AD NUMBER

AD819125

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution: Further dissemination only as directed by Office of Civil Defense, Washington, DC, Jan 1967, or higher DoD authority.

AUTHORITY

OCD D/A ltr, 11 Jan 1972

RESEARCH PAPER P-310

ALLOCATING CONTESTED SPACE IN A REGIONAL MOVEMENT-TO-SHELTER SYSTEM: A CASE STUDY OF THE CENTRAL GULF COAST REGION

Grace J. Kelleher

January 1967

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

INSTITUTE FOR DEFENSE ANALYSES
ECONOMIC AND POLITICAL STUDIES DIVISION

[redacted]

This document may be further distributed by any holder only with specific prior approval of the Office of Civil Defense.

SUMMARY

This Paper focuses upon the problem of regional interactions in planning movement-to-shelter (MTS) systems. The MTS system envisaged in this research effort is one designed to move urban populations during crises to fallout shelters located in peripheral areas of low target interest. The system would provide fallout protection for both evacuees and permanent residents of the reception area and could be activated if and when the United States was faced with an impending nuclear attack.

Basic criteria are established for use in defining the areas to be evacuated and those to be used as MTS reception centers. The total area to be evacuated includes the urbanized area plus a buffer zone. The boundaries of the buffer zone are determined as follows: It is assumed that the MTS fallout shelters would be built or modified to resist 10-psi overpressure. At this hardness level, shelters located within only four miles of the urban target area would be reasonably safe from the blast effects of a 10-Mt weapon on the city. On the other hand, the same weapon on an MTS shelter system could damage normal (unhardened) structures as far as 10 miles away. Therefore, as a means of clearly separating population and industrial target values, a 10-mile buffer zone is applied. Under this planning criterion, one could expect that usable resources would be available for post-attack support of those people surviving either a direct or mixed attack in which population is targeted.

It was assumed that a distance of 50 miles measured from the edge of the urbanized area would be a practical outer bound for the reception region. The resulting 40-mile-wide annulus (50 miles minus the 10-mile buffer zone) was the basis for identifying potential reception areas. Possible military targets and otherwise unsuitable

land areas (swamps, etc.) were then deleted in identifying usable reception areas within the 40-mile annulus.

Applying these criteria to closely located cities such as those of the Central Gulf Coast Region, one soon encounters the problem of overlapping reception areas: those which could be claimed by two or more evacuating cities. This problem is resolved by use of a linear programming model (fully described in the Paper) which allocates regional reception space on an optimal basis. Its objective is to allocate evacuating population in a manner that will minimize the fatalities expected from nuclear weapons delivered upon the region.

The Paper also includes the results of a case study in which the above MTS criteria and the regional allocations model were applied to the Central Gulf Coast Region of the United States. This region encompasses the following urbanized areas: New Orleans, Mobile, Baton Rouge, Lake Charles, Port Arthur, Beaumont, Houston, and Galveston.

RESEARCH PAPER P-310

ALLOCATING CONTESTED SPACE IN A REGIONAL MOVEMENT-TO-SHELTER SYSTEM: A CASE STUDY OF THE CENTRAL GULF COAST REGION

Grace J. Kelleher

January 1967

INSTITUTE FOR DEFENSE ANALYSES
ECONOMIC AND POLITICAL STUDIES DIVISION

Contract OCD PS-66-113
Subtask 4131A

FOREWORD

The work reported in this Paper is part of a continuing effort in the analyses of alternative civil defense systems by the Economic and Political Studies Division, Institute for Defense Analyses, under Contract No. OCD-PS-66-113 (dated June 1966) with the Office of Civil Defense, Department of the Army. This Paper is specifically related to Task Number 4131A, Evaluation of a Crisis-Oriented Civil Defense System.[1]

This Paper focuses upon the problem of regional interactions in planning movement-to-shelter systems (movement of urbanized populations to peripheral fallout shelters). A model for use in making optimal population assignments to available reception areas is described. The objective of the model is to allocate personnel in a manner that will minimize the fatalities expected from a nuclear weapons attack upon the region.

I wish to acknowledge with appreciation important contributions to this Paper by other members of the Civil Defense Systems Project. James R. Storey assisted in the development of the localized planning approach (described in Section 2) and in its initial application to New Orleans. Edward S. Pearsall assisted in the development of the regional planning model by programming and testing the computational algorithm described in Appendix B. Thomas P. Cullen was principal research assistant on the regional MTS study and personally compiled many of the detailed results presented in this Paper; Sandra Fucigna and Jeffrey Cooper also assisted in earlier phases of the study.

---

1. IDA's total research effort under this Task Order is concerned with determining both the physical and economic feasibility of movement-to-shelter as an alternative civil defense system.

I am especially grateful to Dr. W. A. Niskanen and Mr. C. S. Lerner for their constructive comments on the draft version of this Paper.

Grace J. Kelleher

CONTENTS

FIGURES

TABLES

SUMMARY

This Paper focuses upon the problem of regional interactions in p‾ nning movement-to-shelter (MTS) systems. The MTS system envisaged in this research effort is one designed to move urban populations during crises to fallout shelters located in peripheral areas of low target interest. The system would provide fallout protection for both evacuees and permanent residents of the reception area and could be activated if and when the United States was faced with an impending nuclear attack.

Basic criteria are established for use in defining the areas to be evacuated and those to be used as MTS reception centers. The total area to be evacuated includes the urbanized area plus a buffer zone. The boundaries of the buffer zone are determined as follows: It is assumed that the MTS fallout shelters would be built or modified to resist 10-psi overpressure. At this hardness level, shelters located within only four miles of the urban target area would be reasonably safe from the blast effects of a 10-Mt weapon on the city. On the other hand, the same weapon on an MTS shelter system could damage normal (unhardened) structures as far as 10 miles away. Therefore, as a means of clearly separating population and industrial target values, a 10-mile buffer zone is applied. Under this planning criterion, one could expect that usable resources would be available for post-attack support of those people surviving either a direct or mixed attack in which population is targeted.

It was assumed that a distance of 50 miles measured from the edge of the urbanized area would be a practical outer bound for the reception region. The resulting 40-mile-wide annulus (50 miles minus the 10-mile buffer zone) was the basis for identifying potential reception areas. Possible military targets and otherwise unsuitable

land areas (swamps, etc.) were then deleted in identifying usable reception areas within the 40-mile annulus.

Applying these criteria to closely located cities such as those of the Central Gulf Coast Region, one soon encounters the problem of overlapping reception areas: those which could be claimed by two or more evacuating cities. This problem is resolved by use of a linear programming model (fully described in the Paper) which allocates regional reception space on an optimal basis. Its objective is to allocate evacuating population in a manner that will minimize the fatalities expected from nuclear weapons delivered upon the region.

The Paper also includes the results of a case study in which the above MTS criteria and the regional allocations model were applied to the Central Gulf Coast Region of the United States. This region encompasses the following urbanized areas: New Orleans, Mobile, Baton Rouge, Lake Charles, Port Arthur, Beaumont, Houston, and Galveston.

1

INTRODUCTION

The movement-to-shelter (MTS) system envisaged in this study is designed to move city populations during crises to fallout shelters located in peripheral areas of low target interest. The system would provide fallout protection for both evacuees and permanent residents of the reception area and could be activated if and when the United States was faced with an impending nuclear attack.

The research covered in this Paper is concerned with the problem of allocating population to the space available within a regional movement-to-shelter system. Criteria are established for use in defining the areas to be evacuated and those to be used as MTS reception centers (Section 2). Reception areas which could be claimed by two or more evacuating cities, and data required for resolution of the allocation problem, are identified (Section 3). Finally, a model for use in allocating regional reception space is described along with the results of a pilot study of the Central Gulf Coast Region (Section 4). By use of this model, the maximum post-attack density is minimized throughout the regional MTS system, subject to certain generalized time and distance constraints.

Cost constraints were not applied in this initial study as suitable cost estimates were not available. In allocating contested reception areas, it was assumed that per capita systems cost would not vary among reception areas according to evacuee origin or the distance to be traveled. Similarly, no attempt was made to evaluate the effectiveness of MTS against that of other possible defense measures; such analyses were deferred pending the availability of appropriate cost information.

To explore this problem by way of a pilot study, a group of cities were identified which contend only among themselves for the reception space available in a regional MTS system. The interaction problem can be bounded for such a group thus permitting the attainment of optimal solutions. The group of interacting cities[1] ultimately selected were Galveston, Houston, Beaumont, and Port Arthur, Texas; Lake Charles, Baton Rouge and New Orleans, Louisiana; and Mobile, Alabama. For MTS planning purposes, these cities comprise a closed region, spanning the Gulf Coast from Galveston to Mobile. A map of this region is given in Figure 1.

The data utilized in this Paper were obtained from the following sources:

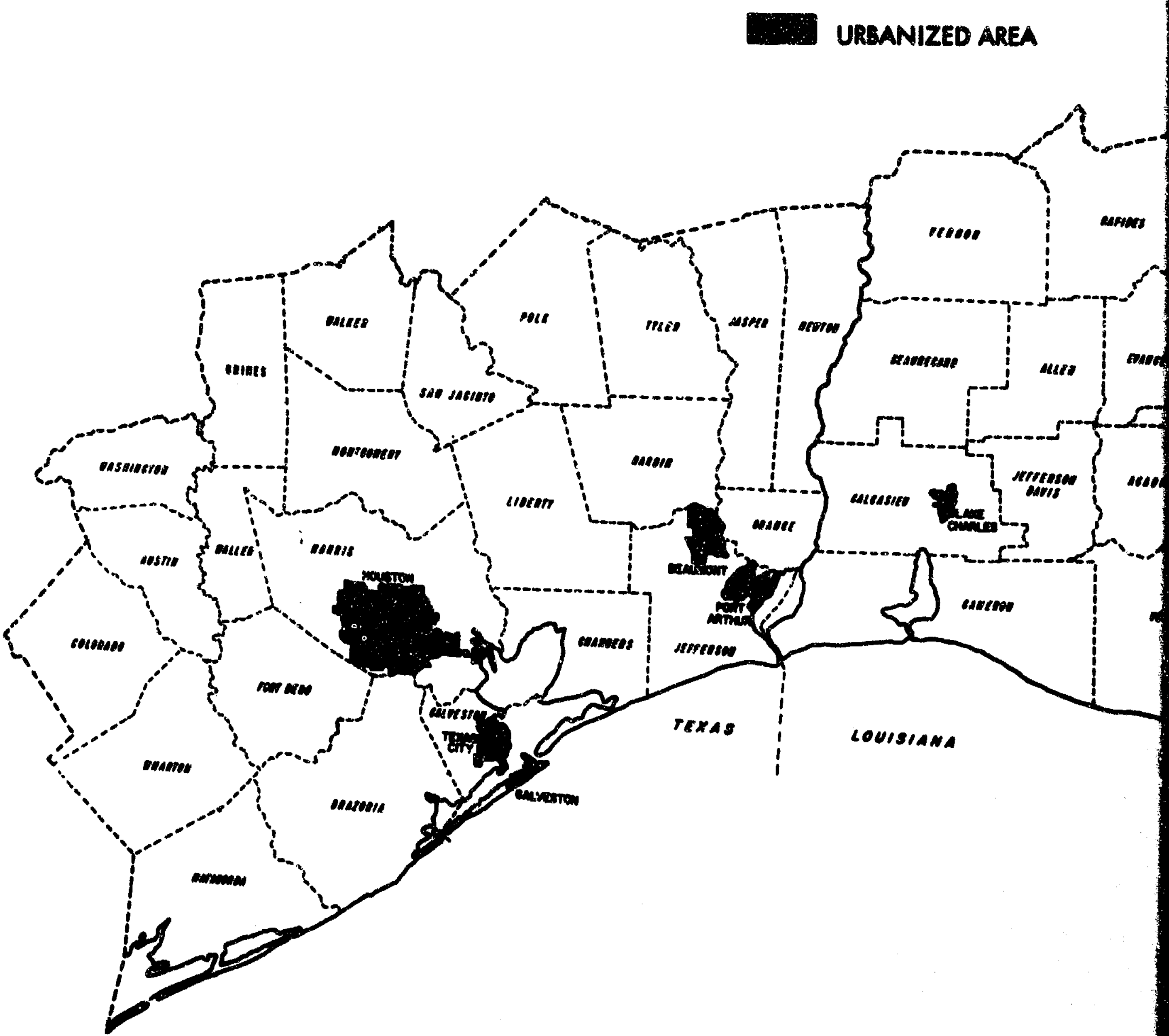
U.S. Department of Commerce, Bureau of the Census, 1960 Census of the Population, Volume I, Parts 2, "Alabama," 20, "Louisiana," and 45, "Texas," (Washington, D.C.: Government Printing Office, 1963).

________, _______, "Alabama: 1960" (No. 2, February, 1965) and "Texas: 1960" (No. 45, December, 1965), Area Measurement Reports, Series GE-20 (Washington, D.C.: Government Printing Office).

________, _______, County and City Data Book, 1962: Statistical Abstract Supplement (Washington, D.C.: Government Printing Office, 1963).

Encyclopedia Britannica World Atlas, Unabridged (Chicago: Encyclopedia Britannica Inc., 1958).

