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Strategic locating of refuges for extreme heat events (or heat waves)

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ABSTRACT

Public cooling centers are a recommended component of heat management plans aimed at reducing morbidity and mortality during extreme heat events. Access to air conditioned space is known to reduce health risks associated with heat exposure, it is not known if these facilities are well positioned to serve those who are vulnerable to heat. Other public air-conditioned spaces such as indoor shopping malls, libraries, and movie theaters are also recommended. Placement of official cooling centers near these types of facilities provides redundant coverage. As a constrained resource, these facilities could be better located in areas where other heat relief options are limited. We explored the distribution of two public cooling center networks (Los Angeles County, CA and Maricopa County, AZ) and found that significant fractions of the networks were located in areas with abundant, publically available, air-conditioned spaces Instead of allowing the networks to develop in an ad hoc nature, location analysis should be used to site a potentially life-saving resource more effectively. Using a new iterative method of the maximal covering location problem, we identified potential facilities that improve access for those who are more susceptible to heat without access to potential alternatives and identified locations for network expansion.

1. Introduction

With increasing evidence of climate change, cities are developing response and management plans to mitigate potential impacts (Rockefeller Foundation, 2016). In addition to the direct impacts to infrastructure (Neumann et al., 2015), there is also a significant concern for how climate change and the increasing frequency, intensity and duration of extreme weather events will affect people (Epstein, 2005; Haines et al., 2006; Huang et al., 2011; McMichael and Lindgren, 2011). Hurricanes, tornadoes, and coastal storms are widely recognized for their destructive potential but there is also a growing concern for the impact that rising average temperatures and future heatwaves will have on public health (Luber and McGeehin, 2008). Health impacts resulting from heat exposure can range from mild discomfort and fatigue to death (Stafoggia et al., 2006). In addition to known heat-related clinical syndromes, environmental heat stress is also known to exacerbate existing medical conditions leading to increases in hospitalizations and mortality (Schwartz, 2005; Stafoggia et al., 2006) (Schwartz, 2005; Stafoggia et al., 2006). Extreme heat events, in particular, are associated with higher risks of negative heat-health outcomes. Though there is no universal definition of an extreme heat event, they can be generally described as “periods of summertime weather that are substantially hotter and/or more humid than typical for a given location at that time of year” (U.S. EPA, 2006). Heat management plans and programs are being implemented in many cities

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across the United States to reduce public health risks. Of particular concern is the US Southwest, where heat forecasts are particularly severe and populations are growing quickly (Bartos and Chester, 2014). There is indirect evidence that heat-health warning systems which couple early warnings with emergency response measures reduce heat related mortality but there have been concerns as to whether they are adequately reaching those who are at the greatest risk of negative health outcomes (Bassil and Cole, 2010; Ebi et al., 2004; Widerynski et al., 2017). While the characteristics of vulnerable groups vary between locals, groups at higher risk often include the elderly, those living in poverty and those with preexisting medical conditions (Li et al., 2015).

The most important physical resource in reducing heat-health consequences is cooled space (Kovats and Hajat, 2008). Air-conditioning has been shown to be an important protective factor and the prevalence of in-home units has increased but there are many places (e.g. older neighborhoods and temperate climate cities) where it is still uncommon in residential buildings (Braga et al., 2001; Curriero et al., 2002; Kaiser et al., 2001; O'Neill et al., 2005). In response to known disparities in access to in-home air-conditioning (Fraser et al., 2016), cities across the United States have developed networks of public cooling centers to provide heat refuges (Berisha et al., 2017; Nayak et al., 2017; Widerynski et al., 2017).These facilities help the public to escape the heat. Cooling centers are often sited at public libraries, senior citizen centers, and community based organizations (Fraser et al., 2016). However, while these centers can help reduce health risks, there is no evidence that quantitative methods have been used to site these facilities. Everyone is vulnerable to heat but there are particular population subsets that are more likely to experience negative health outcomes when exposed to extreme temperatures (Eisenman et al., 2016; Harlan et al., 2013; O'Neill et al., 2005; Reid et al., 2009; Weisskopf et al., 2002). The strategic placement of these facilities should consider underlying characteristics (age, ethnicity, economic status, etc.) of nearby communities that contribute to higher risks of heat-health incidents.

