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# A Florida County Locates Disaster Recovery Centers

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In 2001, the Federal Emergency Management Agency (FEMA) required every Florida county to identify potential locations of disaster recovery centers (DRCs). The DRCs are to be opened and staffed by FEMA personnel, subsequent to any declared disaster. The Emergency Management Division of the Alachua County Department of Fire/Rescue Services sponsored a project to identify potential DRC sites. The project team used a mathematical analysis tool called **the covering location model** in a two-stage approach to find, recommend, and have accepted DRC locations. The “stage 1” approach gave three idealized DRC locations requiring each residence in the county to be within 20 miles of the closest DRC. Next, the team relaxed the 20-mile requirement and identified locations close to the “stage 1” locations that also satisfied evaluation criteria not included in stage 1. The “stage 2” results provided significant improvements to the original FEMA location criteria, while maintaining acceptable travel distances to the nearest DRC.

*Key words:* facilities, equipment planning; location; programming; integer.

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The Federal Emergency Management Agency (FEMA) is the US government agency responsible for dealing with large-scale disasters. Disasters can include floods, tornadoes, hurricanes, large-scale fires, and terrorist attacks. After a nationally declared disaster, FEMA typically opens disaster recovery centers (DRCs) in the area affected. The DRCs serve as temporary offices to provide recovery assistance to victims. Services include finding temporary housing, financing home rebuilding, and obtaining various other types of financial aid. In addition, representatives from state offices, local government, and volunteer organizations offer services to the community. The duration and magnitude of services offered at each DRC varies with the scale and impact of the disaster.

In 2001, FEMA required every county in Florida to identify potential DRC sites; Alachua County was required to identify at least three. FEMA would use these sites, should an emergency of sufficient magnitude occur. Therefore, the county was to make arrangements for using the sites on a contingency planning basis.

## Formulating the Problem

Alachua County is located in north-central Florida and has a population of about 219,000. Of 67 Florida counties, Alachua County is the 20th largest in population. Its only large town is Gainesville, with a (city limits)

population of about 96,000. The east-west and north-south dimensions of the county are approximately 32 and 30 miles (51.52, 48.3 km), respectively; the land area is about 874 square miles (2,266 km<sup>2</sup>).

The first three listed authors (Dekle, Lavieri, and Martin) undertook a study to determine DRC sites for Alachua County as undergraduate students in a senior-level design course in the Department of Industrial and Systems Engineering at the University of Florida. They, *the team*, received support of various kinds from Francis, the design course instructor, and Emir-Farinas, a PhD student writing a dissertation on demand-point aggregation for covering-location problems under Francis' direction. Kenneth Allen, a senior planner for the Emergency Management Division of the Alachua County Department of Fire/Rescue Services, was the project sponsor.

As part of the design course, the team members were required to complete a project using their accumulated knowledge and skills. One team member contacted the county and discussed potential projects; the team explored them and selected the DRC location project. The team member had several phone discussions with Allen before the team met him to finalize the scope of the project and select an objective. The team provided periodic updates to Allen and when the project was finished, delivered a report and made a formal presentation of its recommendations. In addition, the team had periodic meetings with Francis and with Emir-Farinas to learn more about location modeling.

One of our first steps in the project was to consider FEMA's requirements for a DRC. FEMA provided a one-page form to identify three DRCs for Alachua County. The form listed the following requirements for recommended DRC locations:

- at least 2,000 square feet of floor space,
- access for the disabled,
- heating and air conditioning,
- not in a flood plain,
- phone and fax lines,
- restroom facilities, and
- adequate parking.

The form identified no overall objective, and made no mention of travel times needed for DRC users. Accordingly, in the course of the study, the team and the local sponsoring agency identified several impor-

tant additional extra criteria for potential DRCs:

- adequate road access,
- easy to find or well-known buildings,
- adequate building security, and
- reasonable travel times for DRC users.

The team and the sponsor discussed at length the choice of a principal objective from the following proposed objectives:

- (1) minimize the average travel distance to a closest DRC,
- (2) minimize the maximum travel distance to a closest DRC,
- (3) minimize the total number of DRCs needed, subject to each county resident being within a distance/radius  $r$  of a nearest DRC, and
- (4) maximize the probability that at least one DRC will be useable following a disaster.

