Household Dislocation Algorithm 1:
*A Modified HAZUS Approach**

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After a severe disaster residents may leave their homes willingly or unwillingly for a variety of reasons such as structure damage, housing repair or remodeling, utility failures, request or requirements to leave by building owners or public officials, job loss, suspension of public service (transportation), or general neighborhood degradation. Dislocated households can face many difficulties. For example, there may be extra expenses and stress associated with the need to relocate and reestablish new living arrangements. For homeowners, repairing or rebuilding of their original home can be made more difficult because of distance and require additional transportation expenses as the work is undertaken and monitored. There may also be additional transportation costs as household members travel to jobs or schools located closer to their original homes. In addition, many dislocated residents will have limited alternative living choices (e.g. home of relatives or friends, rental units, or hotels etc.), which may force reliance on public shelters and temporary housing solutions which will often, of necessity, be provided by the local, state, or federal government. The loss of population will also have consequences for local business as they attempt to recover and reestablish themselves.

In light of these issues it is important for emergency managers, planners, concerned community organizations, businesses, and policy makers to be able to estimate dislocation patterns that might follow a disaster so that pragmatic emergency response planning and efficient deployment of response and recovery resources can be undertaken. By knowing the numbers of households likely to be dislocated and the dislocation pattern within an area, policy makers can take actions to reduce disorder during the emergency and response stages, and potentially enhance restoration and recovery processes.

Basic logic behind this approach:

The following algorithm is based on a *modified HAZUS* approach for estimating household dislocation. HAZUS derives it estimates of dislocated households based on aggregate census tract data and damage estimates. Damage estimates are used to derive the percent of single-family dwelling units in *complete* damage state and the percent of non-single family structures (multifamily) in both *extensive* and *complete* damage states for each census tract. These figures are then weighted and multiplied by the number of single and non single-family dwelling units respectively to estimate the total number of dwelling units that will generate dislocated households, which in turn is multiplied by the average number of household per dwelling unit to derive the number of dislocated households for a census tract.

We term the approach specified in this document a *Modified HAZUS* approach because it employs the basic logic utilized by HAZUS, however it differs in a number of important ways. First, it will utilize damage state probabilities ($P_{i|IM}$) for <u>each</u> residential structure following Bai, Hueste and Gardoni (2006). These structure based estimates are likely to be different those utilized by HAZUS. Second, we will employ damage states also propose by Bai et al (2006) which are different but comparable to HAZUS and these damage states will be weighted by *dislocation factors* in a fashion similar to HAZUS. Our approach also utilizes the richer structural inventory data for the MTB which provides data on the actual number of dwelling units per residential structure. Rather than predicting household dislocation by tract, this approach will use census block-groups as the base level of aggregation because block-groups are likely to be more meaningful to planners and emergency managers. Finally, we will recommend that maps of the spatial distribution of dislocated households by block-group also be generated to facilitate planning.

The Modified HAZUS Dislocation Algorithm

I. Base data requirements.

1. **Census data at the block group level:** In the HAZUS package, the data at Census tract level of aggregation are used to estimate possible dislocation household. Block group data are used here to estimate more detailed information thereby facilitating planning within local communities and counties. The following are the data needed for the dislocation algorithm that are part of the Shelby County US Census data provided by French and Muthukumar. These data are also available in the downloadable zip file created for the social vulnerability algorithm at http://thelab.tamu.edu/students/j0l2853/web/sv.zip . They are in the file called: shelby_sv_tnsp.dbf.

   Variable name → Variable definition
   - TOT_HH → Total No. of Households
   - TOT_HU → Total Housing Units

   The above data are employed to calculate the average number of households per dwelling unit.

2. **From the inventory data:** The modified HAZUS algorithm will require data from the Shelby County Inventory data (v4.0) produced by French and Muthukumar. The algorithm will be executed for <u>residential structures</u> only. It is therefore critical that MAEViz be able to clearly identify residential structures and these structures must be clustered into their respective census block-group areas. In the inventory data (v4.0) structure type is recorded under the variable: OCC_TYPE. While there are a variety of types of structures, the algorithm should only be run using single family residential structures (RES1) and multi family structures (RES3). The dislocation algorithm will also need the number of dwelling units per structure from the inventory data. Following the inventory data names the dwelling units for structure *k* will be designated NO_DU_k. So, the variables needed from the Inventory data (v4.0) are:

   Variable name → Variable definition
   - OCC_TYPE → Structure occupation type. The algorithm needs only single family structures (RES1) and multi-family structures (RES3)
   - NO_DU → No. of dwelling units in the structure. NOTE if this is missing for RES1, assume the value is 1.

