

A Web-based System for Optimizing Post Disaster Temporary Housing Allocation

Lei Chen

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Committee:

Zelda B. Zabinsky

Omar El-Anwar

Joseph A. Heim

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ABSTRACT

Thesis Title: A Web-based System for Optimizing Post Disaster Temporary Housing Allocation

Lei Chen

Chair of the Supervisory Committee:

Zelda B. Zabinsky

Omar El-Anwar

Natural catastrophes can result in large scale displacement of populations, who are in urgent need of temporary quarters until permanent housing can be provided. During this period, the temporary housing plays an important role in the families' physical, psychological, social and economic recovery. A number of research studies have addressed this specific temporary housing problem and aimed at identifying the optimal temporary housing arrangements, but few used quantitative methods to incorporate the displaced families' specific socioeconomic needs and housing preferences. From the decision makers' perspective, current temporary housing practices often result in high cost, late delivery and frequent family complaints caused by improper allocation. The scale and complexity of the problem requires strategic planning and a fast decision support system.

The main objective of this thesis is to present a way of effectively matching available temporary housing resources to displaced families' social, economic and psychological needs with the minimum required public expenditure. A new web-based post disaster temporary housing

management system is developed to accomplish this task. It fully considers individual family's specific needs and provides comprehensive decision support.

The web-based system first solicits and stores the data from potential housing providers. It applies Google Map® in the user interface to facilitate data acquisition. The collected families' needs and preferences are then translated into a socioeconomic index to evaluate housing alternatives. In order to maximize overall families' utility and minimize expenditure, a multi-objective optimization module is formulated using the classic weighted sum method. A customized Hungarian Algorithm is developed to solve the optimization problem. In addition, the system also provides decision support for the total cost and overall socioeconomic benefit trade off and cost-benefit analysis for various potential housing.

The web-based system can significantly improve the current temporary housing practices. It has a user friendly interface and allows families to better describe their requirements. With the customized Hungarian Algorithm the optimization process won't cause computer out of memory in the large scale problems and it saves significant running time. The computational speed and efficiency of the system enables its use in the response phase following a disaster, where it can offer high quality allocation solutions with low cost.

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I. INTRODUCTION

1.1. Overview and Problem Statement

Natural catastrophes can cause large scale displacement of populations, who are in urgent need for temporary quarters until new permanent housing can be provided or their pre-disaster housing can be repaired. During this critical period, the temporary housing location plays a significant role in the displaced family's psychological, social, and economic recovery. When selecting the housing location it is essential to meet a number of needs (which can vary from household to another), such as proximity to jobs, kinship ties, educational facilities (K-12 and/or higher education), social support networks, religious groups, healthcare facilities, and public transportation and important services (Bolin and Bolton 1986; El-Anwar et al. 2008; El-Anwar et al. 2010c; FEMA 2005a; FEMA 2005b; FEMA 2007; Hidayat and Egbu 2010; Johnson 2002a; Johnson 2002b; Quercia and Bates 2002; Rakes et al. 2010; Shlay 1995). The poor selection of temporary housing locations can add to the displaced families' compound stresses after the disaster and disrupt their neighborhood patterns, social support networks, and familiar surroundings (Bolin and Bolton 1986). The inability to meet the families' needs can result in a wide range of consequences; starting from families rejecting the offered temporary housing because of its unreasonable distance from their jobs and ending by high suicide rates due to loneliness and despair attributed to being cut off from their communities (Comerio 1998; Johnson 2007; Tomioka 1997).

For decades, post-disaster temporary housing programs have been criticized for their inability to meet the expectations of displaced populations. This criticism stems from various reasons, including (1) the temporary housing late delivery (Bolin 1993; Friday 1999; Johnson 2007); (2) inability to fulfill the social, psychological, and economic needs of displaced families (Bolin 1982; Bolin and Bolton 1986; Comerio 1998; Friday 1999; Golec 1983; Johnson 2007; Lizarralde and Johnson 2003; Tomioka 1997); and (3) poor accessibility of temporary housing locations to essential services and public transportation (Bolin 1993). Despite their poor performance, many temporary housing programs tend to be expensive, which draws from the limited budgets available for recovery and reconstruction (Friday 1999; Johnson 2002a).

1.2. Literature Review and Research Gap

A number of research studies have addressed the specific problem of identifying the optimal configurations of temporary housing arrangements in a timely manner following disasters. Three representative types of models are explained as follow:

Model 1: The first model aims to achieve a specific type of objective, which includes maximizing temporary housing structural safety (El-Anwar et al 2010a), minimizing the environmental impacts of constructing and maintaining post-disaster accelerated housing projects (El-Anwar et al 2010b) and minimizing the distance between the assigned temporary housing and the preferred location by families (El-Anwar and El-Rayes 2007).