After much discussion, the sponsor chose objective (3); this objective defines a problem called a **covering-location problem**. This choice left open the question of what value of distance/radius  $r$  was appropriate. The team could not identify a value of  $r$  a priori. Therefore, it proposed to solve the problem for three possible choices of  $r$ : 10, 15, and 20 miles (16.1, 24.2, and 32.2 km). The covering radius figure of 20 miles exceeds half the largest of the  $x$  and  $y$  dimensions of the county and resulted in three DRCs (the minimal number required). There thus seemed no point in exploring a radius figure exceeding 20 miles. The other two radii, 10 and 15 miles, seemed like reasonable, simple, and smaller alternative choices. The choices were basically subjective and provided a variety of solutions to assist the sponsor in making a good choice of DRC locations.

Most of the project effort went into obtaining and analyzing the data. The principal data sources came from GIS data available from the university library and from the county property appraiser's office. These files are accessible with ArcVIEW, a GIS software. The county data was indexed by parcels of land. The information available for each parcel included the number of buildings, the total heated square footage of the buildings, whether buildings are commercial or residential, and the  $x$  and  $y$  coordinates of the parcel center. The county data included about 6,600 parcels, of which as many as 3,900 seemed usable for DRC sites: they had public or commercial buildings whose total square footage exceeded 2,000 square feet.

The team, under the guidance of Emir and Francis, sought a good way to deal with all the evaluation criteria and the covering problem (objective (3) above). With unlimited resources, we could have examined each parcel physically to identify those meeting all the criteria. This choice, along with all the parcel/demand point data, could then have been used to identify the input data for the covering problem. Due to limited resources, we decided to use a two-stage process to help make the problem manageable. In stage 1, we would solve the idealized covering location problem, temporarily disregarding most of the evaluation criteria. Once we knew the optimal solutions from stage 1, we obtained information about buildings close to these locations from local residents and emergency management staff. These buildings were then graded based on the combined evaluation criteria from FEMA and the county. Effectively, stage 1 provided in-the-ballpark approximate solutions that were refined in stage 2.

To grade buildings on how well they met the FEMA criteria, the team, in conjunction with the sponsor, devised what amounted to a building grade card. The building/site grade card considered the following five categories: security, safety and condition of the building, accessibility, site requirements, and equipment. Each category had subcategories. The sponsor assigned a weight to each subcategory, and we assigned a grade between 0 and 4 (bad to good) to each subcategory. Each grade was then multiplied by its weight and the sum of products totaled to obtain a total grade card score, normalized to a number between 0 and 100.

The team created  $x$  and  $y$  coordinates of buildings with good grades, plotted the locations relative to all the demand points, and carried out supplementary analysis (Tables 1 and 2). The team members realized that the final solutions found in stage 2 might not meet all the covering conditions but believed that, overall, they should be satisfactory, particularly as the covering conditions were basically soft constraints.

We give the mathematical representation of the covering-location model as an integer program (IP) in the appendix. The geometric interpretation of our covering model is to place a minimum number of identical spatial units on a map of the county so that

Disaster recovery center performance measures	Travel limit radius		
	10 miles	15 miles	20 miles
Maximum travel distance (miles)	10.9	15.1	20.3
Average travel distance (miles)	4.9	9.1	7.6
% parcels within travel limit radius of a center	99.78	99.96	99.92
Average distance in excess of travel limit for parcels farther from any center than the travel limit (miles)	0.184	0.84	0.184

**Table 1:** The table shows how some disaster recovery center performance measures change with travel service limits of 10, 15, and 20 miles, respectively, for the idealized stage 1 disaster recovery center locations. The idealized locations were found disregarding the supplementary building/site grade-card criteria.

each customer's location is covered by at least one spatial unit (Figures 3 and 4). With Euclidean distance, the unit would be a circle of radius  $r$ . However, in our case, the distance measures were for traveling on grid-like road structures. Thus, a more realistic measure of distance is rectilinear. The spatial unit for rectilinear distances is a diamond (a square of diagonal length  $2r$  whose edges make  $45^\circ$  angles with the axes).