3. **Damage State Probabilities ($P_{i|IM}$):** The final critical data necessary for these calculations will be the Damage State Probabilities for each residential structure given the intensity measures ($P_{i|IM}$) for an earthquake event or scenario. The damage state probabilities ($P_{i|IM}$) are those discussed by Bai, Hueste and Gardoni (2006). These will be combined with Dislocation Factors (see Table 1 below) for single family and multi-family (non-single family) residential structures to determine the dislocation probability for each residential structure given the damage state probabilities for a given intensity measure.

II. Dislocation assumptions: The HAZUS model, assumes that structure damage is the only factor driving household dislocation and it differentiates residential housing into two forms single family and multifamily (i.e., non-single family) residential structures. The possibility of household dislocation is based on the damage states of these two forms of housing. Specifically the expectation is that single-family housing in slight, moderate, and extensive damage states and multifamily housing in slight and moderate damage states will not result in household dislocation. On the other hand, it is assumed that100% of the household in completely damaged single family and multifamily housing will be dislocated, and that 90% of the households in extensively damaged multifamily housing are dislocated. We will employ the same basic logic, however the damage state categories proposed by Bai, Hueste and Gardoni (2006) – Insignificant (I), Moderate (M), Heavy (H), and Complete (C) – will be employed. The dislocation factors (*DisF*) for each state and for each type of residential structure are presented below in Table 1.

Table 1. Dislocation Factors by Damage States

Proposed MAE Damage States	Dislocation factors	
	Single Family $\left(DisF_{sf_i}\right)$	Multi-family $\left(DisF_{mf_i}\right)$
Insignificant (I)	0.0	0.0
Moderate (M)	0.0	0.0
Heavy (H)	0.0	0.9
Complete (C)	1.0	1.0

III. Process for estimating dislocation household for block group:

1. **Calculate average number of households per dwelling unit by block-group**, **$AveHhDu_{bg}$:** By calculating the average number of households per dwelling units we get some notion of the number of households adjusting for occupancy rates. This adjusted mean will be used to estimate the number of dislocated households.

   - $AveHhDU_{bg} = TOT\_HH / TOT\_HU$

2. **Calculating the dislocated households:** The following assumes that these calculations will 1) be produced for residential structures [OCC_TYPE=RES1 or RES3] and 2) that structures can be identified as single-family [RES1] or multi-family (non-single family) [RES3] structures. NOTE the $P_{i|IM}$ value is generated following Bai, Hueste and Gardoni (2006). In other words, $P_{i|IM}$ is the probability associated with each damage state (I, M, H, and C) for a particular structure given a specified intensity measure (S_a).

a. Calculating the number of households dislocated for each structure based on whether it is a single family (RES1) or multi-family structure (RES3):

1. Calculating the number of dislocated households for each single family [OCC_TYPE=RES1] structure *k.* This formula does not include NO_DU_k as will be included in the next formula because the number of dwelling units is assumed to be one for single family:

- $HhD_{sf_k} = \sum_{i=1}^{4} \left(DisF_{sf_i} \times P_{i|IM} \right) \times AveHhDU_{bg}$

2. Calculating the number of dislocated households for each multi-family [OCC_TYPE=RES3] structure k:

- $HhD_{mf_k} = \sum_{i=1}^{4} \left(DisF_{mf_i} \times P_{i|IM} \right) \times NO\_DU_k \times AveHhDU_{bg}$

b. Calculate the number of dislocated households: The following recommends generating a total number of dislocated households by block group. Calculation of the total number of displaced household in the block group, **DisHh$_{bg}$**, is simply the sum of dislocated single and multi family households in each block-group. It might also make sense to calculate the percentage of households dislocated from the block-group, **PDisHh$_{bg}$.**[1] In these formulas, the K stands for the total number of residential structures (buildings) of each type (single [K_{sf}] and multifamily [K_{mf}]).