1. Census data for the "urbanized areas" corresponding to these cities were used throughout this Paper.


URBANIZED AREA
HOUSTON
BEAUMONT
PORT ARTHUR
LAKE CHARLES
TEXAS CITY
GALVESTON
TEXAS
LOUISIANA

URBANIZED AREA

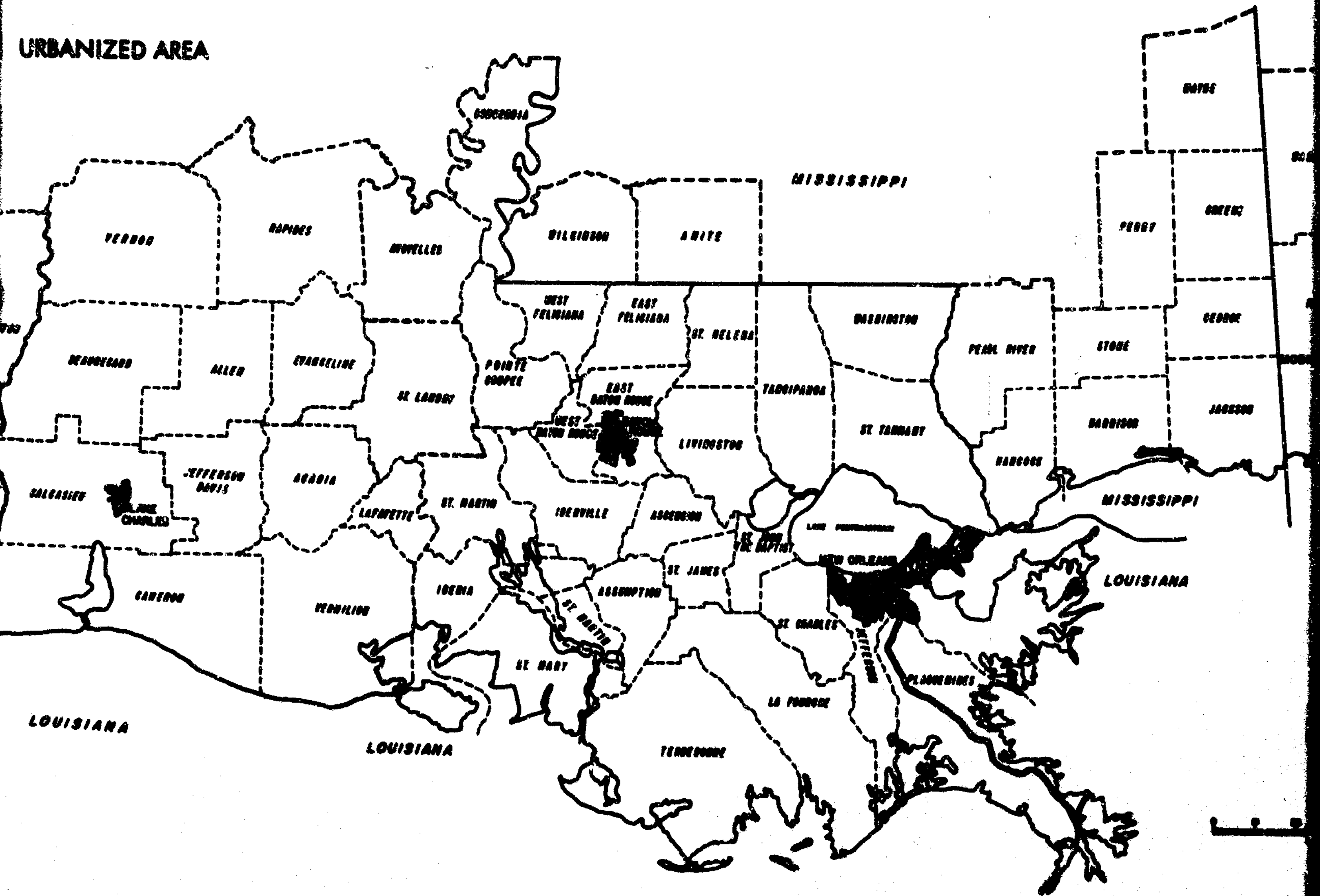


FIGURE 1. Cent

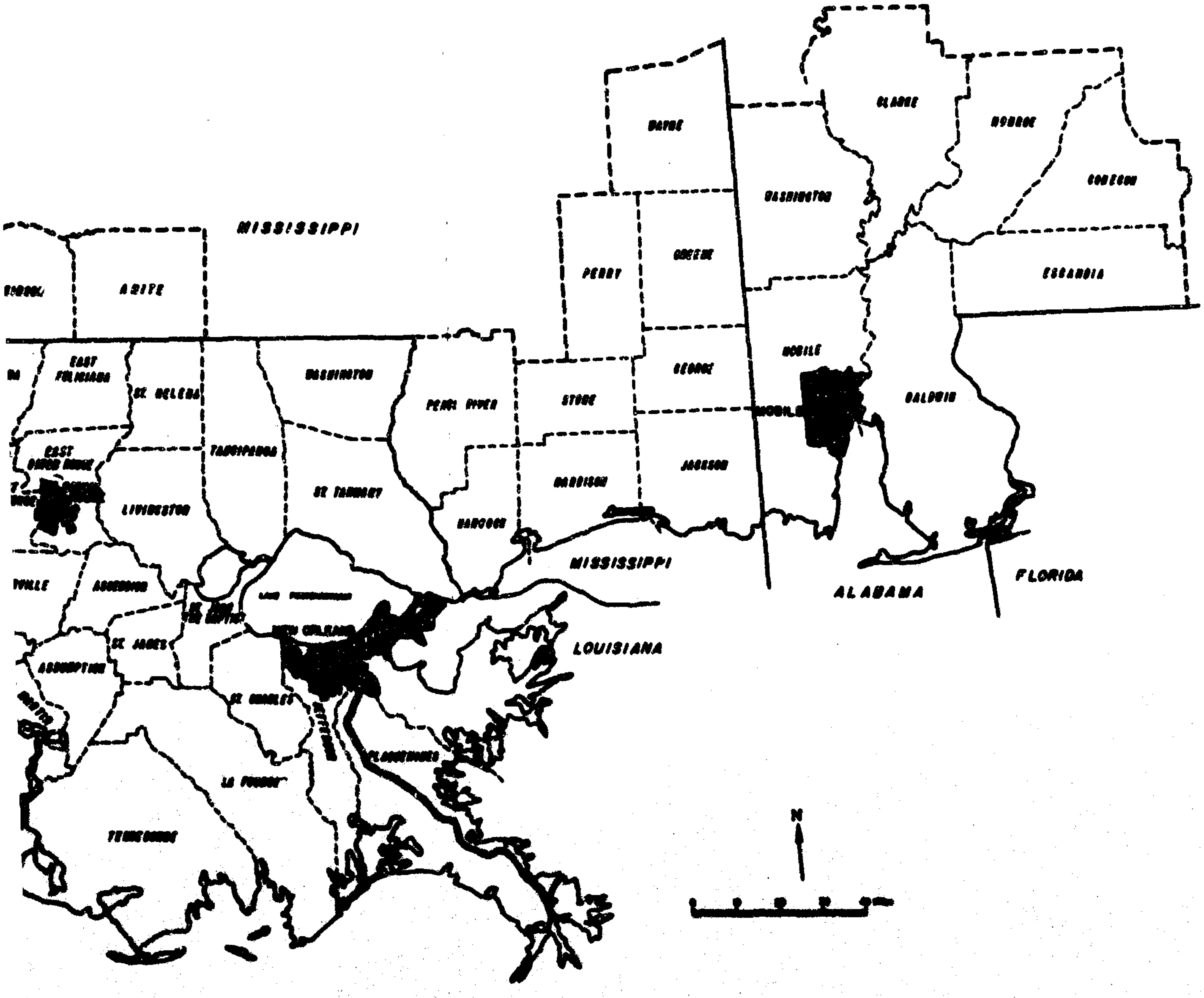


FIGURE 1. Central Gulf Coast Region

2

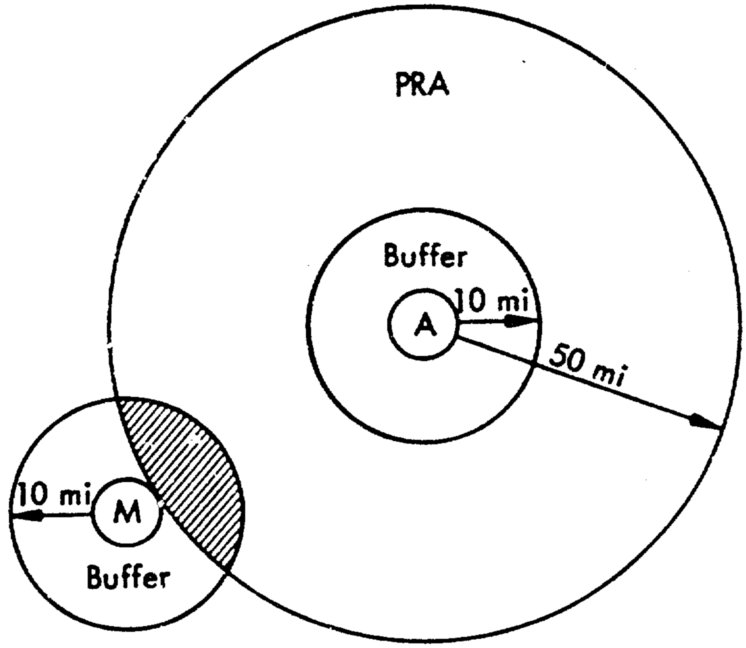
PRINCIPLES OF MTS PLANNING

2.1 DEFINITIONS AND DECISION RULES

As a first step in the study, it was necessary to establish a set of criteria for use in defining areas to be evacuated and areas where MTS fallout shelters might be located or constructed. The decision rules applied for this purpose are illustrated in Figure 2. As shown, the target is identified to be an urbanized area. The total area to be evacuated includes the target area plus a buffer zone. The boundaries of the buffer zone were determined as follows. It was assumed that the MTS fallout shelters would be built or modified to resist 10-psi overpressure. At this hardness level, shelters located within only 4 miles of the urban target area would be reasonably safe from the blast effects of a 10-Mt weapon on the city. On the other hand, the same weapon on an MTS shelter system could damage normal (unhardened) structures as far as 10 miles away. Therefore, as a means of clearly separating population and industrial target values, a 10-mile buffer zone was selected for use in this study. Under this planning criterion, one could expect that usable resources would be available for post-attack support of those people surviving either a population attack or a mixed attack[1] that included population.

The potential reception area begins at the outer limit of the 10-mile buffer zone and extends out to an acceptable distance. This distance should be determined not only on the basis of available

1. "Mixed" attacks are directed toward combinations of target values: military, industrial, population, etc.



A: Urbanized Target Area

M: Military Target Area

PRA: Potential Reception Area

Area overlapped by other targets or buffer zones is eliminated from PRA.

FIGURE 2 Potential Reception Area Defined for a Movement-to-Shelter Program

E9-22-66-1

reception areas but also on the basis of movement-time constraints. Key questions are:

(1) How far should people be moved considering expected warning time and the fact that they would be unprotected while enroute to shelter?

(2) Similarly, how far should essential workers have to travel in commuting to and from their work in the target area? (If avoidable, the same personnel should not be forced to remain in the target area 24 hours per day throughout the crisis period.)

To move ahead at this point in developing a systematic approach to MTS planning, a detailed study of the route structure and movement times applicable to each city was postponed by making the assumption that a distance of 50 miles[2] measured from the edge of the urbanized area would be a practical outer bound for the reception region. The resulting 40-mile-wide annulus, as depicted in Figure 2, was the basis for identifying potential reception areas (PRAs).

Next, military targets in the vicinity of the urbanized areas were identified and a 10-mile buffer zone was applied around such targets[3] for the purpose of further delineating the feasible reception area. If a military target or its surrounding buffer zone mapped any part of the potential reception area (the initial 40-mile-wide band) the portion affected was eliminated from further consideration. Other areas obviously unsuitable for shelter construction (swamps, uninhabitable mountains, etc.) also were excluded.

If the above criteria were applied to a number of closely located cities, one might reasonably expect to encounter the problem of overlapping reception areas. This problem is illustrated in Figure 3.

---

2. This parameter was fixed for pilot study purposes only and could be varied in other studies of broader scope.

3. Although consistent with the criterion applied to urbanized target areas, the 10-mile buffer zone with respect to military targets deserves further evaluation. A priori, the same rationale, separation of population and industrial values, could hardly apply.

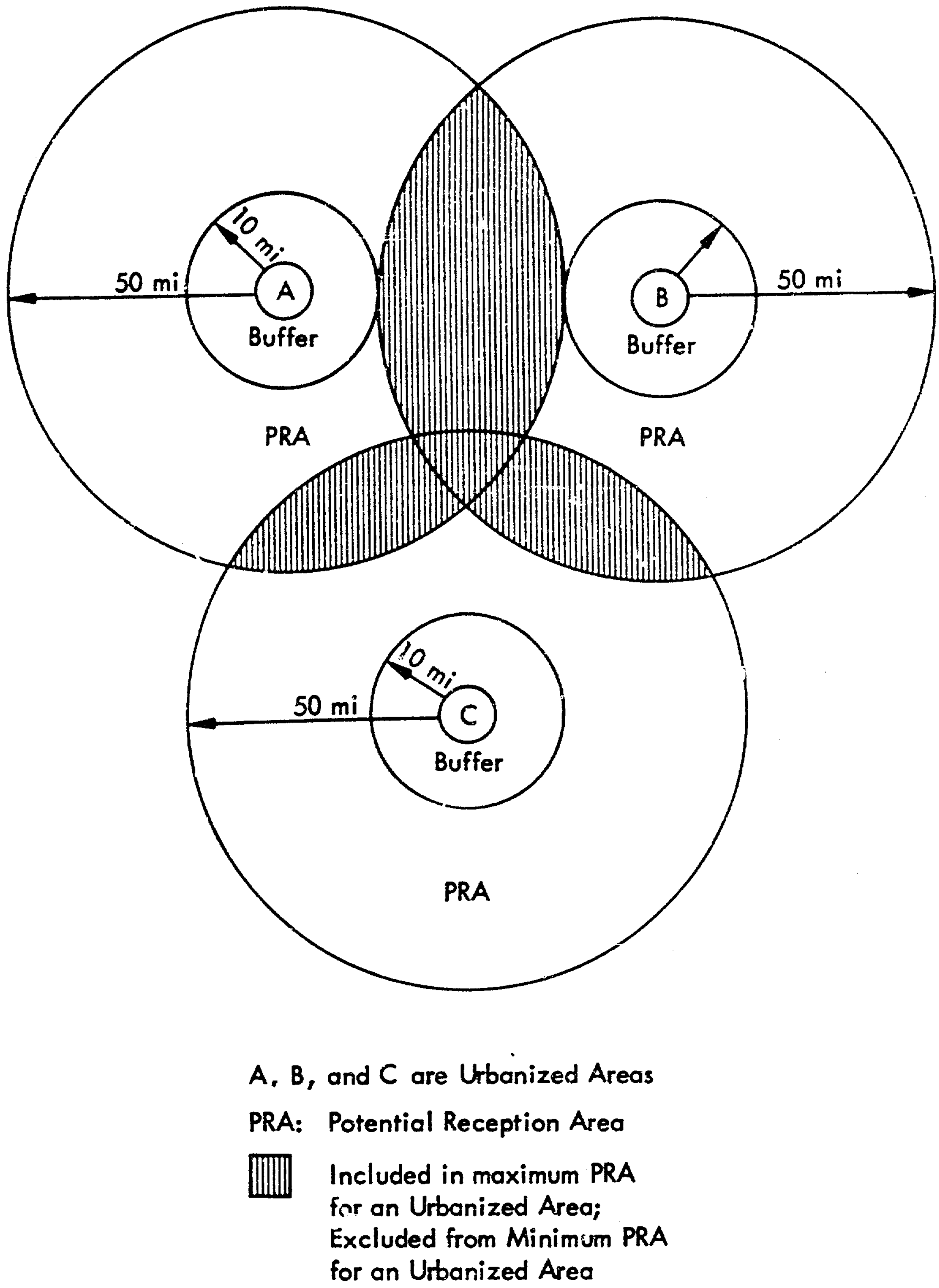


FIGURE 3 Inter-City Contests for Same Reception Area

E9-22-86-2

Before attempting to resolve such contests on a regional basis, some initial insight was gained by first defining and evaluating a maximum and a minimum reception area for each city studied. The maximum and minimum were determined by respectively including and excluding all contested portions of a city's total reception area.

2.2 PILOT APPLICATION TO NEW ORLEANS

These procedures for determining maximum and minimum reception areas were first tested in exploring MTS feasibility for New Orleans,[4] one of the eight cities of the pilot study region. The target areas of interest in the New Orleans vicinity include the New Orleans Urbanized Area, as defined by the Bureau of the Census, and the New Orleans Naval Air Station, a possible counterforce target, located to the south of the city. Both of these target areas and their surrounding buffer zones would be earmarked for evacuation.

To facilitate the compilation of population and land data for use in the study, the evacuation and reception areas were adjusted to coincide with local political boundaries. The outer reception-area border (50 miles out from the urbanized area boundary) was made coincidental with county boundaries; if any portion of a county was intersected by the 50-mile border, the entire county was included. The reception area's inner border (10 miles out) was made to coincide with the boundaries of minor civil divisions (wards, beats, townships, etc.). A minor civil division was included if at least 50 percent of its land was within the boundaries defined for the potential reception area.

The borders of the evacuation and reception areas for New Orleans, determined in accordance with the above guidelines, are depicted in Figure 4.

---

4. New Orleans also is one of the five cities that are a focus of current OCD research. The others are Albuquerque; Detroit; Providence; and San Jose, California.