Model 2: The second model was designed to identify the optimal locations and types of temporary housing in order to achieve various socioeconomic, safety, environmental, and cost objectives (El-Anwar et al. 2009b; Kandil et al. 2010). Despite the significant contributions of this formulation to improving temporary housing practices, it did not aim at capturing the specific needs of each displaced family. In this case, the number of decision variables was equal to the number of available temporary housing alternatives (H).

Model 3: The third model maintained the same optimization objectives as Model 2. However, it categorized the families based on their preferred locations for temporary housing (e.g., zip codes or census tracts), and the corresponding optimization models accounted for these preferences when optimizing temporary housing assignments (El-Anwar et al. 2009a; El-Anwar et al. 2010; McLaren et al. 2009). Accordingly, the decision variables for this formulation were equal to the number of available temporary housing alternatives (H) multiplied by the number of preferred housing locations (L) resulting in a running time in the order of one hour on consumer-grade computers.

Despite the significant contributions of the aforementioned models in optimizing temporary housing arrangements, there is a need for an innovative methodology that can explicitly account for the displacement distance and housing characteristics from various socioeconomic needs and effectively evaluate housing assignments based on the individual needs of each family.

Besides, as the complexity of the model increases, the running time also increases significantly. The new model, as it attempts to capture each family's specific socioeconomic needs as well as temporary housing characteristics and optimize housing decisions accordingly, will have a challenge to keep the running time in the acceptable range.

1.3. Research Objectives and Research Methodology

The main objective of this thesis is to present a system which can effectively match available temporary housing alternatives to displaced families' social, economic and psychological needs with the minimum required public expenditure. It should incorporate sufficient strategic planning so as to reduce the response time. And the system must

improve on the disadvantage of current temporary housing practice and offer comprehensive decision support to the emergency management agencies.

The research methodology can be divided into eight major tasks: 1) conduct comprehensive literature review; 2) build the interface to effectively capture the specific needs and preferences of each displaced family; 3) appropriately quantify the performance of candidate temporary housing configurations in fulfilling the families' specific needs; 4) account for and control temporary housing projects life cycle costs; 5) develop a multi-objective optimization model to maximize families utility while minimizing the life cycle cost; 6) minimize the computational requirements or find an efficient algorithm when solving the associated large-scale optimization problem; 7) provide adequate decision support tools for decision makers; and 8) report the output to the families and housing providers once the decision is made. In order to accomplish these tasks, a new integrated post-disaster temporary housing management system is needed.

The system will have a big contribution in the disaster management field; it transforms the one-size-fits-all housing program to a need-tailored approach which considers every displaced family's needs. Furthermore, the system can be applied in many other contexts where the problem aims to match the individual demands to various supplies in different locations. The algorithm developed for the multi-objective optimization is also of great value in optimizing similar assignment problems. As a result, the systematic approach and optimization tool makes this thesis a contribution to Industrial and Systems Engineering as well.

1.4. Thesis Organization

Figure 1.1 shows the general structure of the system and the interrelation among different modules. The following chapters will describe each module in detail.

