs and fast rescue boats.

This distribution of fast rescue boats and helicopters is based in estimating the urgency in the intervention. The greater the urgency, the greater the weight assigned to the helicopter. Also the weight of the helicopter increases when the state of sea worsens or, for example, grounding has taken place in places inaccessible from the coast. This assignment is inverted in favor of the boats when the accident is placed in estuaries, ports or in free close waters. The ranging carried out helped us greatly in this aspect

Large tugboats were only assigned a significant weight when towing vessels or extinguishing large fires that surpassed the capacity of the light crafts was required.

So that, to assign weights we employed the fields of the database, and placed the accidents, one by one, on the nautical chart.

5.2 Zoning.

The gravity model might be applied accident by accident. However, this way of proceeding would imply calculating distances between every accident and the different locations of the salvage resources. Calculations can be simplified if we divide in zones the waters object of study.

On the other hand, as we have seen above, the assignment of weight between the helicopter and the boat is dependent on their location. In this way, not all the accidents are treated equally in the model. It is, therefore, essential to delimit some zones. These zones must be composed by regions in which we can treat the accidents in a homogeneous way.

The accidents that took place in each of these zones were grouped in a super accident . The weight of this one was obtained adding those of the respective accidents. In the oceanic regions the situation of the super accident is calculated as a weighted average of the latitudes and longitudes corresponding to the accidents which took place in the area. In coastal waters we must analyze the weighted average and, if it is necessary, we must divide the zone. Super accidents which took place in ports or estuaries were lo - cated on the geographical center of such areas.

At open sea, zone sizes are greatest. Small zones lead to unnecessary calculations. On the other hand, too large zones lead to treating equally accidents that should be dealt with separately.

Maximum size of the oceanic zones depends on the type of SAR source. A zone must be a sea region with such a size to allow access to any of its points in homogeneous conditions. In other words, the size of the zone has to be small in comparison with the radio of action of the SAR vehicle.

For the application of our model we divided the coast of the Bay of Biscay and Galicia (Northern coast of Spain) in 207 zones for the fast rescue boats and 34 for the tugboats and helicopters.

We can apply regression analysis to forecast the future needs of salvage resources for each zone.

5.3 Accessibility.

Following the steps of Hansen's model, we may calculate accessibility now. With that in mind, let s place a SAR vehicle in a location i. The following expression evaluates the ability with which this SAR source gains access to the accident from the above mentioned location:

$$Ai = \sum_j \frac{Pj}{t_{ij}}$$

Ai is a coefficient that measures the value of a SAR vehicle placed in a certain location.
Pj is the weight of the super accident placed within reach of the above mentioned SAR resour ce.
tij is the time of arrival to the super accident .

The values of t will always be over a minimum that will depend on vehicle in question. This way, we limit the importance that the model grants to those mishaps that take place in the surroundings of location i.

Access time calculation is carried out using distances measured on the nautical chart and typical vehicle speeds. When these are maritime, way points are established along the coast in order to obtain credible tracks with a minimum of calculations.

5.4 The capacity of group and the potential of development.

The grouping capacity of Hansen's model is translated to our model as suitability factor . This factor, from 0 to 1, tries to evaluate the advantages and disadvantages of the infrastructures associated with the location at question. In case of the fast rescue boats, this factor takes into consideration the number of days when the port remains closed by bad weather, as well as the land traveling time up to a well equipped hospital.

For tugboats, the suitability factor depends on the days that the port remains closed due to bad weather and also its possible restrictions of draught. The autonomy of the tugboats allows them to go far out of their bases and tow the assisted vessel to any suitable port.

The bases proposed for the helicopters are all airports, with a suitability factor equal to one. Obviously, helicopters can take off from her bases and can land near the best hospital.

One we have obtained the suitability factors, a numeric estimation of the value of locating any SAR vehicle in i location is expressed by:

$$Di = f\,Ai$$

5.5 Assignment of the means of salvage to the different locations.

From this moment on, the nature of our problem requires us to separate our model from that of Hansen's. Hansen's model does not raise any restriction to the possibility that the population desert certain zones. In the case of maritime SAR, we can not accept that SAR resources be concentrated in zones with a greater number of casualties, while others are left unattended.

We also observe that the settlement of the population does not affect the distribution of the employment. Nevertheless, in the case of SAR, the assignment of a resource to a location supposes that several zones remain attended, and we must disregard these zones at the time of assigning the following source.

Our way of proceeding solves these questions. First, we calculate the *Di* values taking into consideration the totality of super accidents . A fast rescue boat, a rescue tugboat or a helicopter is assigned to those locations that clearly stand out of the set. The attended zones from these locations are removed from the sample, and the values of *Di* are calculated again. The process is repeated until all areas are attended.

When all zones are covered, the remaining salvage resources are assigned in accordance with the initial *Di*.

6. Conclusion.

Our model distinguished the merchant, fishing and pleasure fleet when the weight of the accident was distributed among the different salvage resources. It is evident that an accident of a merchant vessel does not need the same means than another accident in which only a light craft is involved.

We think that the model does not answer correctly to the seasonal variation of different factors. Fundamentally, it would be convenient that the model took into consideration the summer increase of the activity of pleasure boats and also that during summer time most ports remain open 100 % of the time (there exists, so, a seasonal variation of the suitability factor).

We recommend therefore that the model should be applied twice. Once for the summer time, and the other for the rest of the year. Our experience indicates that this way of proceeding leads to that in summer some fast rescue boats are moved toward minor ports. These ports are bad winter bases, but they allow better SAR operations to summer users.

We have revised the location of the SAR resources in the Northern coast of Spain, and we have concluded that there is a reasonable distribution of the means. We must only emphasize that the superposition of responsibilities leads to an accumulation of SAR resources at the main ports, which in many cases are redundant.

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