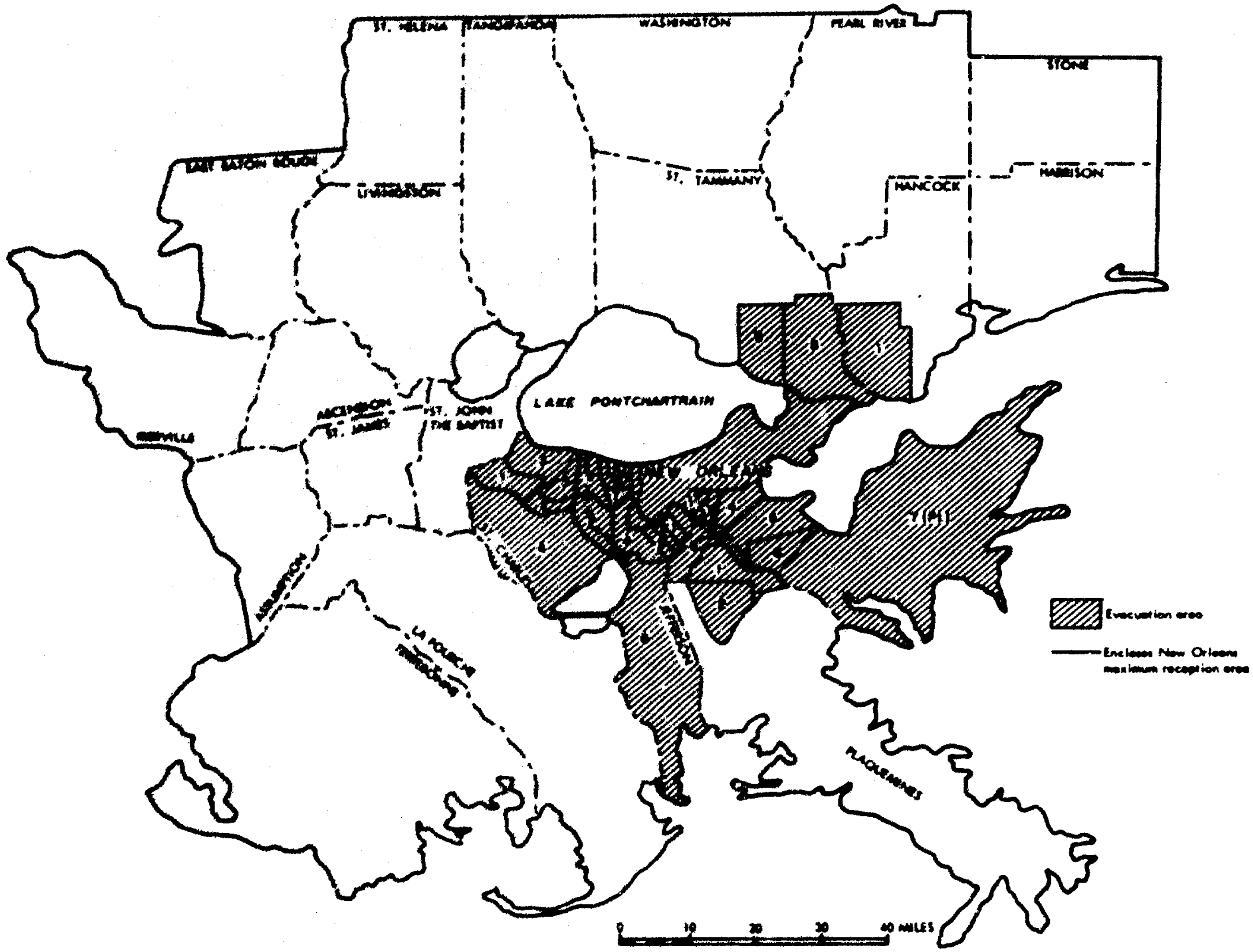


FIGURE 4 New Orleans Maximum Reception Area

The reception area was further adjusted to exclude swamps because without reclamation, these areas obviously would be unsuitable for construction of MTS shelters. The lands excluded for this reason are depicted in Figure 5.

Nearness to other urbanized areas complicates MTS planning for cities such as New Orleans. All areas defined as probable targets or buffer zones must be deleted from further consideration as a reception area. Figure 6 shows the evacuation areas of Mobile and Baton Rouge and their MTS relationship to New Orleans. That part of the Baton Rouge evacuation area that overlaps New Orleans' PRA must be excluded as it would not qualify as a reception area for any city. In the case of Mobile, no such overlap is involved.

Figure 7 depicts the New Orleans maximum reception area after all the above adjustments had been made. As shown, one sector could be claimed by Mobile and another by Baton Rouge. The uncontested portion was identified as New Orleans' minimum reception area.

The problem of allocating contested areas among these three cities clearly could not be resolved without first determining and evaluating the extent to which Mobile and Baton Rouge might interact with cities other than New Orleans. (The analysis depicted in Figure 7 focused upon only those portions of the Mobile and Baton Rouge recepti areas that would directly affect MTS planning for New Orleans.) It was also recognized that similar problems could be encountered in attempting to resolve contests involving other cities of the region. Accordingly, the next phase of the study was concerned with identifying all contested and uncontested reception areas in the region and in each case, the specific claimants involved.

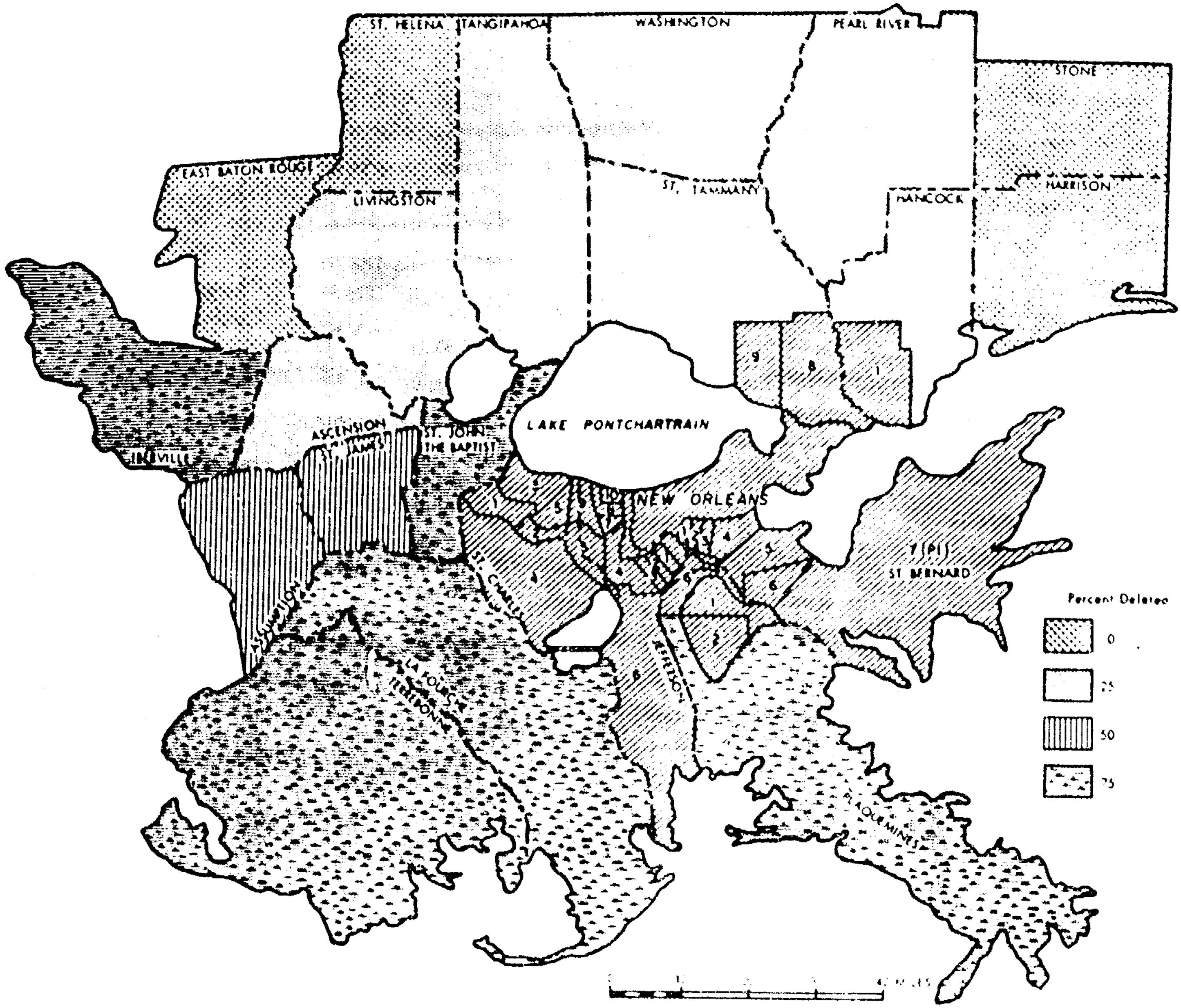


FIGURE 5 Deletion of Swamps from New Orelans Maximum Reception Area

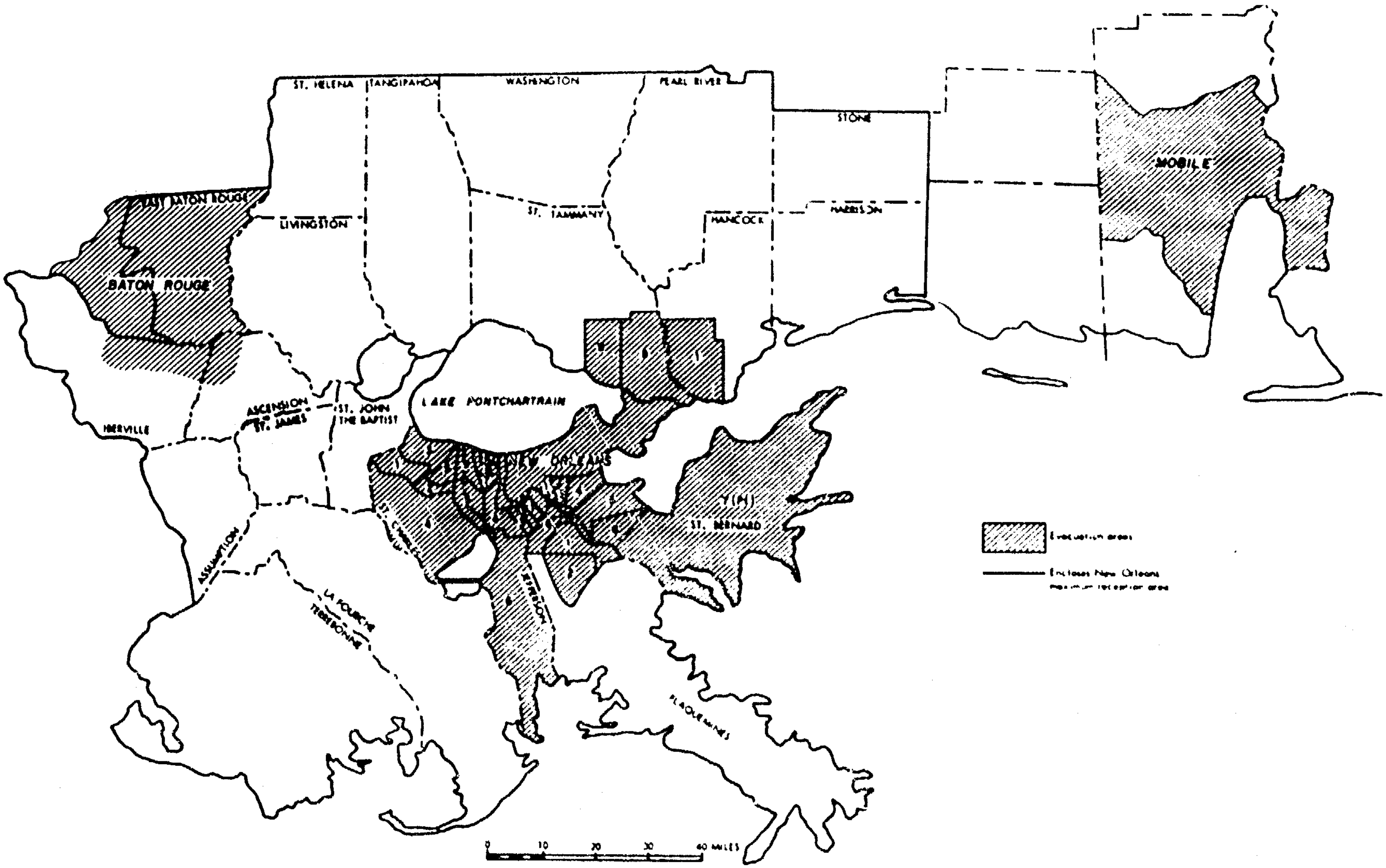


FIGURE 6 Other Evacuation Areas Affecting MTS Planning for New Orleans

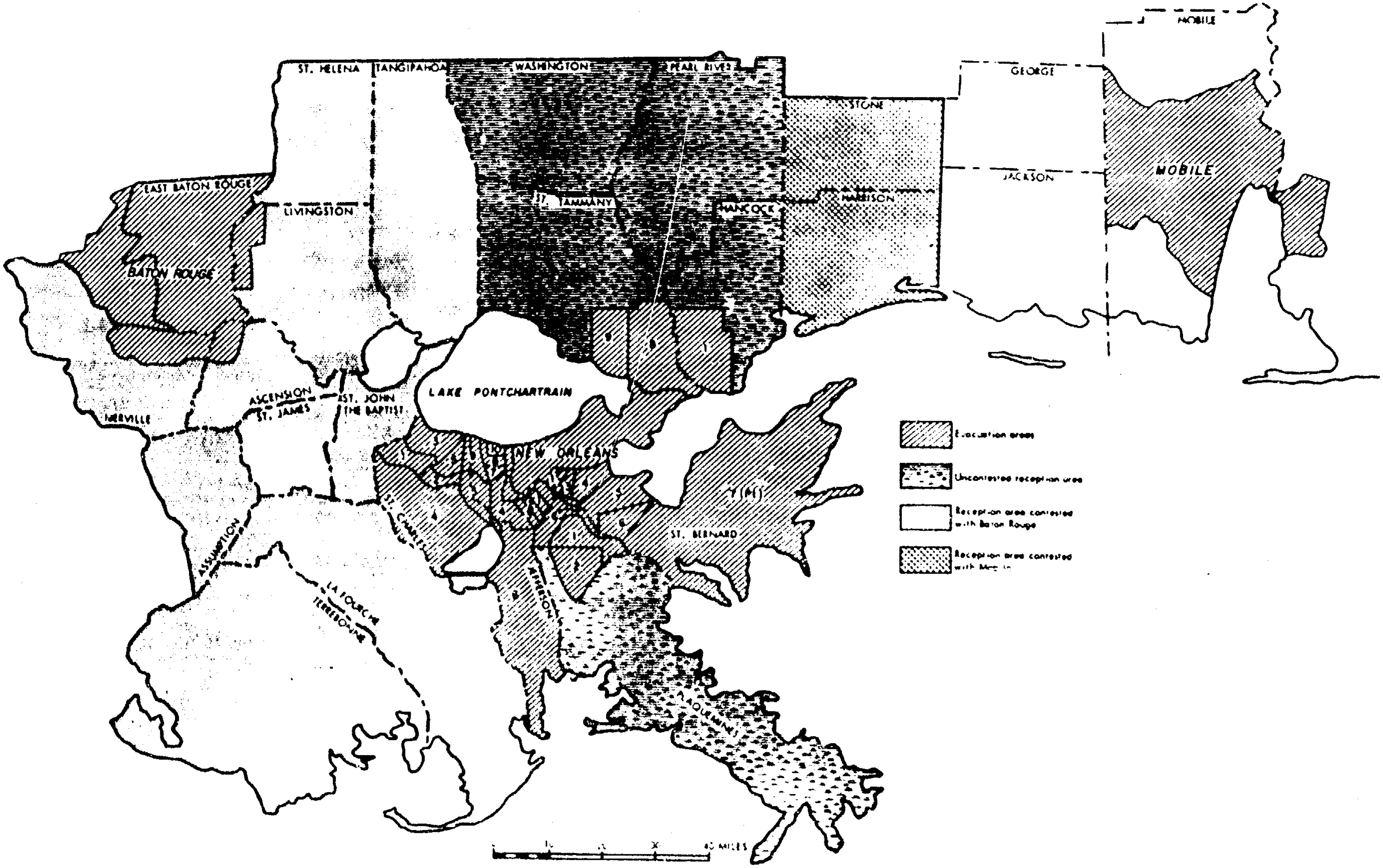


FIGURE 7 Contested Portions of New Orleans Reception Area

3

THE REGIONAL ALLOCATION PROBLEM

3.1 THE SPACE AND THE CONTENDERS

In setting up the allocation problem for the Central Gulf Coast Region, the first step was to identify all qualified reception areas and contending populations. This was accomplished by applying the ground rules defined in the previous Section to the complete set of urbanized areas involved. In so doing, it was possible to gain a preview of the optimal MTS densities achievable within the region. This was done by using the minimum and maximum reception areas as bases for determining respectively the maximum and the minimum density that might be achieved by each city.