- $DisHh_{bg} = \sum_{k=1}^{K_{sf}} HhD_{sf_k} + \sum_{k=1}^{K_{mf}} HhD_{mf_k}$; where K_{sf} and K_{mf} are the number of single and multi family structures respectively.

- $PDisHh_{bg} = \left(DisHh_{bg} / TOT\_HH_{bg} \right) 100$

c. Aggregate the total number of dislocated households for a jurisdiction by simply summing across block-groups in the jurisdiction, **TotDh$_j$.** The default should be the County (i.e., Shelby) but the user should be able to define areas (with the caveat/warning that block-groups may not conform to the jurisdictional boundaries one might be interested in).

- $TotDh_j = \sum_{i=1}^{n} DisHh_{bg_i}$

IV. Expected output:

1. First there should be a report of dislocated household by block group and the total number of dislocated household at county level. See Appendix 4.
2. Second, there should also be a map of number of displaced household by block group (using **DisHh$_{bg}$**). See Appendix 5.
3. Third maps of percent of displaced household within the block group (using **PDisHh$_{bg}$**). See Appendix 6.

V. A note on uncertainties:

It should be noted that the *modified HAZUS* approach presented above relies heavily on Bai, Hueste and Gardoni's (2006). Drawing upon the logic of their work, it would be possible to consider HhD_{sf} as the mean dislocation, $\hat{u}_{HhD_{sf}|IM}$, for structure i given a certain intensity

[1] Note: Since the total number of households is taken from U.S. Census data and the displaced households will be estimated based on structures in a block-group from the inventory data, it is possible that these percentages may be problematic, particularly in communities experiencing rapid development since the census data were collected.

measure. Furthermore, continuing with their logic, it would appear that one might be able to calculate the standard deviation, $\hat{\sigma}_{HhD_{sf}|IM}$, and hence develop confidence intervals and prediction intervals, by following the procedure they outlined. However, that would require some degree of confidence in the dislocation factors ($DisF_{sf}$ and $DisF_{mf}$ or, employing their symbology, $\mu_{DisF_{sf_i}}$ and $\mu_{DisF_{mf_i}}$) treating them as mean values for dislocation probabilities given specific damage states (I, M, H, and C). Unfortunately there are no systematically collected data from which the dislocation factors suggested by HAZUS were based other than expert opinion (founded on qualitative interviews of dislocated households). Hence extending the logic they suggest for the estimation of dislocated households may well be questionable.

In addition, the procedure Bai et. al., (2006) suggest derives confidence intervals and prediction bands for a particular structure, while the goal here is to develop estimates for a block-group and ultimately some jurisdiction, such as a county or municipality. I suppose we could consider $DisHh_{bg}$ a random variable and thereby calculate a mean ($\hat{\mu}_{DisHh_j}$) and standard deviation ($\hat{\sigma}_{DisHh_j}$) for a given jurisdiction (such as a county) to derive confidence intervals. However, it would be difficult to ignore the issue that the estimates themselves (particularly the dislocation factors) are derived from a paucity of empirical evidence. Additional concerns would be that we are dealing here with multiple error sources (e.g., in the dislocation factors, in the applications of multiple fragility curves across a variety of residential structure types) that would undoubtedly propagated through the process of deriving these estimates. Furthermore, I would doubt that the error is randomly distributed throughout an area. For example, the algorithm is likely to generate error somewhat proportional to the distance from areas of highest damage (i.e., work better near areas of higher levels of damage generating higher errors as one moves away from those areas). All of these factors should be considered as we attempt to develop some notion of the uncertainties in estimation. The simple fact is that there are almost no systematic studies that have attempted to document actual dislocation resulting from any form of disaster, for any period of time.