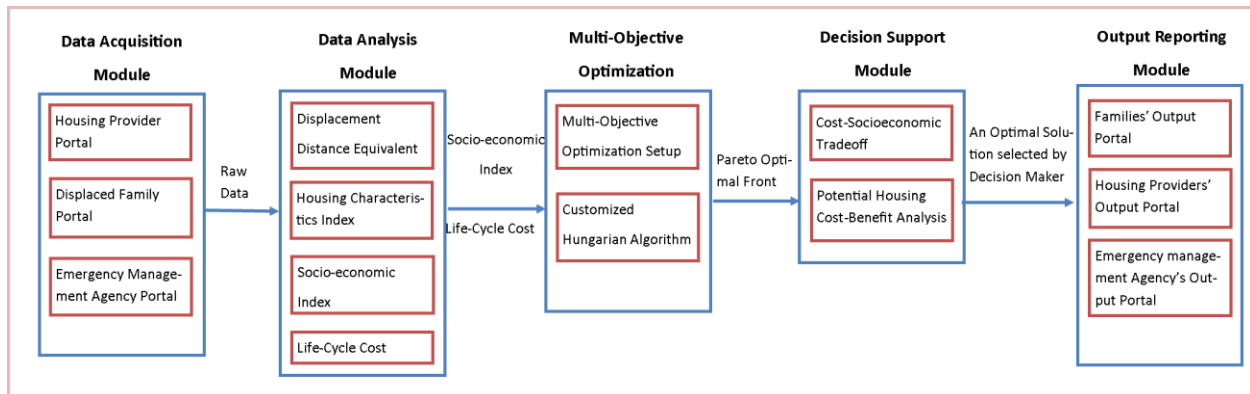


Figure 1.1. General Structure of the System

Chapter II - Data Acquisition Module: This chapter introduces web portals for data acquisition from displaced families, housing providers and Emergency Management Agency. The Emergency Management Agency is the decision maker in the system. A brief explanation of the database is also presented in this chapter.

Chapter III - Data Analysis Module: This chapter explains how the system processes the raw data and uses the socio-economic index to evaluate the performance of candidate temporary housing in fulfilling families' needs.

Chapter IV- Multi-Objective Optimization Module: This chapter presents the formulation of the optimization module, and describes the customized Hungarian algorithm.

Chapter V - Decision Support Module: This chapter explains the Cost-Socioeconomic tradeoff and Potential Housing Cost Benefit Analysis support functions.

Chapter VI - Output Reporting Result: This chapter briefly shows the way that the system reports the housing assignment to family and display assignment family list to the housing providers.

II. DATA ACQUISITION MODULE

The Data Acquisition Module is the front-end of the web-based system; the objective is to quickly collect the information necessary to provide families with the housing solutions that would fulfill their needs. It has three web-portals that serve the Displaced Families, Housing Providers, and Emergency Management Agencies (as in Figure 2.1). This section briefly introduces each of the web portals and explains the underlying database structure. The portals are capable to run in various browsers, and with the fast development of mobile technology, the module enables the system to quickly identify the families' socioeconomic needs and effectively allocate available housing close to the impacted areas.

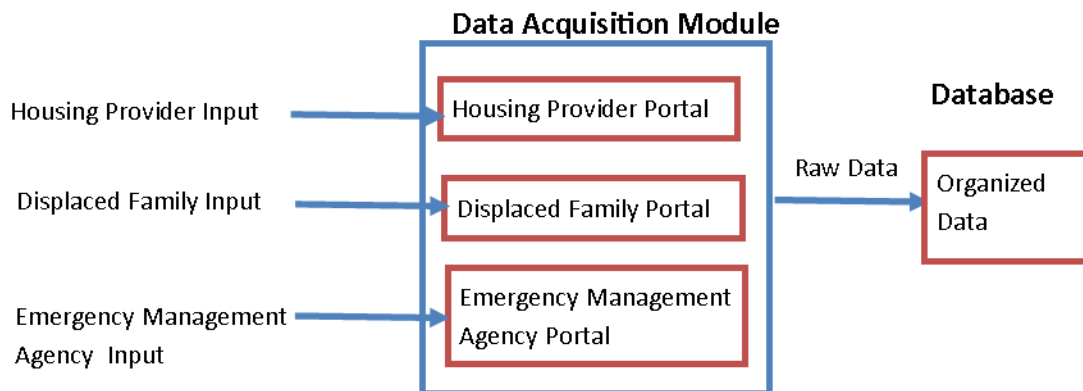


Figure 2.1. The Structure of Module 1

2.1.Housing Provider Portal

The Housing Provider Portal is an important component for strategic planning in the temporary housing management program. It collects all the housing alternative providers' information prior to disaster occurrence. This housing data allows emergency management agencies to evaluate the size of the housing market and access a large pool of housing information immediately after a disaster happens.

The housing alternative providers include hotels, motels, housing rental businesses, etc. Before any disaster occurs, the data housing providers are invited to input includes: (1) housing type and address; and (2) housing characteristics such as housing quality using a pre-defined rating system, level of access to public transportation and other essential services, neighborhood safety, etc. When a disaster occurs, the emergency management agencies need to first re-examine the housings, make sure the housing is in good condition for displaced families. The qualified housing providers are requested to provide the number of available housing units, their prices and sizes, and availability dates.