If a city was limited to the use of its minimum reception area--that which could not be claimed by another city--its MTS density would be at its highest feasible level. On the other hand, if all qualified areas, contested and uncontested, were allocated to a city, the resulting density would constitute a minimum. The optimal MTS densities for the study region can be expected to fall within the bounds given in Table 1.

In total, 15 MTS reception areas were identified in the region; they are identified geographically in Figure 8 along with appropriate planning data. A more detailed description of each area, including political identities (counties, etc.), land areas and resident populations are provided in Appendix A.

By linking the eight evacuating cities to the reception areas for which they qualify, twenty-nine (29) counterpart relationships were established. These relationships are summarized in Table 2.

Table 1

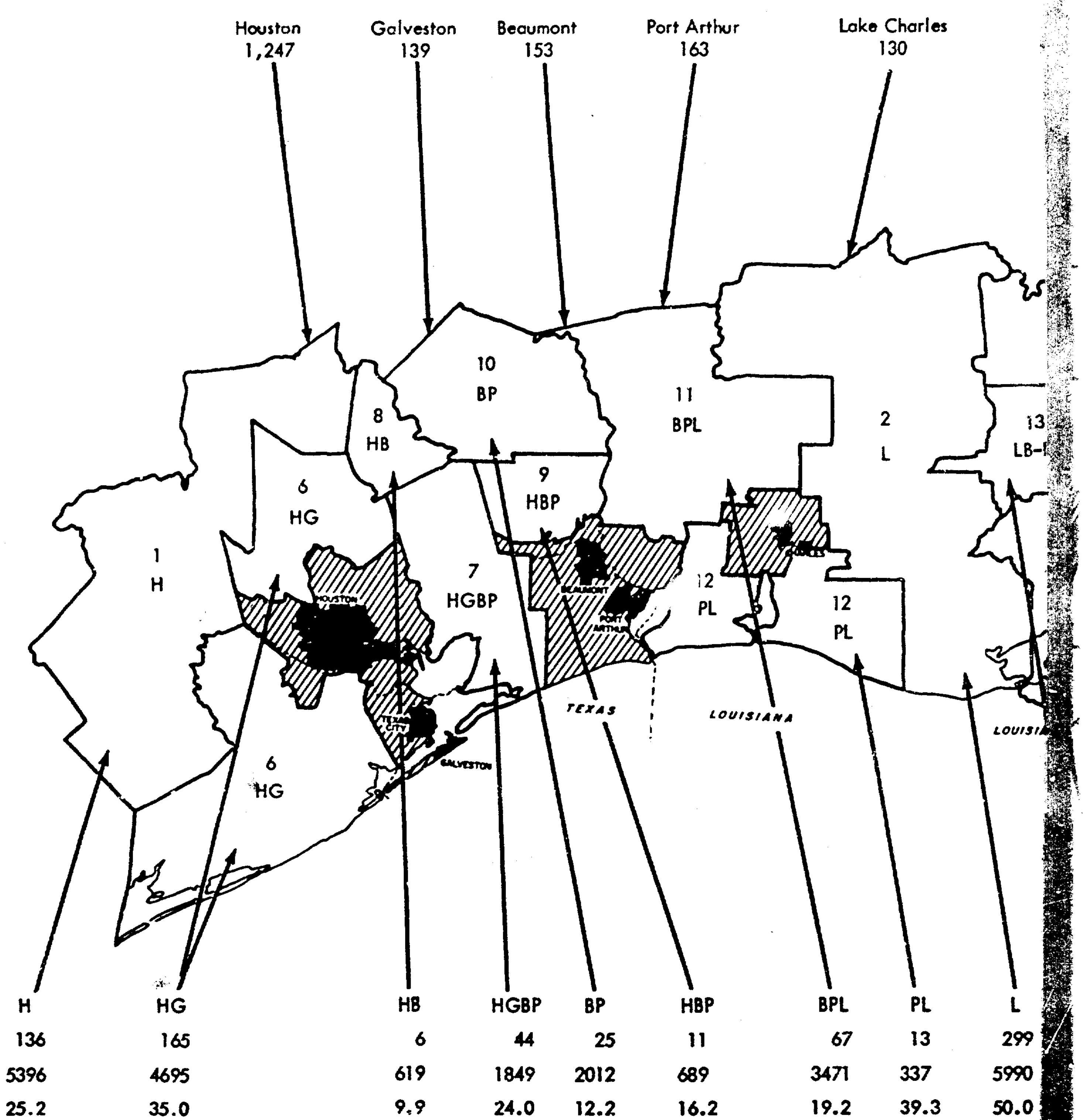
UPPER AND LOWER DENSITIES ACHIEVABLE UNDER REGIONAL MTS SYSTEM
Central Gulf Coast Region

Urbanized Area	Total Population To Be Evacuated[a]	Average Post-Evacuation Density per Sq Mi	
		Maximum Reception Area	Minimum Reception Area
Galveston	138,670	53.1	(407.6)[b]
Houston	1,247,150	121.5	256.3
Beaumont	153,053	35.3	(190.6)[b]
Port Arthur	162,751	38.5	(190.3)[b]
Lake Charles	130,391	55.1	71.8
Baton Rouge	268,137	127.5	142.5
New Orleans	908,595	254.0	477.2
Mobile	301,988	61.0	55.0
Total evacuees	3,310,735		
Reception area residents	2,020,841		
Total shelter spaces required	5,331,576		

a. 1960 Census population. Includes urbanized area, closeby military target areas, and their buffer zones.
b. These three cities have no "minimum" reception area as all surrounding land could be claimed by other cities. However, the vulnerability of these three cities could be reduced by moving the population to shelters uniformly distributed over the target area. Such action would reduce their densities to the levels shown in parentheses.

3.2 ALLOCATION OBJECTIVES

The regional allocation problem, simply stated, is to determine how many evacuees from a city should be assigned to which reception area. These determinations must be consistent with the national defense objective of minimizing the number of US fatalities expected to result from a nuclear attack. The following specific objectives were established for the regional allocation model:


Houston 1,247
Galveston 139
Beaumont 153
Port Arthur 163
Lake Charles 130
1 H
6 HG
8 HB
10 BP
9 HBP
7 HGBP
11 BPL
12 PL
2 L
13 LB-
HOUSTON
TEXAS CITY
GALVESTON
BEAUMONT
PORT ARTHUR
TEXAS
LOUISIANA
H 136 5396 25.2
HG 165 4695 35.0
HB 6 619 9.9
HGBP 44 1849 24.0
BP 25 2012 12.2
HBP 11 689 16.2
BPL 67 3471 19.2
PL 13 337 39.3
L 299 5990 50.0

1

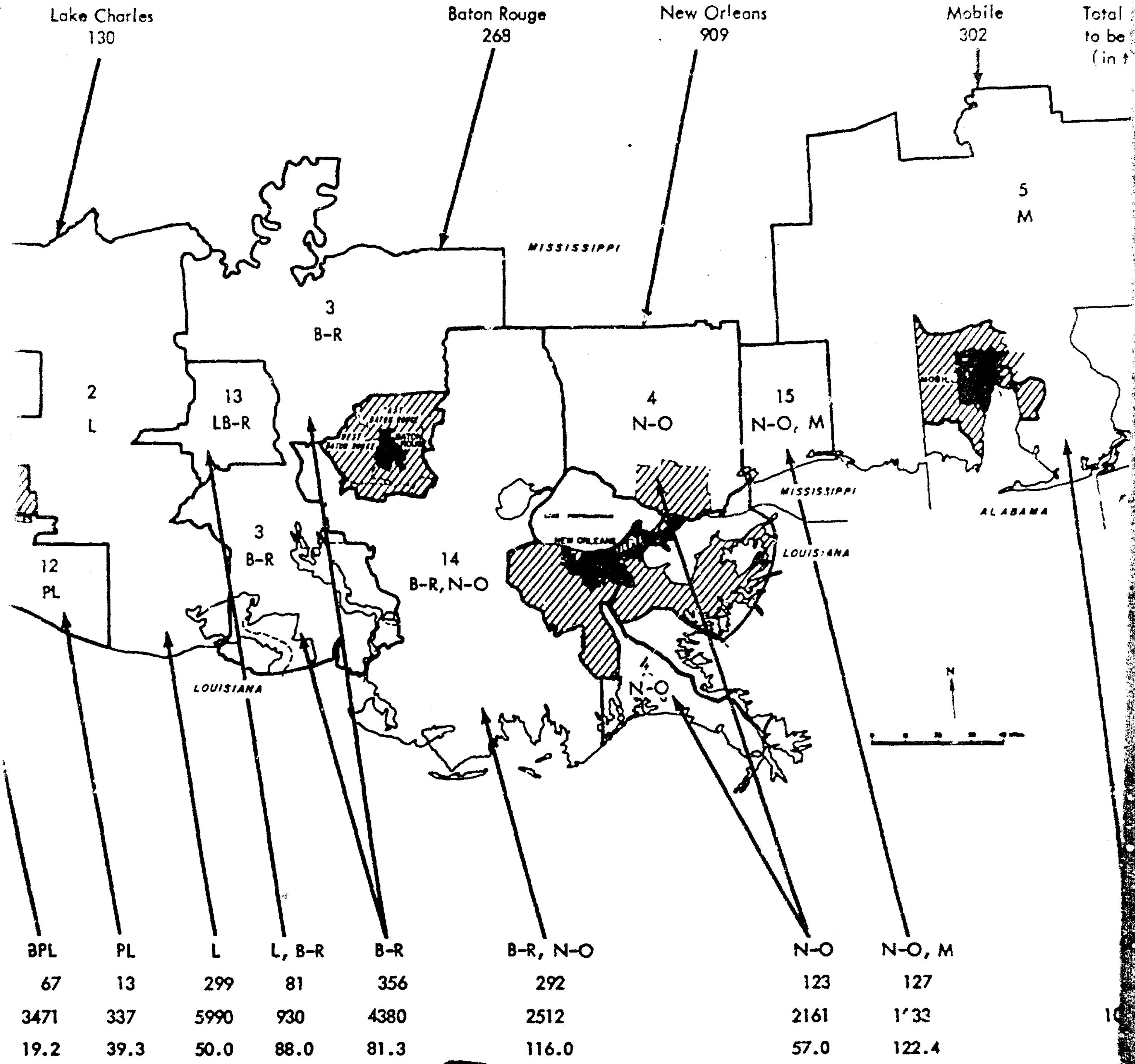


FIGURE 8. The Regional MTS Problem for the Ce..tral Gulf Co

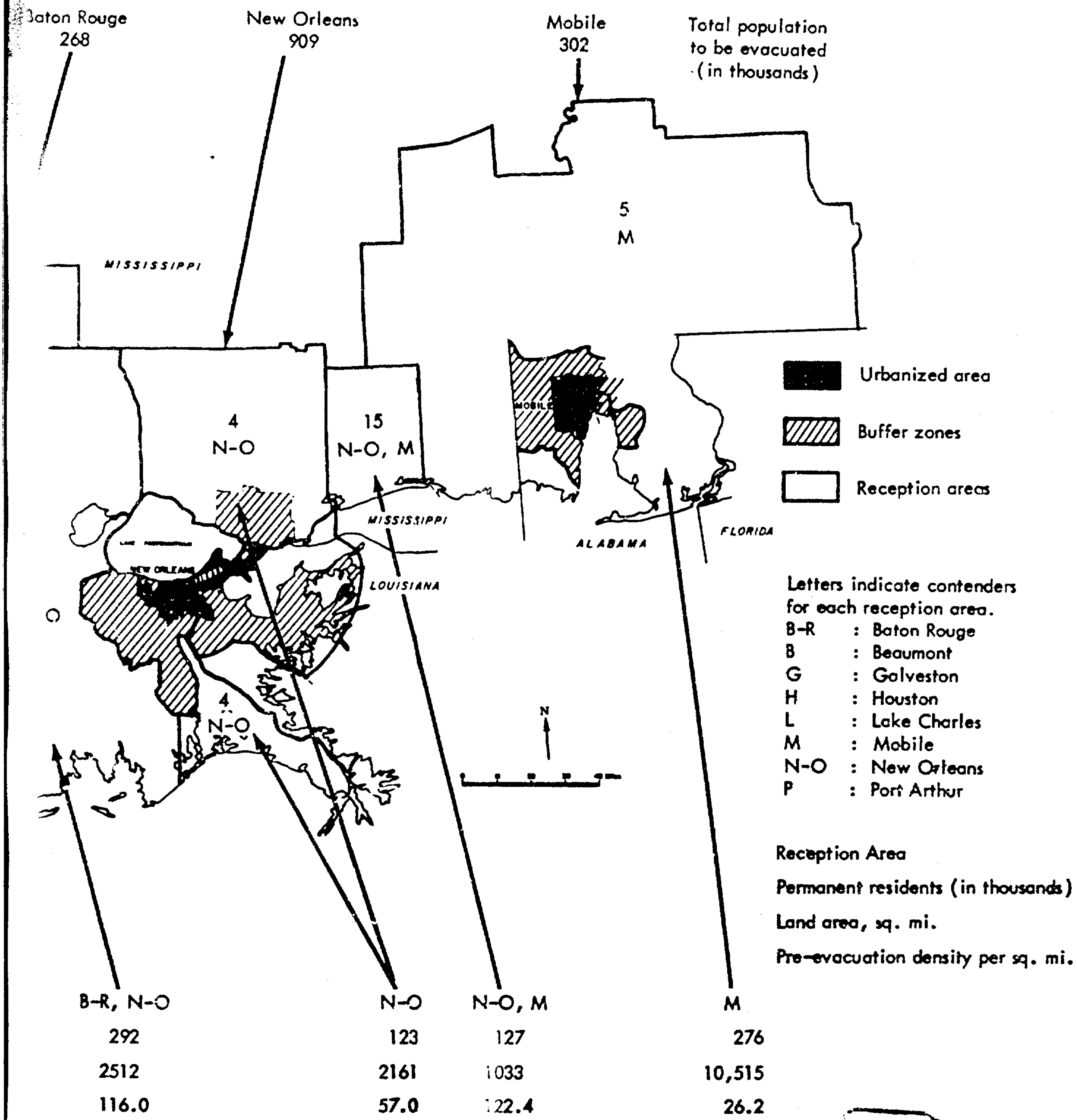


FIGURE 8. The Regional MTS Problem for the Central Gulf Coast

(1) The residents[1] of each evacuation area will be allocated to one or more specific reception areas, subject to the origin/destination constraints reflected in Table 2.

(2) In each reception area, shelter spaces will be allocated to accommodate both permanent residents and assigned evacuees.

(3) These allocations will be made on a basis that will minimize the maximum post-evacuation density of the region, considering all 15 reception areas and any subset thereof. The ultimate objective is to minimize the expected fatalities from any n weapons targeted against the region's population.

Table 2

ORIGIN/DESTINATION RELATIONSHIPS POSSIBLE WITHIN THE REGIONAL MTS SYSTEM
Central Gulf Coast Region

	Reception Areas and Contenders														
Evacuation Areas	1 H	2 L	3 B-R	4 N-O	5 M	6 HG	7 HGBP	8 HB	9 HBP	10 BP	11 BPL	12 PL	13 LB-R	14 B-R,N-O	15 N-O,M
Houston(H)	X					X	X	X	X						
Galveston(G)						X	X								
Beaumont(B)							X	X	X	X	X				
Port Arthur(P)							X		X	X	X	X			
Lake Charles(L)		X									X	X	X		
Baton Rouge(B-R)			X										X	X	
New Orleans(N-O)				X										X	X
Mobile(M)					X										X

1. For social and economic reasons, some specified number of people unquestionably should commute to and from, or remain behind in the target city. However, since definitive estimates of such needs are not yet available this study proceeded on the basis that everyone within a target city and its surrounding buffer zone would be provided a shelter space in a designated reception area.

4

THE REGIONAL ALLOCATION SOLUTION

4.1 ALGORITHM FOR ALLOCATING THE TOTAL RECEPTION SPACE

The optimal evacuee assignments required in this regional study were determined by sequentially solving a connected series of linear programs. The program was first used to allocate evacuees in a manner that would minimax the sheltered density of the total region and in so doing, identify the target and reception areas which dominated the problem. Once this was accomplished, the same program was again applied to solve the minimax problem for the remaining subset of reception areas. This process was repeated until the sheltered (post-evacuation) densities were minimaxed throughout the region. A technical description of the algorithm used in developing this optimal assignment plan is given in Appendix B.