The earliest paper we know of on this sort of location problem is Hakimi's (1965). Toregas et al. (1971) gave an integer-programming formulation for the covering problem and suggested linear programming with branch and bound as a solution technique. Since 1971, many researchers from various disciplines have done research in this area (for reviews, see Schilling 1980, ReVelle 1989, Marianov and ReVelle 1995).

Disaster recovery center performance measures	Travel limit radius		
	10 miles	15 miles	20 miles
Maximum travel distance (miles)	14.0	25.8	26.94
Average travel distance (miles)	4.86	6.76	7.36
% parcels within travel limit radius of a center	97.7	89.8	97.4
Average distance in excess of travel limit for parcels farther from any center than the travel limit (miles)	1.05	2.80	2.55

**Table 2:** The table shows how some disaster recovery center performance measures change with travel service limits of 10, 15, and 20 miles, respectively, for the actual stage 2 disaster recovery center locations. The performance measures shown were somewhat worse than those of stage 1, but the actual locations scored well on a supplementary building/site grade-card criteria. The solution for 20 miles was implemented.

## Problem Analysis and Aggregation

From county property tract records and using a geographic information system, the team created data for an initial computerized version of the covering model which required a *covering table* with a row for each parcel and a column for each possible site, resulting in about 6,600 rows and 3,900 columns (about 25,740,000 table entries). This covering table was too large to be tractable with the model IP solver, Excel, the team wished to use. Therefore, the sites and customer locations had to be aggregated. While it would have been possible, using software not available to the team, to solve the 6,600 by 3,900 problem, we recognized that aggregating the model to a smaller size with an acceptable loss of accuracy would not only make it easier for us to solve but would also demonstrate that industrial practitioners could readily use the same aggregation methods. An easy problem for the team to solve would also be an easy problem for practitioners. Therefore, the problem provided a vehicle for testing various aggregation ideas then under consideration.

Its wide availability, familiarity, and user-friendliness made the Excel IP solver a very attractive option. The standard version of the Excel IP solver had substantial limitations. The maximum number of columns the covering table could have was 200. Therefore, we wanted to reduce the number of potential sites to at most 200. The solver imposes no limit on the number of rows of a covering table. However, in our experience, the computation time increases tremendously as the number of rows increases. Hence, to reduce the computational burden, we needed to reduce the size of the covering table. **Because of the loss of information, doing so would also introduce some aggregation error.**

The only studies we know of on aggregation for the covering-location problem are Current and Schilling's (1990) and Daskin et al.'s (1989). Current and Schilling identify some errors caused by aggregating the covering problem and give some aggregation rules to eliminate some of these errors. Daskin et al. focus on aggregation error for the maximal covering-location problem. Francis et al. (1999) review aggregation approaches to a variety of location models.

To aggregate the demand points as well as the potential DRC sites, we used the following **pick-the-farthest (PTF) algorithm**. The algorithm has an

aggregation error parameter  $b$ . If aggregate demand points are picked according to PTF with termination distance  $b$  and the centers are located according to the aggregated problem, then **the distance from any demand point to its nearest center cannot exceed the covering radius  $r$  plus  $b$** . Hence, even if the analyst violates some covering constraints, he or she controls the amount of violation.

### Pick-the-Farthest (PTF) Algorithm

**Step 0.** Start with an arbitrary demand point and put it in the aggregate demand point set  $Q$ .

#### Repeat

**Step 1.** Pick the demand point that is farthest from a closest demand point in  $Q$ . Let this farthest distance to  $Q$  be  $d$ .

**Step 2.** If the distance  $d$  is greater than the aggregation error parameter  $b$ , put the demand point into  $Q$ . **Until** the distance  $d$  is less than  $b$ .

Dyer and Frieze (1985) introduced PTF with a different termination criterion (stop when  $Q$  has  $p$  elements) to obtain a 2-approximate problem for the  $p$ -center problem. Emir-Farinas and Francis (forthcoming) developed some a priori aggregation error bounds for this algorithm, building on results by Francis and Lowe (1992) and Zemel (1985).