Official cooling centers are meant to serve as the air-conditioning alternative for those who may not have access to or are unable to use in-home air-conditioning. There are, however, questions regarding their utilization and overall effectiveness of these centers. A recent report from the U.S. Center for Disease Control and Prevention (CDC) summarizes existing peer-reviewed and grey literature assessing cooling centers and the related behavior of vulnerable populations during periods of extreme heat (Widerynski et al., 2017). The highlighted studies focused primarily on cooling center networks and citizens in U.S. and Canadian cities. The implementation and use of cooling centers as part of “heat health warning systems” differ by location (one of the purposes of the CDC report is to provide standardized recommendations for implementation) but there were several common threads that emerged within the literature. First, there is a general acknowledgement that public cooling centers are underutilized. Potential barriers to their use identified by various studies include lack of knowledge of cooling centers, lack of transportation, fear or inability to leave home, individuals not self-identifying as heat vulnerable, and a negative stigma associated with cooling centers. It was suggested by several studies that cooling center use is driven by the primary function of the center (e.g. library or senior center) rather than its designation as a cooling center. Lastly, individuals seeking out air-conditioning also use public alternatives instead of official cooling centers such as shopping centers and movie theaters. Seeking out these other public spaces is also recommended the CDC, NOAA, and local public health agencies. To improve the effectiveness of cooling centers in mitigating heat-related death and illness, continued research is needed to address these and other unknown barriers to use. This research sheds light on facility locations relative to where vulnerable populations live within cities and proximity to other alternatives which may contribute to underutilization.

To this end, this paper outlines a method to improve the siting of official cooling center facilities. We employ methods from the field of location science which deals with siting facilities in geographic space to best meet a specified objective(s) (Church and Murray, 2009). To address the siting of public cooling centers we utilize methods associated with a specific class of location science problems known as maximal covering location problems (Church and ReVelle, 1974). The study addresses the following: i) how can disparate and large datasets describing neighborhood level heat vulnerability and residential level access to public air-conditioned space be used to site cooling centers more effectively, ii) how well are the existing cooling center networks positioned to serve vulnerable populations and those without access to alternatives, iii) what geographic areas, and more specifically which facilities, should each county target to expand their network of cooling centers? The research focuses on Los Angeles County, CA and Maricopa County, AZ due to their large existing networks of cooling centers, a public health emphasis on reducing heat morbidity and mortality, and data availability.

2. Methods and materials

To address the research questions, a location analysis mathematical method is employed. In general, location analysis problems use linear and non-linear programing to site facilities in order to optimize some objective. Various models have been utilized to strategically locate both private and public facilities including warehouses, airline hubs, restaurants, schools, fire stations, and emergency medical services. In the private sector the location of a facility influences the firm's ability to compete in the market place and in the public sector, facility location influences the efficiency with which public services are provided (Current et al., 2001). The selection of a particular model for application depends on the context of the specific location analysis problem considered (see (Church and Murray, 2009; Owen and Daskin, 1998; ReVelle and Eiselt, 2005) for detailed descriptions of location analysis problem classes and implementation).

To select an appropriate model for locating cooling centers, the context of their use was considered. Cooling centers are meant to be utilized during periods of extreme heat because exposure to extreme heat is a known health hazard. There are a number of exposure pathways, but one that is critical to understand when siting cooling centers is mobility-based exposure. For those who utilize active modes of transportation, such as walking, accessing a cooling center requires exposure to a hazard that cooling centers are meant to protect against. It is well documented in the literature that the elderly and those living in poverty are among the most vulnerable populations to heat and are also among the groups with the greatest lack of access to an automobile (U.S. DOT FHWA,