4.2 RESULTS FOR THE PILOT REGION

The results of this pilot regional study are summarized in Table 3 and depicted geographically in Figure 9. Greater detail is provided in Appendix A.

As shown, the highest minimized density was generated by New Orleans which was allocated all contested lands within its maximum reception area. This resulted in a minimum density of 254 per square mile in each of its three reception areas.

After New Orleans, Baton Rouge became the leading contender, dominating Lake Charles and ending up with a minimum density of 132.9 in two reception areas. The next highest density was generated jointly by Houston and Galveston. As Galveston has no "minimum," or uncontested reception area, it was necessary for Houston to share the land it contested with Galveston, otherwise the latter city would have to depend upon some other means of population protection. It was not necessary for Houston to share its reception area with any other of its competitors and this resulted in an MTS density of 131.9 in each of the five reception areas involved.

Table 3

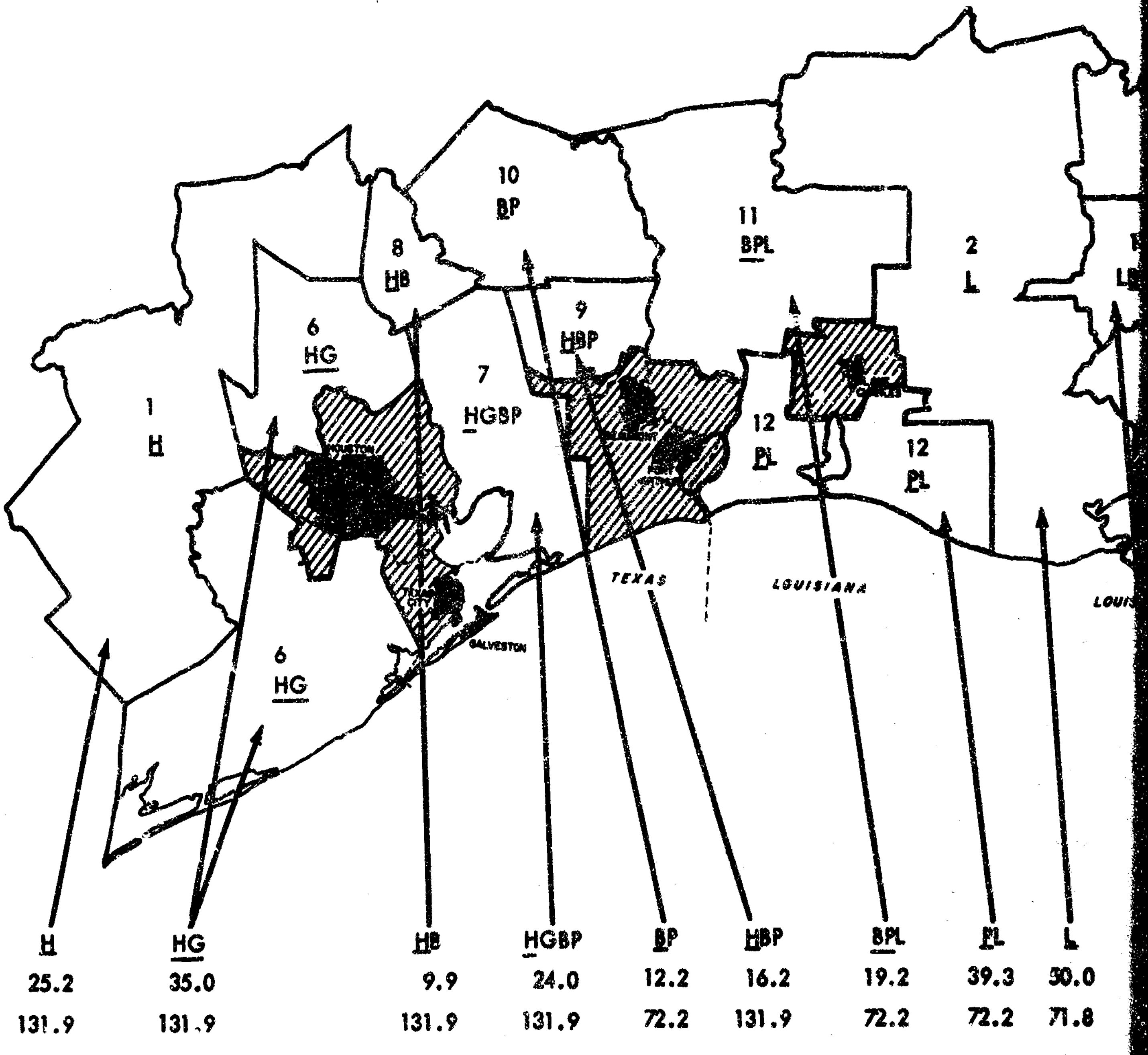
SUMMARY RESULTS OF REGIONAL MTS STUDY

Evacuation Area[a]	Reception Areas Assigned	Post-Evacuation Density Per Sq Mi in Each Reception Area
New Orleans	4,14,15	254.0
Baton Rouge	3,13	132.9
Houston and Galveston	1,6,7,8,9	131.9
Beaumont and Port Arthur	10,11,12	72.2
Lake Charles	2	71.8
Mobile	5	55.0

a. Includes Urbanized Areas and their buffer zones.

The next allocation involved Beaumont and Port Arthur and eliminated three additional reception areas from the contest. The resultant density in these three areas was 72.2. At this point, there were no further contests. Lake Charles and Mobile had been confined to their minimum reception areas with a density of 71.8 and 55.0, respectively.

Given these optimal evacuee assignments, the number of expected fatalities from a multiple weapons attack on the region have been minimized. An evacuation-assignment plan developed by use of this algorithm is unique. It is impossible to reassign evacuees in such a manner that the post-evacuation population density of any given reception area can be decreased without increasing the density of another reception area which is already <u>as densely or more densely filled</u> than the reception area whose density is being decreased.


1
H
6
HG
6
HG
7
HGBP
8
HB
9
HBP
10
BP
11
BPL
2
L
12
PL
12
PL
HOUSTON
GALVESTON
TEXAS
LOUISIANA
H
25.2
131.9
HG
35.0
131.9
HB
9.9
131.9
HGBP
24.0
131.9
BP
12.2
72.2
HBP
16.2
131.9
BPL
19.2
72.2
PL
39.3
72.2
L
50.0
71.8

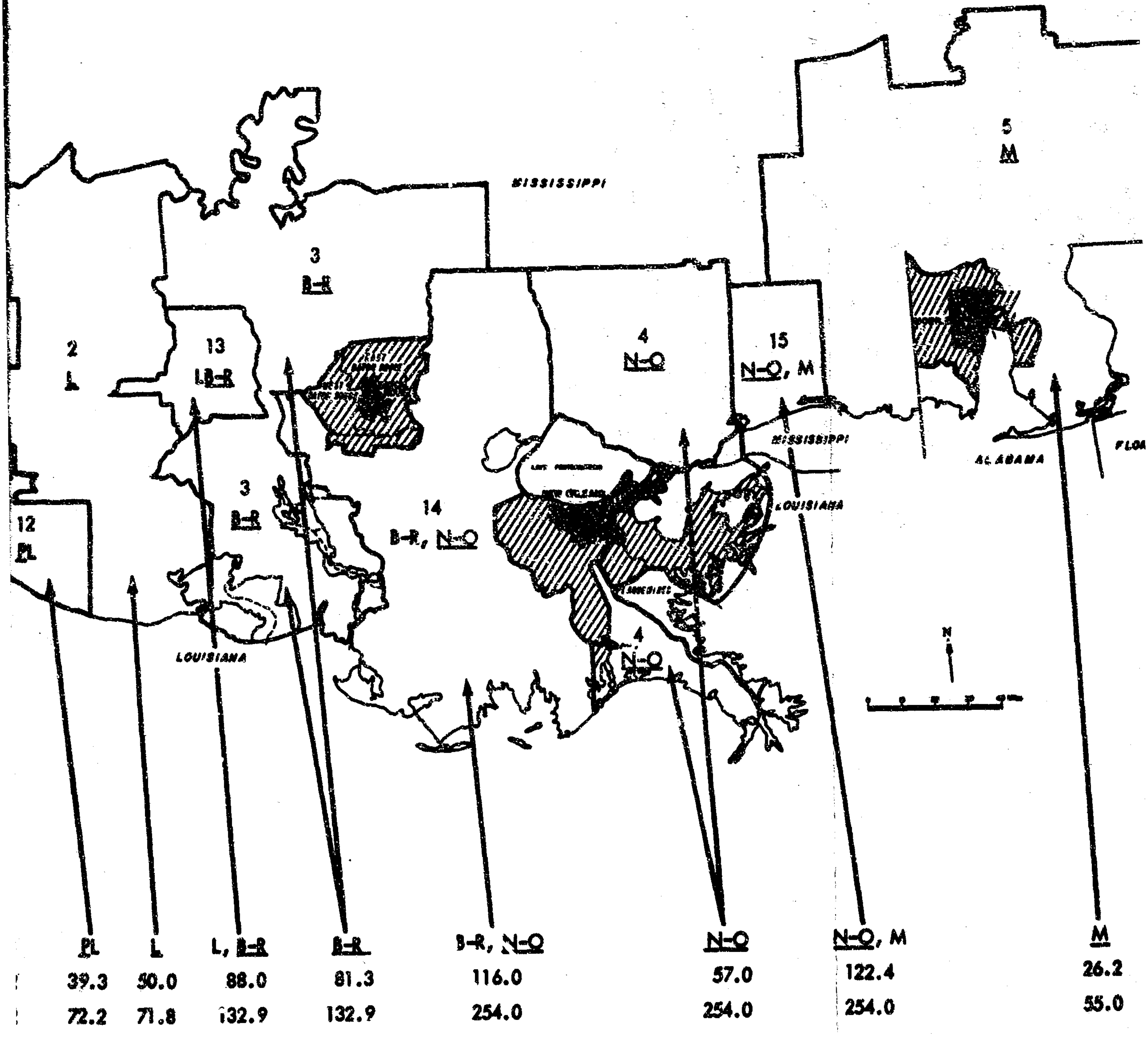
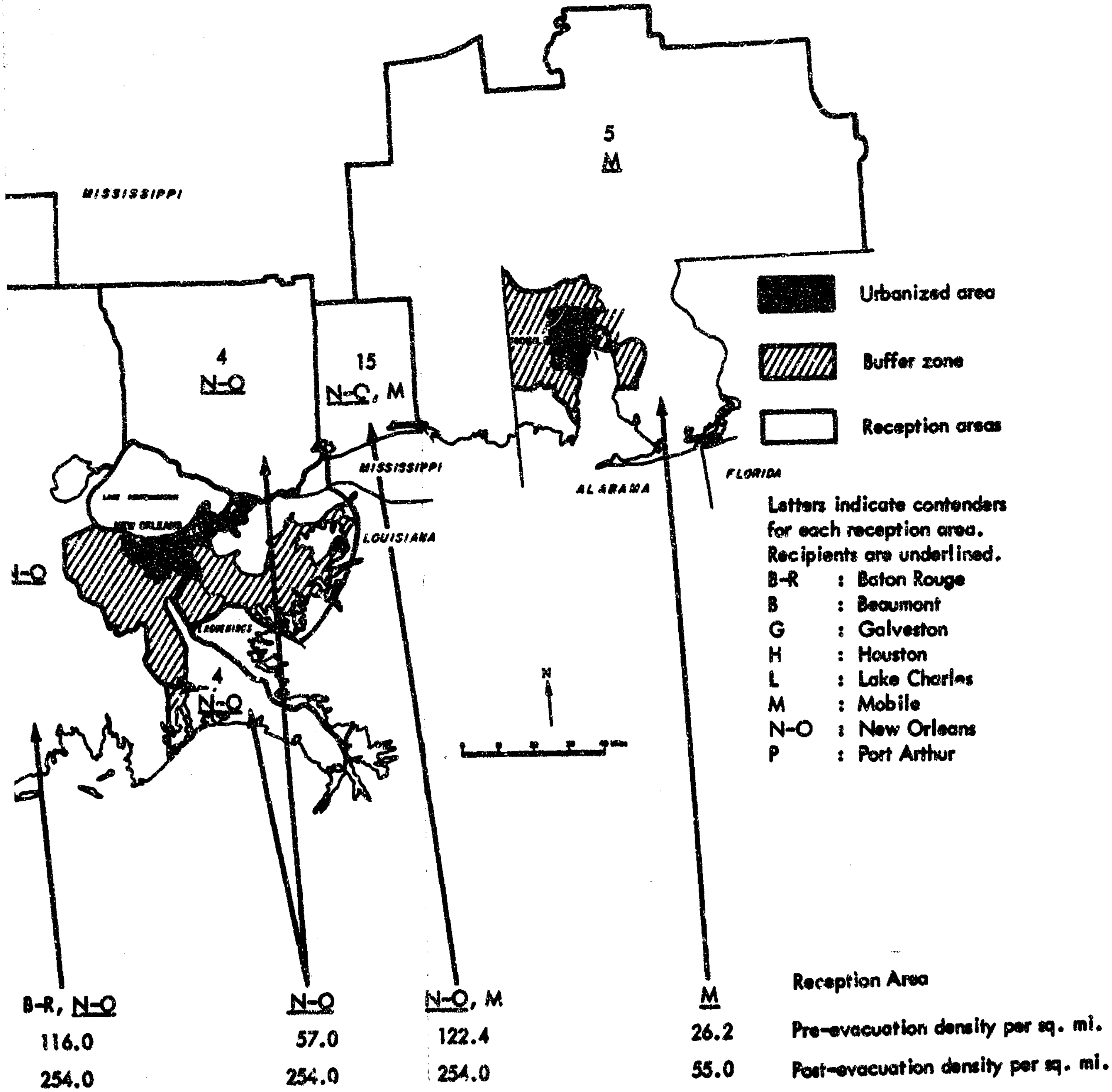


FIGURE 9. Allocation of Population to Reception Areas within a Regional MTS System



IE 9. Allocation of Population to Reception Areas within a Regional MTS System

4.3 DISTRIBUTION OF EVACUEES BY COUNTY

The next step was to distribute the post-evacuation population of each of the 15 reception areas to the subordinate counties or parishes involved.

For those reception areas assigned to a single claimant city, the county allocations were made in a straightforward manner. First, the number of evacuees that could be assigned to each county was determined as follows:

$V_i L_j - R_j = E_j$ for any reception area i and component county j,

where

V = maximum allowable density,

L = land area in square miles,

VL = maximum allowable population,

R = number of permanent residents, and

E = quota for assignment of evacuees.

Then the total evacuees assigned to the parent reception area were applied against the county quotas, E_j, until all had been assigned.

The problem was more complicated in the two shared-reception areas (Area 6 shared by Houston and Galveston and Area 11 shared by Beaumont and Port Arthur) as it was necessary to identify by origin the evacuees assigned to each county. Additional decision rules were required for this purpose and are as follows:

(1) Evacuees were assigned so that none would be required to move through another target area or, to the extent feasible, the exclusive reception area of another city.

(2) A county was not utilized as a reception center unless it was directly accessible by an existing highway.