Another reason for our interest in PTF is that the aggregate demand points it produces are well dispersed. This means that any solution to the aggregated problem would not place two DRCs very close to each other. This has two advantages: first, should a disaster occur, the probability that it would affect more than one DRC site is reduced. Second, even though a solution with two DRCs close to each other might provide the same quality of service as a solution with well-dispersed centers, members of the public might view a more dispersed solution as being more equitable.

We sought the minimal error parameter  $b$  that would give less than 200 aggregate demand points. After some study, we decided on  $b = 1.5$  miles. With  $b = 1.5$  miles, we reduced the number of demand points from 6,600 to 198 and the number of potential DRC sites from 3,900 to 162. **Therefore, the aggregation shrank the covering table approximately 802 times.**

Making  $x, y$  plots of all the parcels with the software Excel was quite helpful in visualizing the data



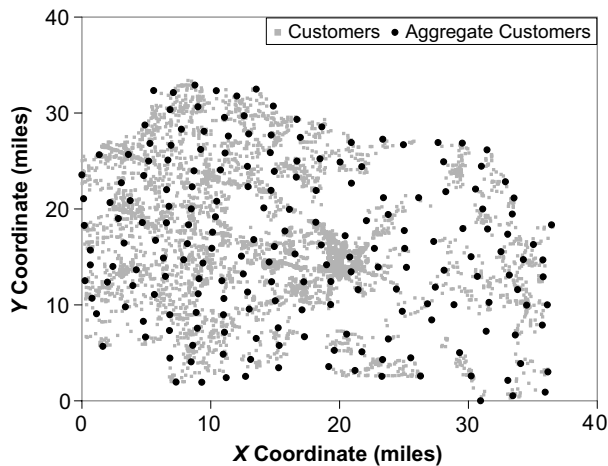


Figure 1: The small, background dots provide a plot of the approximately 6,600 potential disaster recovery center customers for Alachua County. The large black dots provide a plot of the 198 aggregated customers, thus giving a smaller, approximating location problem to solve.

and seeing how the parcels were distributed throughout the county (Figures 1 and 2).

## Findings

After solving the aggregated covering model, the team found that the minimal number of DRCs needed for  $r = 10, 15,$  and  $20$  miles was 8, 4, and 3, respectively (Figures 3 and 4, Table 1).

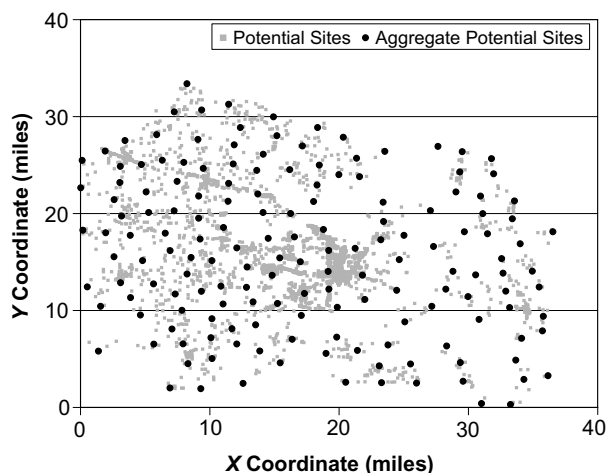


Figure 2: The small, background dots provide a plot of the approximately 3,900 potential disaster recovery center sites for Alachua County. The large black dots provide a plot of the 162 aggregated sites, thus giving a smaller, approximating location problem to solve.