Appendix 1. Variable List

Variable Name	Description	Note
TOT_HH	Total No. of Households	2000 Census (from Dr. French)
TOT_HU	Total Housing Units	2000 Census (from Dr. French)
$DisF_{sf_i}$	Dislocation Factor for Single Family structures by damage state	See Table 1, based on HAZUS
$DisF_{mf_i}$	Dislocation Factor for Multi-family structures by damage state	See Table 1, based on HAZUS
$AveHhDU_{bg}$	Average number of household per multi-family structure	TOT_HH / TOT_HU
$P_{i\|IM}$	Probability of each damage state for a structure (residential in this case) given IM	Based on Bai, Hueste and Gardoni (2006)
NO_DU_k	Number of dwelling units in a particular residential structure k	From Building Inventory Data for Shelby County (v4.0)
OCC_TYPE	Occupancy type (type of structure) This algorithm only needs **RES1** and **RES3** structures	From Building Inventory Data for Shelby County (v4.0)
HhD_{sf_k}	Estimated dislocated households for each single family structure in a given block group. Note, NO-DU$_k$ is not included because the number of dwelling units is assumed to be 1.	$\sum_{i=1}^{4}\left(DisF_{sf_i} \times P_{i\|IM}\right) \times AveHhDU_{bg}$
HhD_{mf_k}	Estimated dislocated households for each multi-family structure in a given block group.	$\sum_{i=1}^{4}\left(DisF_{mf_i} \times P_{i\|IM}\right) \times NO\_DU_k \times AveHhDU_{bg}$
$DisHh_{bg}$	Estimated number of dislocated households for a given block.	$\sum_{k=1}^{K} HhD_{sf_k} + \sum_{k=1}^{K} HhD_{mf_k}$
$PDisHh_{bg}$	Percent of block group households dislocated	$\left(DisHh_{bg} / TOT\_HH_{bg}\right) \times 100$
$TotDh_j$	Estimated total households in a jurisdiction dislocated	$\sum_{i=1}^{n} DisHh_{bg_i}$

Appendix 2. Example Calculations for a single block-group with only Four Structures. The first two structures are multi-family residential structures (OCC_TYPE=RES3) and the final two are single family residences (OCC_TYPE=RES1).