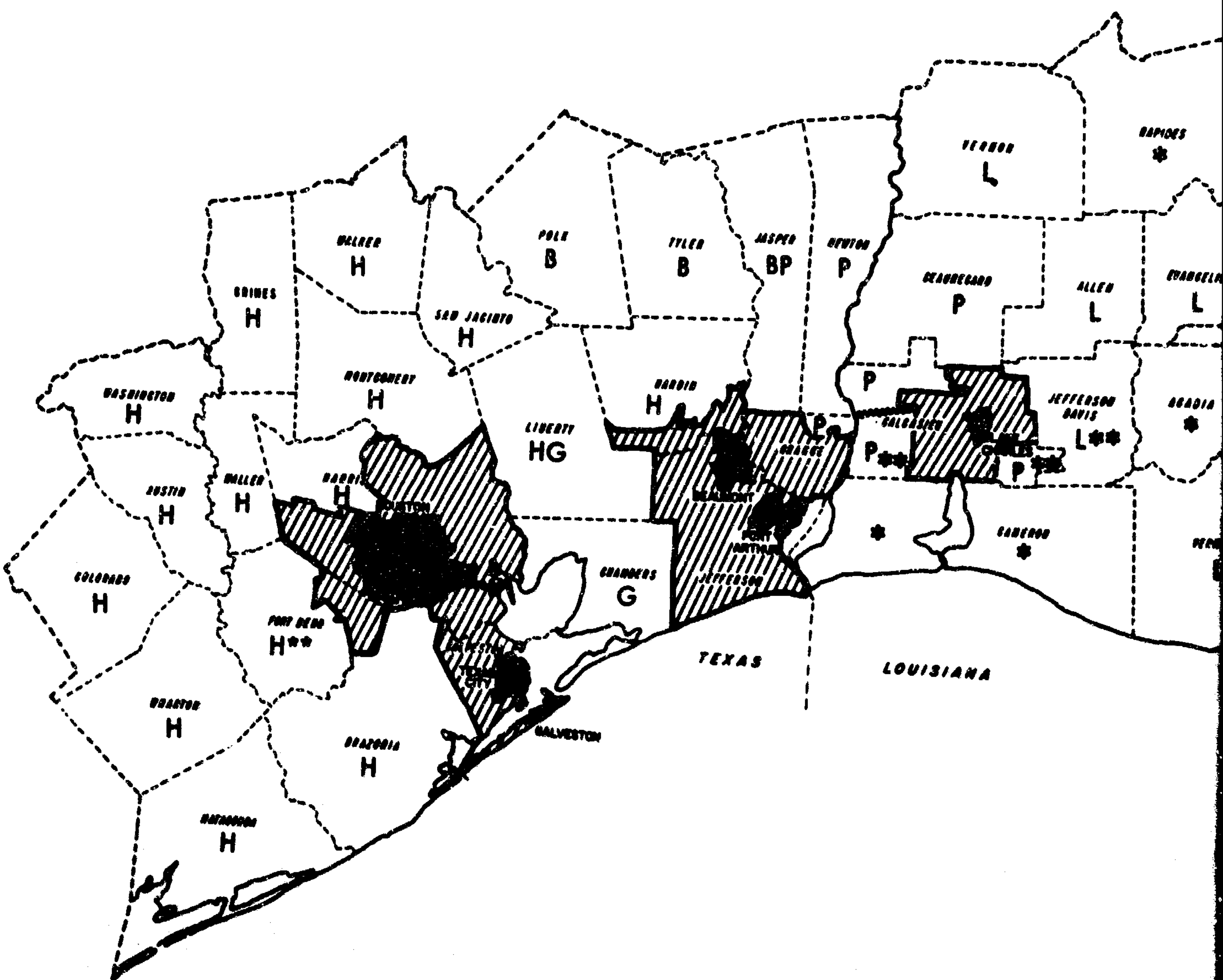
(3) Counties containing both target and reception areas (e.g., Galveston County) were reserved for exclusive use of their own residents. That is, a city (such as Galveston) did not have to compete with another evacuation area (such as Houston) for use of its own home county.

(4) When a choice remained after applying all other constraints, evacuees were assigned to the closest reception county. For example, in Area 11 the entire quota of evacuees from Beaumont was assigned to Jasper County because it was the closest of the five counties involved.

Another problem encountered in attempting to assign evacuees to counties initially identified as potential reception areas was that the normal density of a number of counties (14 in all) already exceeded that permitted under the regional MTS plan. Consequently, no incoming evacuees could be accommodated; instead, the county itself was treated as an evacuation area and evacuated to the extent necessary to reduce its density to the established minimax level, V_i.[1] In such instances, the overflow residents were assigned to the nearest reception county whose density was still below the maximum allowable for the area. For example, over 16,000 residents of Rapides Parish were allocated to nearby Vernon Parish in developing the county-level assignment plan for the Lake Charles uncontested reception area (Area 2).

Detailed MTS planning data for each county of the Central Gulf Coast Region are given in Appendix B. The total plan for the region is shown geographically in Figure 10.

1. Accordingly, a final decision in planning population movements under a regional MTS plan might be whether or not populations outside the assumed target areas are to be evacuated also in order to achieve an optimal MTS posture for the entire region.


TEXAS
LOUISIANA
GALVESTON
WALKER H
POLK B
TYLER B
JASPER BP
NEWTON P
VERNON L
BEAUREGARD P
ALLEN L
GRIMES H
SAN JACINTO H
MONTGOMERY H
WASHINGTON H
LIBERTY HG
HARDIN H
AUSTIN H
WALLER H
HARRIS H
COLORADO H
FORT BEND H**
WHARTON H
BRAZORIA H
MATAGORDA H
CHAMBERS G
CAMERON

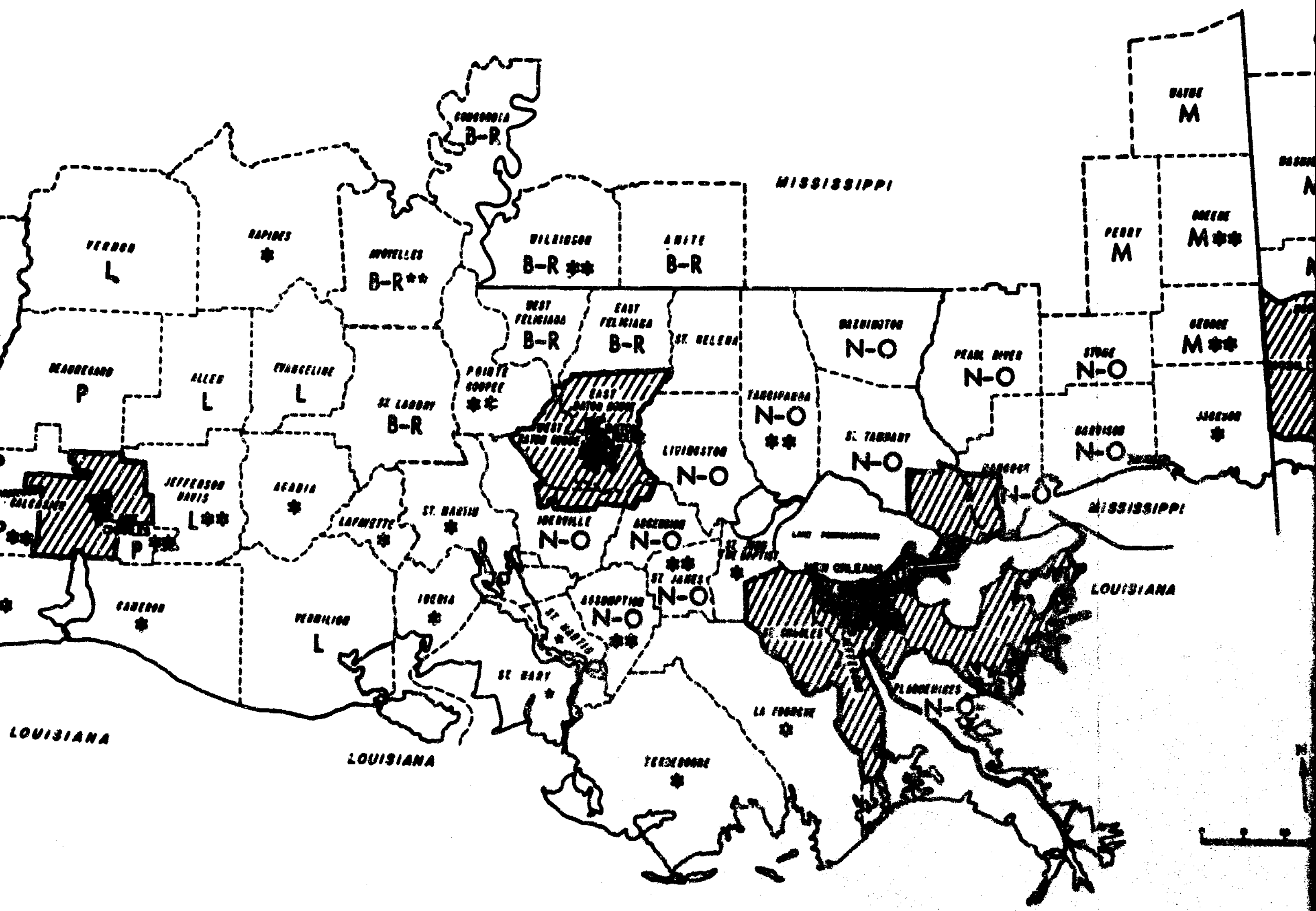


FIGURE 10. Reception-

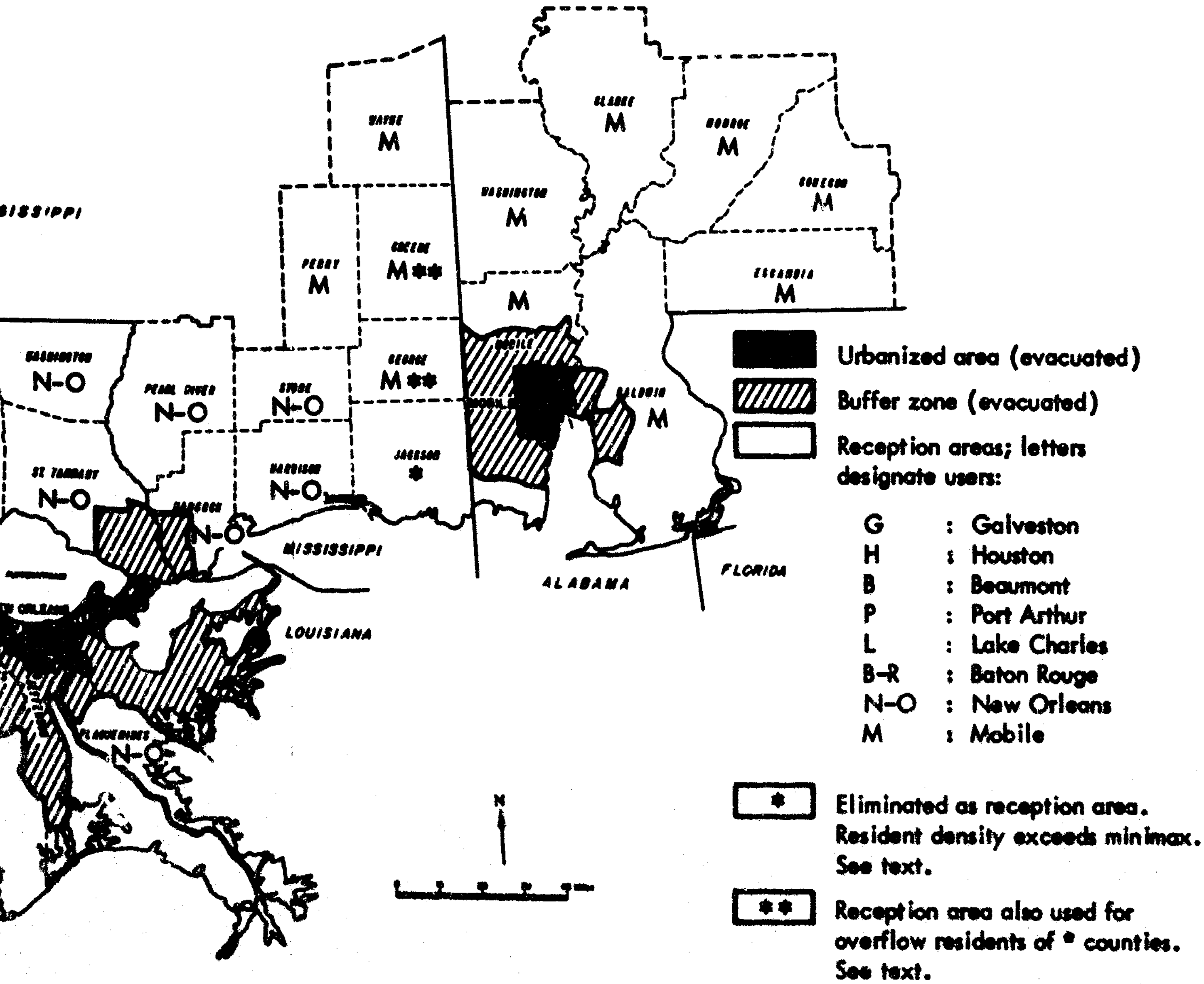


FIGURE 10. Reception-County Assignments

3

5

CONCLUSIONS

An MTS assignment plan developed by use of the regional algorithm presented in this Paper is unique and has an attractive property shared by no other feasible plan: It is impossible to reassign evacuees in such a manner that the post-evacuation population density of any given reception area can be further decreased without increasing the density of another reception area which is already as densely or more densely filled than the reception area whose density is being decreased. The allocation model applied in this pilot study of the Central Gulf Coast Region could be readily adapted for use in studying MTS for larger regions or even the nation as a whole.

Another important finding of the study is that the post-evacuation density data calculated separately for each city's maximum and minimum MTS reception areas, determined as an initial step in the regional analysis, are quite meaningful and could be used to simplify the attainment of regional MTS solutions. These density data are reproduced here for ready reference. (See Table 4.)

Note that the New Orleans density would be 254.0 per square mile if it were assigned its maximum reception area. Each of its competitors, Baton Rouge and Mobile, could achieve a lower density even if they were restricted to their minimum reception areas: 142.5 and 55.0, respectively. Therefore, given the objective of minimizing the maximum MTS density over the total region involved, the solutions to these particular contests are fairly obvious: New Orleans should be allocated all contested sectors included in its maximum reception area. This is precisely the result obtained when the regional allocation model was applied to the total region.

Table 4

DENSITY DATA FOR USE IN PRELIMINARY REGIONAL ANALYSIS
Central Gulf Coast Region

		Average Post-Evacuation Density per Sq Mi	
Urbanized Area	Interacts with	Maximum Reception Area	Minimum Reception Area
Galveston (G)	H,B,P	53.1	(407.6)[a]
Houston (H)	G,B,P	121.5	256.3
Beaumont (B)	G,H,P,L	35.3	(190.6)[a]
Port Arthur (P)	G,H,B,L	38.5	(190.3)[a]
Lake Charles (L)	B,P,B-R	55.1	71.8
Baton Rouge (B-R)	L,N-O	127.5	142.5
New Orleans (N-O)	B-R,M	254.0	477.2
Mobile (M)	N-O	61.0	55.0

a. These three cities have no "minimum" reception area as all surrounding land could be claimed by other cities. However, the vulnerability of these three cities could be reduced by moving the population to shelters uniformly distributed over the target area. Such action would reduce their densities to the levels shown in parentheses.

In future regional studies, the type of preliminary analysis described above should be done as a matter of routine in order to reduce the magnitude and complexity of the regional assignment problem.

This approach can also be useful in defining additional regions for MTS study purposes. The procedure recommended is as follows. Determine the core cities of interest (e.g., Cincinnati, Dayton and Columbus, Ohio). Continue to add surrounding, interacting cities to the problem until boundary conditions are obtained as follows: Once a city is reached which dominates all cities with which it would interact within the established set, no additional cities need be considered in that direction for the purpose of allocating contested reception space. To illustrate, had this analytic device been recognized at the time a region was selected for this study, the region beginning with Galveston and Houston could have been closed once it was determined that New Orleans would dominate Baton Rouge and Mobile. Initially, the closed set might include Baton Rouge because it interacts with Lake Charles; but New Orleans and Mobile could be excluded from the regional contest. However, by applying to Baton Rouge the same rationale that was initially applied to New Orleans, Baton Rouge could also be excluded because it clearly dominates Lake Charles: it has a maximum-area density of 127.5 as compared to Lake Charles' minimum of 71.8 (see Table 4). Consequently, had it been desired, the regional set selected for this pilot study could have been limited to five cities: Galveston, Houston, Beaumont, Port Arthur, and Lake Charles.

The above screening technique could be invaluable in determining MTS feasibility for more complex regions such as the industrialized Northeast. It would greatly facilitate identification of those urbanized areas comprising a closed region for MTS planning purposes and also permit early allocation decisions in cases like New Orleans versus Baton Rouge and Mobile, for which obvious solutions exist. The linear programming algorithm (Appendix B) could then be applied to allocate the remainder of the regional reception space. The resultant evacuee assignment plan would be optimal, having minimized the maximum post-evacuation density over the total region.