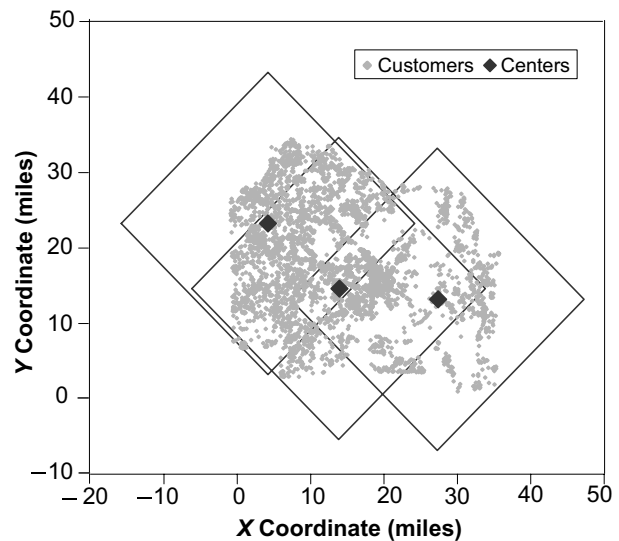


Figure 3: The small, background dots provide a plot of the approximately 6,600 customers for Alachua County. The small black diamonds provide a plot of three disaster recovery center locations; each is the center of a 20-mile radius travel service limit region depicted by the large black diamonds.

Beginning with the three idealized covering solutions, the team began stage 2 of the two-stage process; physical site inspections to find potential DRC sites close to the idealized solutions that scored well on

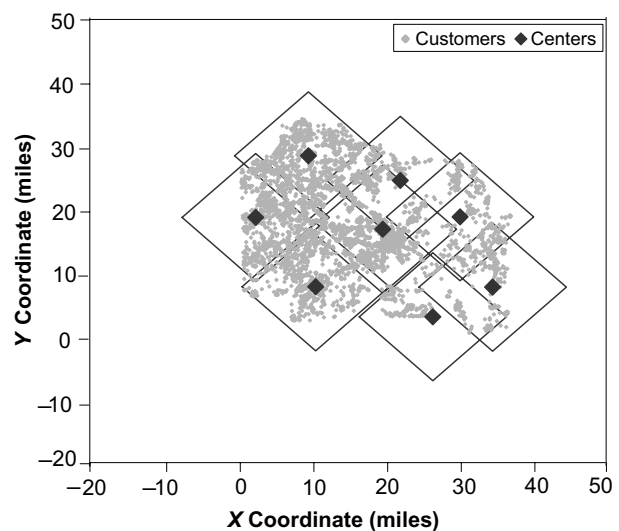


Figure 4: The small, background dots provide a plot of the approximately 6,600 customers for Alachua County. The small black diamonds provide a plot of eight disaster recovery center locations; each is the center of a 10-mile radius travel service limit region depicted by the large black diamonds.

all the listed evaluation criteria. The sites we recommended typically consisted of a mix of schools, recreation centers, churches, and the Gainesville Health Department. Aggregation criteria (Table 2) worsened only slightly between the ideal solutions of Table 1, which we did not evaluate with the grade card, and the three actual final solutions, which had good grade-card scores.

## Conclusions

After careful consideration, the team recommended and the sponsor accepted the three-DRC solution with a distance between each resident and a closest DRC of at most 20 miles. The sponsor was quite pleased with the work. In an evaluation letter, he commented as follows:

“The Florida Division of Emergency Management has requested that all county emergency management offices provide a list of at least three sites pre-identified as potential DRCs. With completion of this project, Alachua County is now able to comply with the request...”

Overall, this was an outstanding project which has provided the Office of Emergency Management with tangible results. When DRCs must be opened in the future, it will be based upon careful research and problem solving rather than guesses on which locations would be best.”

The county was prepared to open disaster recovery centers had the hurricanes that swept through Florida in 2004 created a disaster in Alachua County.

In summary, we obtained many insights during the project. It is easy to concentrate on a few aspects of a problem and ignore the entire problem. Doing so can lead to wrong conclusions about what is most important. We found it illuminating to work on an entire location problem. It puts into a new perspective many of the things we might otherwise dismiss or take for granted. We learned the following:

- (1) Sponsors may not have an overall objective.
- (2) The choice of a model may be somewhat subjective (soft).
- (3) Getting all the data can be most of the work.
- (4) Data aggregation may be necessary, and it can be effective.
- (5) Solving an idealized model can help.

(6) The model may not capture the entire problem.

