The Weighted Fuzzy Barycenter:
Definition and Application to Forest Fire Control in the PACA Region

Julio Rojas-Mora, UMR Espace CNRS, Université d'Avignon et des Pays de Vaucluse, Avignon, France & Institute of Statistics, Universidad Austral de Chile, Valdivia, Chile

Didier Josselin, UMR Espace CNRS, Université d'Avignon et des Pays de Vaucluse, Avignon, France

Jagannath Aryal, School of Land and Food, University of Tasmania, Hobart, TAS, Australia

Adrien Mangiavillano, CEREN, Gardanne, France

Philippe Ellerkamp, UMR Espace CNRS, Université d'Avignon et des Pays de Vaucluse, Avignon, France

ABSTRACT

In this paper, the authors present a methodology to solve the weighted barycenter problem when the data is inherently fuzzy. This method, from data clustered by expert visual inspection of maps, calculates bi-dimensional fuzzy numbers from the spatial clusters, which in turn are used to obtain the weighted fuzzy barycenter of a particular area. The authors apply the methodology, to a particularly apt data set of forest fire breakouts in the PACA region of southeastern France, gathered from 1986 to 2008, and sliced into five periods over which the fuzzy weighted barycenter for each one is obtained. Two weighting schemes based on fire intensity and fire density in a cluster were used. The center provided with this fuzzy method provides leeway to planners, which can see how the membership function of the fuzzy solution can be used as a measurement of "appropriateness" of the final location.

Keywords: *Barycenter, Forest Fires, Fuzzy Sets, Location Problem, Robustness*

INTRODUCTION

Forest fire detection and surveillance management rely on historical data that record fire occurrence for a long time. In practice, firemen know that fire outbreak and its subsequent spread are related to local environmental characteristics as well as the population distribution and road network layout. Although it is difficult to model, foresee and prevent fires, fire fighting efficiency highly depends on the time needed to respond to an event; positioning resources in a way that minimizes the time of response is of crucial importance in areas

DOI: 10.4018/ijaeis.2013100103

where fires arise more frequently. Nevertheless, there remains a strong uncertainty about where a fire can appear, and even the data is imprecise, being vague about the location of a wildfire. This calls for methods to take into account the associated uncertainty, for instance using a fuzzy sets framework, as we propose in this article.

It is important to study the evolution of the center of outbreaks for forest fire managers who look after the logistics in such incidents. It can show, in a very simple way, the stability of the underlying process of forest fires outbreaks and how natural and human changes affect it.

At the scale on which we have worked, space can be considered almost as isotropic and the distance separating the center from a fire is Euclidian. Thus, we propose to search an optimal center location within a continuous two-dimensional space, using historic data on forest fire breakouts. This paper can also be seen as following a line of research that searches for the geographic center of a region, weighting points with a variable that most of the times is population (Kumler & Goodchild, 1992; Enedy, 1993; Zhao & Chung, 2001; Bureau, 2001; Aboufadela & Austin, 2006).

In a more formalized point of view, the problem handled belongs to the optimal location problem frame (Hakimi, 1964; Nickel & Puerto, 2005) and more precisely can be defined as the *1*-facility optimal discrete location problem for a set of discrete demand points in a continuous space (Labbé, Peeters, & Thisse, 1995; Shan, 2005). In this field of the operations research, most studies deal with three well-known metrics from the L*p*-norm family: the *k*-median, that models the L*1*-norm (minimizing the sum of Euclidian distances), the *k*-center, that models the $L\infty$ -norm (minimizing the maximum distance) and, between those, the gravity center, that models the L*2*-norm (minimizing the sum of the squared Euclidean distances). It is known that the relation between the damage caused by a fire due to its size and the time or the distance to access to its location is not linear, but exponential (Rasbash, Ramachandran, Kandola, Watts, & Law, 2004). Nevertheless, our problem is not in the context of active fire surveillance, but only ex-post evaluation of the fire outbreak process. The L2-norm was chosen because is assumes all the fires to be equal in the center location definition, which fits our objective.

The application of GIS in studying the forest fire problem was implemented from different perspectives ranging from hill fire impact (Fung & Jim, 1998), mapping fire regime across time and scale (Morgan, Hardy, Swetnam, Rollins, & Long, 1999) and spatial data for national fire planning and fuel management (Hardy, Schmidt, Menakis, & Sampson, 1999). In particular, the control of forest fires has been a subject of research in which the application of GIS has been recurrently used (Erten, Kurgun, & Musaoglu, 2002; Vakalis, Sarimveis, Kiranoudis, Alexandridis, & Bafas, 2004). Nevertheless, only traditional operations research methods, like the *k*-median and *k*-center, are implemented in commercially available GIS software to solve the optimal location problem.

However, in practice as well as in research, due to constraints presented by the crisp nature of these well know methods, it is necessary to assume that data has a crisp shape, even when it was gathered in a fuzzy way that mixes both uncertainty and subjectivity. Hence, the solution obtained by the process is "accurate" and "crisp", even when our dataset is far away from this definition. We present a methodology that, while based on the principles of the classical optimal location problems, considers demand points as fuzzy bidimensional points, incorporating this uncertainty in the foundation of the optimal location problem. This change induces uncertainty in the distance between fuzzy points, affecting the solution of the problem, which is no longer a point, but a fuzzy bidimensional point, i.e., an area in which every point has a value from a membership function. An extension of the weighted barycenter to the fuzzy sets theory, that we call a "weighted fuzzy barycenter", is the solution that we define and apply in this paper.

We use the Provence-Alpes-Côte d'Azur (PACA) region of France as case study to solve