Appendix A

SUPPORTING DATA FOR REGIONAL MTS SYSTEM

Tables

Appendix A

SUPPORTING DATA FOR REGIONAL MTS SYSTEM

Table A1

RECEPTION AREAS IN THE CENTRAL GULF COAST REGION
Galveston to Mobile

Reception Area No. and Contestants	Counties or Parishes Included	Permanent Residents	Land Area, sq mi
1. (H)	Wharton	38,152	1,079
	Colorado	18,463	950
	Austin	13,777	662
	Waller	12,071	507
	Washington	19,145	611
	Grimes	12,709	801
	Walker	21,475	785
		135,792	5,396
2. (L)	Vermilion	38,855	612
	Jefferson Davis	29,825	658
	Acadia	49,931	596
	Allen	19,867	775
	Evangeline	31,639	677
	Vernon	18,301	1,356
	Rapides	111,351	1,316
		299,769	5,990
3. (B-R)	Lafayette	84,656	283
	St. Martin	29,063	180
	Iberia	51,657	294
	St. Mary	48,833	151
	Concordia	20,467	472
	Avoyelles	37,606	413
	Point Coupee	22,488	423
	West Feliciana	12,395	306
	East Feliciana	20,198	454
	Wilkinson (Miss.)	13,235	675
	Amite (Miss.)	15,573	729
		356,171	4,380
4. (N-O)	Plaquemines: (Wards 3-5,7,9&10)	17,214	223.6
	Jefferson: (Ward 11)	2,082	10.4
	Washington	44,015	499.0
	St. Tammany: (Wards 1-7, 10)	24,329	523.6
	Pearl River (Miss.)	22,411	621
	Hancock (Miss.) (Beats 2-5)	12,706	283.4
		122,757	2,161.0

Table A1 (Cont.)

Reception Area No. and Contestants	Counties or Parishes Included	Permanent Residents	Land Area, sq mi
5. (M)	Mobile (Ala.):		
	Bayou La Batre	6,604	84.7
	Citronelle	4,230	240.6
	Mt. Vernon	6,881	129.5
	Baldwin:		
	Stockton	2,899	48.5
	Perdido	1,675	76.4
	Bay Minette	10,788	467.5
	Robertsdale	7,847	191.9
	Summerdale	1,559	323.9
	Fairhope	8,745	66.4
	Foley	7,788	170.9
	Elberta	2,385	124.7
	Escambia	33,511	962
	Monroe	22,372	1,035
	Conecuh	17,762	850
	Clarke	25,738	1,241
	Washington	15,372	1,069
	Wayne (Miss.)	16,258	827
	Greene (Miss.)	8,366	728
	George (Miss.)	11,098	481
	Jackson (Miss.)	55,522	744
	Perry (Miss.)	8,745	633
		276,145	10,515.0
6. (H,G)	Brazoria	76,204	1,422
	Matagorda	25,744	1,140
	Fort Bend		
	Beaseley-Orchard Div.	3,421	143.9
	Fulshear-Simonton Div.	2,844	160.4
	Needville Div.	4,288	197.2
	Richmond Div.	4,992	128.0
	Rosenburg Div.	12,498	55.6
	Harris:		
	Hockley-Tomball Div.	8,492	357.7
	Montgomery	26,839	1,090
		165,322	4,694.8
7. (H,G,B,P)	Chambers	10,379	617
	Liberty	31,595	1,173
	Galveston (Bolivar Penin.)	1,694	58.8
		43,668	1,848.8
8. (H,B)	San Jacinto	6,153	619

Table A1 (Cont.)

Reception Area No. and Contestants	Counties or Parishes Included	Permanent Residents	Land Area sq mi
9. (H,B,P)	Hardin:		
	Kountze Div.	4,680	277.4
	Saratoga-Batson Div.	2,489	301.7
	Silsbee North Div.	4,002	109.9
		11,171	689.0
10. (B,P)	Polk	13,861	1,094
	Tyler	10,666	918
		24,527	2,012
11. (B,P,L)	Jasper	22,100	938
	Newton	10,372	941
	Orange:		
	Mauriceville-Pinehurst Div.	4,058	65.9
	Little Cypress Div.	2,056	49.9
	Beauregard (La.)	19,191	1,184.0
	Calcasieu (La.) (Wards 5 & 6)	8,747	292.4
		66,524	3,471.2
12. (P,L)	Cameron	6,909	72
	Calcasieu: (Wards 2 & 7)	6,337	264.9
		13,246	336.9
13. (L,B-R)	St. Landry	81,493	930
14. (B-R,N-O)	La Fourche	55,381	116
	Iberville: (Wards 1,5,7,8&9)	15,475	218.1
	Ascension: (Wards 1,2,4-7,9-10)	20,523	157.2
	Terrebone	60,771	139
	Assumption	17,991	267
	St. James	18,369	186
	St. John the Baptist	18,439	28
	Tangipahoa	59,434	640
	St. Helena	9,162	420
	Livingston: (Wards 3 to 11)	16,056	340.8
		291,601	2,512.1
15. (N-O,M)	Harrison (Miss.)	119,489	585
	Stone (Miss.)	7,013	448
		126,502	1,033
TOTALS		2,020,841	46,589

Table A2

EVACUEE ASSIGNMENT PLAN
Central Gulf Coast Region

Reception Area No.	Contestants	Evacuees Assigned	Permanent Residents	Total Shelter Spaces Required	Land, sq mi	Density per Sq Mi Original	Density per Sq Mi Sheltered
1	Houston	576,156	135,792	711,948	5396	25.2	131.9
2	Lake Charles	130,391	299,769	430,160	5990	50.0	71.8
3	Baton Rouge	226,018	356,171	582,189	4380	81.3	132.9
4	New Orleans	426,180	122,757	548,937	2161	57.0	254.0
5	Mobile	301,988	276,145	578,133	10,515	26.2	55.0
6	Galveston Houston Total	138,670 315,466 454,136	165,322	619,458	4695	35.0	131.9
7	Houston Galveston Beaumont Port Arthur Total	200,275 0 0 0 200,275	43,668	243,957	1849	24.0	131.9
8	Houston Beaumont Total	75,518 0 75,518	6,153	81,671	619	9.9	131.9
9	Houston Beaumont Port Arthur Total	79,735 0 0 79,735	11,171	90,906	689	16.2	131.9

Table A2 (Cont.)

Reception Area No.	Contestants	Evacuees Assigned	Permanent Residents	Total Shelter Spaces Required	Land, sq mi	Density per Sq Mi	
						Original	Sheltered
10	Beaumont	120,701					
	Port Arthur	0					
	Total	120,701	24,527	145,228	2012	12.2	72.2
11	Beaumont	32,352					
	Port Arthur	151,679					
	Lake Charles	0					
	Total	184,031	66,524	250,555	3471	19.2	72.2
12	Port Arthur	11,072					
	Lake Charles	0					
	Total	11,072	13,246	24,318	337	39.3	72.2
13	Lake Charles	0					
	Baton Rouge	42,119					
	Total	42,119	81,493	123,612	930	88.0	132.9
14	Baton Rouge	0					
	New Orleans	346,515					
	Total	346,515	291,601	638,116	2512	116.0	254.0
15	New Orleans	135,900					
	Mobile	0					
	Total	135,900	126,502	262,402	1033	122.4	254.0

Table A3

ALLOCATION OF EVACUEES BY COUNTY

(Inter-County Movements of Population Within Same Reception Area Are Noted by Plus Marks)

Reception Area No., Original Contestants and Post-Evacuation Density Per Sq Mi	Counties or Parishes Included	Land Area, sq mi	Shelter Spaces Required			
			Total	For Residents	For Evacuees	
					Number	From
1. (H) 131.9	Total	5396	711,948	135,792	576,156	Houston
	Wharton	1079	142,351	38,152	104,199	Houston
	Colorado	950	125,336	18,463	106,873	Houston
	Austin	662	87,348	13,777	73,571	Houston
	Waller	507	66,904	12,071	54,833	Houston
	Washington	611	80,622	19,145	61,477	Houston
	Grimes	801	105,683	12,709	92,974	Houston
	Walker	786	103,704	21,475	82,229	Houston
2. (L) 72.2	Total	5990	433,628	299,769	130,391[b]	Lake Charles
	Vermilion	612	44,174	38,855	3,118	Lake Charles
	Jefferson Davis	658	47,495	29,825	+6,912	Acadia Parish
					10,758	Lake Charles
	Acadia[a]	596	43,019	49,931	---	
	Allen	775	55,940	19,867	36,073	Lake Charles
	Evangeline	677	48,866	31,639	17,227	Lake Charles
	Vernon	1356	97,877	18,301	+16,361	Rapides Parish
					63,215	Lake Charles
	Rapides[a]	1316	94,990	111,351	---	

a. The normal density of this county or minor civil division exceeds the minimax density established for its parent reception area. Therefore, it was treated as an evacuation area rather than a reception center and was evacuated to the extent necessary to reduce its density to the established minimax level.

b. Net gain to reception area. Does not include redistribution (+) of population already residing within same area.

Table A3 (cont.)

Reception Area No., Original Contestants and Post-Evacuation Density Per Sq Mi	Counties or Parishes Included	Land Area, sq mi	Shelter Spaces Required: Total	For Residents	For Evacuees: Number	For Evacuees: From
3. (BR) 132.9	Total	4380	582,189	356,171	226,018[b]	Baton Rouge
	Lafayette[a]	283	37,619	84,656	---	
	St. Martin[a]	180	23,930	29,063	---	
	Iberia[a]	294	39,081	51,657	---	
	St. Mary[a]	151	20,076	48,833	---	
	Concordia	472	62,737	20,467	42,270	Baton Rouge
	Avoyelles	413	54,8[illegible]6	37,606	+7,776	Iberia Parish
					+5,133	St. Martin's Parish
					+4,381	Baton Rouge
	Pointe Coupee	423	56,225	22,488	+28,757	St. Mary's Parish
					+ 4,980	Iberia Parish
	West Feliciana	306	40,675	12,395	28,280	Baton Rouge
	East Feliciana	454	60,345	20,198	40,147	Baton Rouge
	Wilkinson (Miss.)	675	89,716	13,235	+47,037	Lafayette Parish
					29,444	Baton Rouge
	Amite (Miss.)	729	96,892	15,573	81,319	Baton Rouge
4. (NO) 254	Total	2161	548,937	122,757	426,180	New Orleans
	Plaquemines Wards 3-5, 7, 9 & 10	224	56,904	17,214	39,690	New Orleans
	Jefferson (Ward 11)	10	2,548	2,082	461	New Orleans
	Washington	499	126,754	44,015	82,739	New Orleans
	St. Tammany Wards 1-7, 10	524	133,104	24,329	108,775	New Orleans

Table A3 (cont.)

Reception Area No., Original Contestants and Post-Evacuation Density Per Sq Mi	Counties or Parishes Included	Land Area, sq mi	Shelter Spaces Required			
			Total	For Residents	For Evacuees	
					Number	From
4. (NO) 254 (cont.)	Pearl River (Miss.)	621	157,742	22,411	135,331	New Orleans
	Hancock (Miss.) Beats 2-5	283	71,890	12,706	59,184	New Orleans
5. (M) 55	Total	10515	578,133	276,145	301,988[b]	Mobile
	Mobile (Ala.)					
	Bayou La Batre[a]	85	4,661	6,604	---	
	Citronelle	241	13,241	4,230	9,011	Mobile
	Mt. Vernon	130	7,136	6,881	247	Mobile
	Baldwin					
	Stockton[a]	49	2,681	2,899	---	
	Perdido	76	4,166	1,675	2,491	Mobile
	Bay Minette	468	25,726	10,788	14,938	Mobile
	Robertsdale	192	10,546	7,847	2,699	Mobile
	Summerdale	324	17,806	1,559	+5,129	Fairhope Div.
					11,118	Mobile
	Fairhope[a]	66	3,616	8,745	---	
	Foley	171	9,391	7,788	+1,603	Bayou La Batre
	Elberta	125	6,861	2,385	+340	Bayou La Batre
					4,136	Mobile
	Escambia	962	52,896	33,511	+218	Stockton
					19,167	Mobile
	Monroe	1035	56,911	22,372	34,539	Mobile
	Conecuh	850	46,736	17,762	28,974	Mobile
	Clarke	1241	68,241	25,738	42,503	Mobile
	Washington	1069	58,781	15,372	43,409	Mobile

Table A3 (cont.)

Reception Area No., Original Contestants and Post-Evacuation Density Per Sq Mi	Counties or Parishes Included	Land Area, sq mi	Shelter Spaces Required			
			Total	For Residents	For Evacuees	
					Number	From
5. (M) 55 (cont.)						
	Wayne (Miss.)	827	45,471	16,258	29,213	Mobile
	Greene (Miss.)	728	40,026	8,366	31,660	Mobile
	Jackson (Miss.)[a]	744	40,906	55,522	---	
	George (Miss.)	481	26,441	11,098	+14,616	Jackson Co.
					727	Mobile
	Perry (Miss.)	653	35,901	8,745	27,156	Mobile
6. (HG) 131.9	Total	4695	619,458	165,322	315,466[b]	Houston
					138,670	Galveston
	Brazoria	1422	187,583	76,204	111,379	Galveston
	Matagorda	1140	150,387	25,744	27,291	Galveston
					97,352	Houston
	Montgomery	1090	143,792	26,839	116,953	Houston
	Fort Bend					
	Beaseley-Orchard Div.	144	19,015	3,421	15,594	Houston
	Fulshear-Simonton Div.	160	21,125	2,844	18,281	Houston
	Needville Div.	197	26,005	4,288	+5,091	Rosenberg Div.
					16,626	Houston
	Richmond Div.	128	16,904	4,992	11,912	Houston
	Rosenberg Div.[a]	56	7,407	12,498	---	
	Harris County					
	Hockley-Tomball Div.	358	47,241	8,492	38,748	Houston

Table A3 (cont.)

Reception Area No., Original Contestants and Post-Evacuation Density Per Sq Mi	Counties or Parishes Included	Land Area, sq mi	Shelter Spaces Required			
			Total	For Residents	For Evacuees	
					Number	From
7. (HGBP) 131.9	Total	1849	243,957	43,668	200,275	Houston
	Chambers	617	81,407	10,379	71,028	Houston
	Liberty	1173	154,744	31,595	123,149	Houston
	Galveston Bolivar Peninsula Div.	59	7,807	1,694	6,098	Houston
8. (HP) 131.9	Total (San Jacinto County)	619	81,671	6,153	75,518	Houston
9. (HBP) 131.9	Total	689	90,906	11,171	79,735	Houston
	Hardin Kountze Div.	277	36,545	4,680	31,865	Houston
	Saratoga-Batson Div.	302	39,843	2,489	37,354	Houston
	Silsbee North Div.	110	14,518	4,002	10,516	Houston
10. (BP) 72.2	Total	2012	145,228	24,527	120,701	Beaumont
	Polk	1094	78,968	13,861	65,107	Beaumont
	Tyler	918	66,260	10,666	55,594	Beaumont

Table A3 (cont.)

Reception Area No., Original Contestants and Post-Evacuation Density Per Sq Mi	Counties or Parishes Included	Land Area, sq mi	Shelter Spaces Required			
			Total	For Residents	For Evacuees	
					Number	From
11. (BPL) 72.2	Total	3471	250,555	66,524	32,352	Beaumont
					151,679	Port Arthur
	Jasper	938	67,715	22,100	32,352	Beaumont
					13,263	Port Arthur
	Newton	941	67,932	10,372	57,560	Port Arthur
	Orange Mauriceville-Pinehurts Div.	66	4,757	4,058	699	Port Arthur
	Little Cypress Div.	50	3,602	2,056	1,546	Port Arthur
	Beauregard (La.)	1184	85,477	19,191	66,286	Port Arthur
	Calcasieu Wards 5 & 6	292	21,074	8,747	12,327	Port Arthur
12. (PL) 72.2	Total	337	24,318	13,246	11,072[b]	Port Arthur
	Cameron[a]	72	5,195	6,909	---	
	Calcasieu Wards 2 & 7	265	19,123	6,337	+1,714	Cameron Parish
					11,072	Port Arthur
13. (LBR) 132.9	Total (St. Landry)	930	123,615	81,493	42,119	Baton Rouge
14. (BRNO) 254.02	Total	2512	638,116	291,601	346,515[b]	New Orleans
	Lafourche[a]	116	29,471	55,381	---	
	Iberville Wards 1,5,7, 8 & 9	218	55,379	15,475	39,904	New Orleans

Table A3 (cont.)