(7) The covering model (via figures) was easy to explain.

(8) The well-dispersed locations of the covering model had the political and geographic advantages of redundancy.

## Appendix. The Covering-Facility-Location Model

The covering-facility-location problem is a well-known integer-programming problem with rows for customers and columns for possible sites. The  $A = (a_{ij})$  matrix has  $a_{ij} = 1$  (the entry in row  $i$  and column  $j$ ) if the (rectilinear) distance between customer  $i$  and potential DRC site  $j$  is at most  $r$ , and  $a_{ij} = 0$  otherwise. Let  $X = (x_j)$  be the vector of 0–1 variables, with  $x_j$  being 1 if site  $j$  is chosen and 0 otherwise. The problem is to minimize  $\sum_j x_j$  subject to  $AX \geq e$  ( $e$  is a vector of ones). If  $A$  has  $m$  rows and  $n$  columns, then  $AX \geq e$  is a system of  $m$  linear inequalities in  $n$  variables, with each entry in  $X$  being either 0 or 1.

The team assumed direct back-and-forth rectilinear travel between private residences (as represented by land parcels) and DRCs. This was a conservative assumption, because visiting a DRC as part of a multistop round trip would only decrease the travel time involving the DRC. Almost all of the Gainesville road network and much of the county road network is rectilinear. To have obtained more accurate distances would have required the use of, and familiarity with, a computationally intensive network model of the county road network.

The decision to use the Excel solver determined the value of the aggregation error parameter,  $b = 1.5$  miles, needed to obtain at most 200 demand points. Access to a solver allowing more demand points would have allowed using a smaller value of  $b$ . However, one can see from Figures 3 and 4, and Tables 1 and 2, that using 200 aggregate demand points led to little inaccuracy.

It is well known that  $p$ -center location problems can be solved by solving a sequence of covering-location problems. While the team concentrated on solving covering-location problems, the relationship to  $p$ -center problems was useful in that the covering locations, like  $p$ -center locations, were well dispersed among the demand points.

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Kenneth Allen, Emergency Management Coordinator, Alachua County Department of Fire/Rescue Services, Emergency Management Division, PO Box 548, Gainesville, Florida 32602, writes: “I am writing in regards to the senior project conducted by Erica Martin, Jamie Dekle, and Mariel S. Lavieri. The students worked to select sites which can serve as disaster recovery centers (DRCs). DRCs are facilities established in or nearby the community affected by a disaster, where people can meet face-to-face with representatives from federal, state, local, and volunteer agencies to obtain assistance. The completion of their project is a great assistance to this office.

“Their project is directly relevant to the functions of this office. After a disaster, this office is charged with coordinating response and recovery efforts. One

of many tasks after an emergency would be the selection of DRC sites. In fact, the Florida Division of Emergency Management has requested that all county emergency management offices provide a list of at least three sites pre-identified as potential DRCs. With completion of this project, Alachua County is now able to comply with the request.

“The students used a coverage-problem method to provide a list of possible DRC locations based upon three different travel limits. Additionally, the buildings they selected meet criteria mandated by FEMA for DRC locations. This office now has a list of facilities which maximize accessibility to the community and have been graded against FEMA acceptance standards.

“Hopefully, DRCs will not have to be opened again in Alachua County; however, that view is not realistic. Disasters can and do strike at any time in the state of Florida. By having a pre-determined list of DRC sites, this office can move quickly to open facilities which can help disaster victims recover sooner. Without this list, time would have to be expended locating and surveying potential sites after a disaster.

“Erica, Jamie, and Mariel were extremely dedicated to this project. From the beginning they took time to learn about emergency management in general and the specific functions of DRC. Also, they were willing to work around the hectic schedule of this office. During the course of the project the events of September 11, 2001 required staff to spend more time on domestic security planning in the community. The students cooperated by setting meetings around our schedules, having conference calls, and increasing their email use.

“Overall, this was an outstanding project which has provided the Office of Emergency Management with tangible results. When DRCs must be opened in the future, it will be based upon careful research and problem solving rather than guesses on which locations would be best.”