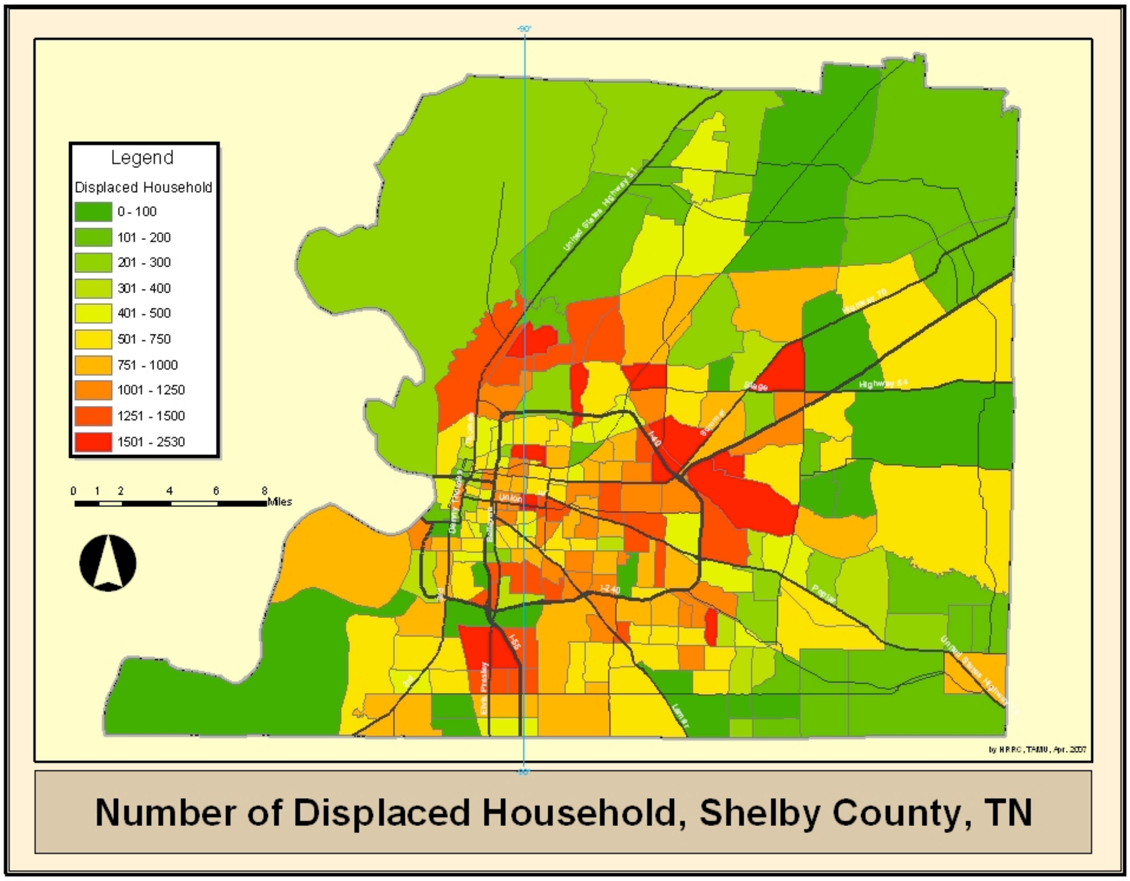
Multi-family structures (OCC_TYPE = RES3)	Multi-family structure with 10 dwelling units (*NO_DU=10*)	Probability ($P_{i\|IM}$)	Dislocation Factor ($DisF_{mf}$)	$P_{i\|m}$ X $DisF_{mf}$	*AveHhDUbg* = .94
	Damage State	(S_a = 0.488g)			
	Insignificant (I)	0.063	0	0	
	Moderate (M)	0.094	0	0	
	Heavy (H)	0.256	0.9	0.2304	
	Complete (C)	0.587	1	0.587	
			$\sum_{i=1}^{4}\left(DisF_{mf_i} \times P_{i\|M}\right) =$	.8174	$HhD_{mf_1} = .8174(10)(.94) = 7.68356$
	Multi-family structure with 30 dwelling units (*NO_DU=30*)				
	Damage State	(S_a = 0.277g)			
	Insignificant (I)	0.118	0	0	
	Moderate (M)	0.485	0	0	
	Heavy (H)	0.224	0.9	0.2016	
	Complete (C)	0.153	1	0.153	
			$\sum_{i=1}^{4}\left(DisF_{mf_i} \times P_{i\|M}\right) =$	.3546	$HhD_{mf_1} = .3546(30)(.94) = 10.0$
single-family structures (OCC_TYPE = RES1)	Single-family 1 (*NO_DU=1*)	Probability ($P_{i\|IM}$	Dislocation Factor ($DisF_{sf}$)	$P_{i\|m}$ X $DisF_{sf}$	
	Damage State	(S_a = 0.488g)			
	Insignificant (I)	0.063	0	0	
	Moderate (M)	0.094	0	0	
	Heavy (H)	0.256	0	0	
	Complete (C)	0.587	1	0.587	
			$\sum_{i=1}^{4}\left(DisF_{sf_i} \times P_{i\|M}\right) =$	.587	$HhD_{sf_1} = .587(1)(.94) = .5578$
	Single-family 2 (*NO_DU = 1*)				
	Damage State	(S_a = 0.277g)			
	Insignificant (I)	0.118	0	0	
	Moderate (M)	0.485	0	0	
	Heavy (H)	0.224	0	0	
	Complete (C)	0.153	1	0.153	
			$\sum_{i=1}^{4}\left(DisF_{sf_2} \times P_{i\|M}\right) =$	.153	$HhD_{sf_2} = .153(1)(.94) = .14382$

$$DisHh_{bg} = \sum_{k=1}^{K} HhD_{sf_k} + \sum_{k=1}^{K} HhD_{mf_k} = 17.68356 + .70162 = 18.38518 \cong 18.4$$

Appendix 3. Example of a fictions report of displaced household by jurisdiction (Shelby county) and by census block group.

	Number of Displaced Household	Percent of Displaced Household
Shelby County, TN		
	153232	46%
Block Group		
47157XXXXXXXX	383	73%
47157XXXXXXXX	453	68%
47157XXXXXXXX	494	59%
47157XXXXXXXX	231	71%
47157XXXXXXXX	673	58%
47157XXXXXXXX	1592	69%
………………..		
47157XXXXXXXX	797	55%
47157XXXXXXXX	921	59%
47157XXXXXXXX	858	59%

Appendix 4 Example Number of Dislocated Household Map



Appendix 5 Example of Percent of Dislocated Household Map