Reception Area No., Original Contestants and Post-Evacuation Density Per Sq Mi	Counties or Parishes Included	Land Area, sq mi	Shelter Spaces Required			
			Total	For Residents	For Evacuees	
					Number	From
14. (BRNO) 254.02 (cont.)	Ascension Wards 1,2,4-7,9-10[a]	157	39,885	20,523	19,362	New Orleans
	Terrebone	139	35,313	60,771	---	New Orleans
	Assumption	267	67,825	17,991	+25,458	Terrebone Parish[a]
					24,376	New Orleans
	St. James	186	47,251	18,369	+25,910	Lafourche Parish[a]
					2,970	New Orleans
	St. John the Baptist	28	7,119	18,439	---	
	Tangipahoa	640	162,567	59,434	+11,320	St. John Baptist Parish[a]
					91,813	New Orleans
	St. Helena	420	106,687	9,162	97,525	New Orleans
	Livingston	341	86,621	16,056	70,565	New Orleans
15. (NOM) 254	Total	1033	262,402	126,502	135,900	New Orleans
	Harrison (Miss.)	585	148,600	119,489	29,111	New Orleans
	Stone (Miss.)	448	113,802	7,013	106,789	New Orleans

Appendix B

A REGIONAL MODEL FOR THE ASSIGNMENT OF EVACUEES TO RECEPTION AREAS

Appendix B

A REGIONAL MODEL FOR THE ASSIGNMENT OF EVACUEES TO RECEPTION AREAS

Presented in the body of this study was an "optimal" plan for assigning evacuees from eight cities to a set of contested and uncontested reception areas within the same region. This assignment was determined by solving a connected series of linear programming problems. This Appendix contains a technical description of the construction of these problems.

B.1 GIVENS OF THE PROBLEM

The model deals with movements to shelters on a highly simplified and basic level. Our assumptions generate only two restrictions which may be stated, using the following notation:

$i=1, 2, \ldots, M$ = index of cities to be evacuated.

$j=1, 2, \ldots, N$ = index of potential reception areas.

$\bar{E}_i$ = number of residents to be evacuated from the i-th city.

$\bar{R}_j$ = pre-evacuation residents of the j-th reception area.

$\bar{A}_j$ = inhabitable area (in square miles) of the j-th reception area.

δ_{ij} = the delta function where:

$\delta_{ij} = 1$ if reception area j may receive evacuees from the i-th city, and

$\delta_{ij} = 0$ in all other cases.

E_{ij} = evacuees from the i-th city who are assigned to the j-th reception area.

V = the maximum post-evacuation population density of any reception area.

The first condition is that the number of evacuees from a given city who are assigned to the city's potential reception areas sum to the total number of residents who must be evacuated from that city. In our notation:

$$\sum_{j=1}^{N} \delta_{ij} E_{ij} = \overline{E}_i \text{ for } i=1, 2, \ldots, M.$$

Second, since V is the maximum post-evacuation population density of any reception area, it must, by definition, equal or exceed the actual density achieved in each reception area after evacuation. In symbols these conditions appear as:

$$V - \sum_{i=1}^{M} \frac{\delta_{ij}}{\overline{A}_j} E_{ij} \geqq \frac{\overline{R}_j}{\overline{A}_j} \quad \text{for } j=1, 2, \ldots, N.$$

In addition to these restrictions we have the self-evident fact that neither the maximum density, V, nor the numbers of evacuees moving from cities to reception areas, E_{ij}, may be negative. That is:

$$V \geqq 0 \text{ and } E_{ij} \geqq 0 \text{ for } i=1, 2, \ldots, M \text{ and } j=1, 2, \ldots, N.$$

B.2 THE OBJECTIVE

An obvious objective which is suggested by the givens of the problem is to minimize V, the maximum population density of any reception area after evacuation. This, in fact, is the objective of the first of the series of linear programming problems.

The solution to the first problem, however, is only a partially satisfactory assignment of evacuees to potential reception areas. Although the maximum population density of any reception area, V, has been minimized, the assignments are characteristically haphazard in one important respect. Among potential reception areas which have not been filled to the density V, a great deal of reassigning may be possible which does not alter the minimum value of V. The first problem, in short, does not usually possess a unique solution.

The second linear programming problem is designed to resolve this degeneracy in the assignment of evacuees to partially filled reception areas. This is done by removing, in effect, potential reception areas which are filled and those evacuees who have been assigned to these areas. With this change in the problem the new objective becomes the minimization of the maximum population density of any of the remaining reception areas after evacuation.

Again, a degeneracy in the solution may appear. And this degeneracy must be resolved with yet a third linear program. This process of solving linear programming problems and eliminating reception areas and evacuees continues until every evacuee and reception area is accounted for. The evacuation assignments which are ultimately obtained minimize a lexicographically ordered series of maximum reception area densities.

B.5 THE LINEAR PROGRAMS

The first linear programming problem is obtained directly from the initial set of restrictions. It is:

Minimize: V

subject to: $\sum_{j=1}^{N} \delta_{ij} E_{ij} = \bar{E}_i \qquad i=1, 2, \ldots, M$

$$V - \sum_{i=1}^{M} \frac{\delta_{ij}}{\bar{A}_j} E_{ij} \geq \frac{\bar{R}_j}{\bar{A}_j} \qquad j=1, 2, \ldots, N$$

and: $V \geq 0$, $E_{ij} \geq 0$ for $i=1, 2, \ldots, M$ and $j=1, 2, \ldots, N$.

The second linear programming problem is derived from the first by inspecting the solution to the first problem's dual program. If the dual price associated with a constraint is positive, that constraint is binding. When a binding constraint is identified in this manner, the solution values of the variables E_{ij} which appear in it are saved but the constraint is omitted from the next problem. Dual prices of zero indicate constraints which are not binding. These constraints remain and the solution values of the variables which appear in them are recomputed by solving the second problem. This second problem is identical in structure to the first, however, several indices and variables have slightly different definitions. These are:

$i=1, 2, \ldots, M$ = index of cities whose evacuations were not determined in the solution to the first problem.

$j=1, 2, \ldots, N$ = index of remaining potential reception areas.

V = the maximum post-evacuation population density of any remaining reception area.

The solution to the dual of the second problem is employed in the construction of the third, and the third dual solution in the construction of the fourth, et cetera, until all constraints and variables are eliminated. The final assignment of evacuees to reception areas is constructed from the solution values of the variables E_{ij} which were saved when the constraints were eliminated.

An evacuation assignment which is computed from the solutions to the series of linear programming problems we have described is unique. Moreover, it has an attractive property shared by no other feasible assignment of evacuees to reception areas. It is impossible to reassign evacuees in such a manner that the post-evacuation population density of any given reception area can be decreased without increasing the density of another reception area which is already as densely or more densely filled than the reception area whose density is being decreased.

Appendix C

BIBLIOGRAPHY

Appendix C

BIBLIOGRAPHY

1. Brown, William M., Strategic and Tactical Considerations for the MTS Program, Draft (U), Hudson Institute, HI-687-D (New York: Harmon-on-Hudson, 1966).

2. Eastman, Samuel E., The Effects of Nuclear Weapons on A Single City, A Pilot Study of Houston, Texas (U), Institute for Defense Analyses, Economic and Political Studies Division, IDA Report R-113 (Arlington, Va., 1965).

3. Flanagan, R.J. et al., Vulnerability Reduction Using Movement and Shelter (U), Dikewood Corporation, DC-FR-1039 (Albuquerque, N.M., 1965), in 2 Vols., Vol. II, "Final Report" (U).

4. Glasstone, S., (Ed.), The Effects of Nuclear Weapons, U.S. Department of Defense (Washington, D.C.: U.S. Atomic Energy Commission, 1962).

FOR OFFICIAL USE ONLY
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) INSTITUTE FOR DEFENSE ANALYSES ECONOMIC AND POLITICAL STUDIES DIVISION	2a. REPORT SECURITY CLASSIFICATION FOR OFFICIAL USE ONLY 2b. GROUP

3. REPORT TITLE
ALLOCATING CONTESTED SPACE IN A REGIONAL MOVEMENT-TO-SHELTER SYSTEM: A CASE STUDY OF THE CENTRAL GULF COAST REGION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)
Grace J. Kelleher

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1967	76	8

8a. CONTRACT OR GRANT NO. PS-66-113 Dept. of Army (OCD)	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. Work Unit 4131A	P-310
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT This document may be further distributed by any holder only with specific prior approval of the Office of Civil Defense.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Civil Defense Department of the Army

13. ABSTRACT This Paper focuses upon the problem of regional interactions in planning movement-to-shelter (MTS) systems. The MTS system envisaged in this research effort is one designed to move urban populations during crises to fallout shelters located in peripheral areas of low target interest. Basic criteria are established for use in defining areas to be evacuated and those to be used as MTS reception centers. The total area to be evacuated includes the urbanized area plus a 10-mile buffer zone. It was assumed that a distance of 50 miles measured from the edge of the urbanized area would be a practical outer bound for the reception region. The resulting 40-mile-wide annulus (50 miles minus the 10-mile buffer zone) was the basis for determining specific reception areas. Possible military targets and otherwise unsuitable land areas (swamps, etc.) were then deleted in identifying usable reception areas within the 40-mile annulus. Applying these criteria to closely located cities such as those of the Central Gulf Coast Region, one soon encounters the problem of overlapping reception areas: those which could be claimed by two or more evacuating cities. This problem is resolved by use of a linear programming model which allocates regional reception space on an optimal basis. Its objective is to allocate evacuating population in a manner that will minimize fatalities.

DD FORM 1 NOV 65 1473

FOR OFFICIAL USE ONLY
Security Classification

FOR OFFICIAL USE ONLY
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
CIVIL DEFENSE SYSTEMS						
PERIPHERAL FALLOUT SHELTERS						
EVACULATION TO FALLOUT SHELTERS						
MOVEMENT-TO-SHELTER SYSTEMS						
EVACUEE RECEPTION AREAS						
ALLOCATION OF POPULATION TO FALLOUT SHELTERS						
ALLOCATION OF RECEPTION AREA SPACE						

FOR OFFICIAL USE ONLY
Security Classification

Allocating Contested Space in a Regional Movement-to-Shelter System: A Case Study of the Central Gulf Coast Region (IDA Research Paper P-310) by Grace J. Kelleher, Unclassified, Institute for Defense Analyses, January 1967, 71 pages (Contract OCD-PS-66-113, Work Unit 4131A)

FOR OFFICIAL USE ONLY

Abstract

This Paper focuses upon the problem of regional interactions in planning movement-to-shelter (MTS) systems. The MTS system envisaged in this research effort is one designed to move urban populations during crises to fallout shelters located in peripheral areas of low target interest. Basic criteria are established for use in defining areas to be evacuated and those to be used as MTS reception centers. The total area to be evacuated includes the urbanized area plus a 10-mile buffer zone. It was assumed that a distance of 50 miles measured from the edge of the urbanized area would be a practical outer bound for the reception region. The resulting 40-mile-wide annulus (50 miles minus the 10-mile buffer zone) was the basis for determining specific reception areas. Possible military targets and otherwise unsuitable land areas (swamps, etc.) were then deleted in identifying usable reception areas within the 40-mile annulus. Applying these criteria to closely located cities such as those of the Central Gulf Coast Region, one soon encounters the problem of overlapping reception areas: those which could be claimed by two or more evacuating cities. This problem is resolved by use of a linear programming model which allocates regional reception space on an optimal basis. Its objective is to allocate evacuating population in a manner that will minimize fatalities.

Allocating Contested Space in a Regional Movement-to-Shelter System: A Case Study of the Central Gulf Coast Region (IDA Research Paper P-310) by Grace J. Kelleher, Unclassified, Institute for Defense Analyses, January 1967, 71 pages (Contract OCD-PS-66-113, Work Unit 4131A)

Abstract

This Paper focuses upon the problem of regional interactions in planning movement-to-shelter (MTS) systems. The MTS system envisaged in this research effort is one designed to move urban populations during crises to fallout shelters located in peripheral areas of low target interest. Basic criteria are established for use in defining areas to be evacuated and those to be used as MTS reception centers. The total area to be evacuated includes the urbanized area plus a 10-mile buffer zone. It was assumed that a distance of 50 miles measured from the edge of the urbanized area would be a practical outer bound for the reception region. The resulting 40-mile-wide annulus (50 miles minus the 10-mile buffer zone) was the basis for determining specific reception areas. Possible military targets and otherwise unsuitable land areas (swamps, etc.) were then deleted in identifying usable reception areas within the 40-mile annulus. Applying these criteria to closely located cities such as those of the Central Gulf Coast Region, one soon encounters the problem of overlapping reception areas: those which could be claimed by two or more evacuating cities. This problem is resolved by use of a linear programming model which allocates regional reception space on an optimal basis. Its objective is to allocate evacuating population in a manner that will minimize fatalities.

Allocating Contested Space in a Regional Movement-to-Shelter System: A Case Study of the Central Gulf Coast Region (IDA Research Paper P-310) by Grace J. Kelleher, Unclassified, Institute for Defense Analyses, January 1967, 71 pages (Contract OCD-PS-66-113, Work Unit 4131A)

Abstract

This Paper focuses upon the problem of regional interactions in planning movement-to-shelter (MTS) systems. The MTS system envisaged in this research effort is one designed to move urban populations during crises to fallout shelters located in peripheral areas of low target interest. Basic criteria are established for use in defining areas to be evacuated and those to be used as MTS reception centers. The total area to be evacuated includes the urbanized area plus a 10-mile buffer zone. It was assumed that a distance of 50 miles measured from the edge of the urbanized area would be a practical outer bound for the reception region. The resulting 40-mile-wide annulus (50 miles minus the 10-mile buffer zone) was the basis for determining specific reception areas. Possible military targets and otherwise unsuitable land areas (swamps, etc.) were then deleted in identifying usable reception areas within the 40-mile annulus. Applying these criteria to closely located cities such as those of the Central Gulf Coast Region, one soon encounters the problem of overlapping reception areas: those which could be claimed by two or more evacuating cities. This problem is resolved by use of a linear programming model which allocates regional reception space on an optimal basis. Its objective is to allocate evacuating population in a manner that will minimize fatalities.

Allocating Contested Space in a Regional Movement-to-Shelter System: A Case Study of the Central Gulf Coast Region (IDA Research Paper P-310) by Grace J. Kelleher, Unclassified, Institute for Defense Analyses, January 1967, 71 pages (Contract OCD-PS-66-113, Work Unit 4131A)

Abstract

This Paper focuses upon the problem of regional interactions in planning movement-to-shelter (MTS) systems. The MTS system envisaged in this research effort is one designed to move urban populations during crises to fallout shelters located in peripheral areas of low target interest. Basic criteria are established for use in defining areas to be evacuated and those to be used as MTS reception centers. The total area to be evacuated includes the urbanized area plus a 10-mile buffer zone. It was assumed that a distance of 50 miles measured from the edge of the urbanized area would be a practical outer bound for the reception region. The resulting 40-mile-wide annulus (50 miles minus the 10-mile buffer zone) was the basis for determining specific reception areas. Possible military targets and otherwise unsuitable land areas (swamps, etc.) were then deleted in identifying usable reception areas within the 40-mile annulus. Applying these criteria to closely located cities such as those of the Central Gulf Coast Region, one soon encounters the problem of overlapping reception areas: those which could be claimed by two or more evacuating cities. This problem is resolved by use of a linear programming model which allocates regional reception space on an optimal basis. Its objective is to allocate evacuating population in a manner that will minimize fatalities.