The screenshot displays the 'Temporary Housing Management' web application. At the top, there is a navigation bar with 'FAMILIES', 'HOUSING PROVIDERS', and 'EMERGENCY MANAGEMENT AGENCY'. The main title is 'Temporary Housing Management'. Below the title, there are two main sections: 'After Disaster' and 'Before Disaster'. The 'After Disaster' section is on the left and contains a form for entering housing provider details, including room counts and rates for normal, ADA, and large rooms, along with an availability date. The 'Before Disaster' section is on the right and contains a form for entering provider information, including name, address, stars, and various utility and transportation access levels. A map of the San Francisco Bay Area is visible on the right side of the interface, showing various locations and a marker. The interface includes buttons for 'RESET', 'SAVE ONLY', and 'SAVE & LOG IN'.

Figure 2.2. Input Interface for Housing Provider

2.2. Displaced Families Portal

The Displaced Families Portal is the web page for collecting displaced families' needs and preference about temporary housing. After disasters happen, the emergency management agency can provide the URL of the portal to the families. They will be able to view the housing alternative information, create their account and enter needs and preference into the system.

Before entering their needs and preference, displaced families can first view the housing information that the emergency management agency selected. A study suggested that comprehensive information can significantly reduce human judgment error, which in our case suggests that the information can guide families to input what truly reflects their needs and preference (Kruglanski and Icek 1983). The system is able to display location, quality, neighborhood safety, unemployment rate and key service levels of each housing (Figure 2.3). Each marker represents a housing alternative, the stars on the marker indicate the quality level of the housing, and the detail information window pumps up when the families click one of the markers.

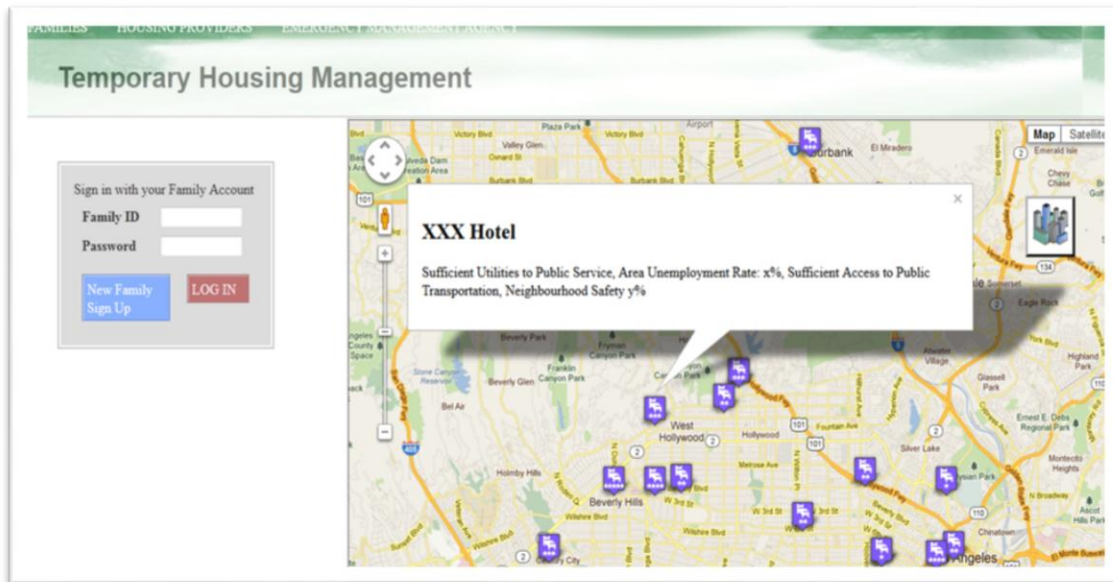


Figure 2.3. The Information about Housing Alternatives

The system allows families to create an account. This will expedite the process to collect information of displaced families, especially in disasters where the number of families are increasing over time. However, not all of the accounts are necessarily processed, the emergency management agency needs to verify and organize all the accounts. Only the selected or filtered accounts will be finally assigned with temporary housing.

When displaced families apply for temporary housing, they use the portal to provide 3 categories of information. The first category is the location needs, it includes (1) original family location; (2) preferred location for temporary housing; (3) locations they need to be close to (e.g., jobs, kinship ties, pre-disaster location, college, etc.); and (4) services they need to be close to (e.g., K-12 public schools, healthcare and eldercare facilities, etc.). The second category is the housing characteristics (e.g., safety, housing quality, access to public services, access to public transportation, etc.). This system requires families to identify their preferences among their location needs as well as the importance of the various housing characteristics to them. The system uses the absolute scale (0-100%) and computes the importance weight for each of the family's location needs and housing characteristics. The third category is the overall preference between the location needs and housing characteristics needs. It also uses the absolute scale (0-100%). Figure 2.4 shows the system screenshot for entering each of the categories of information.

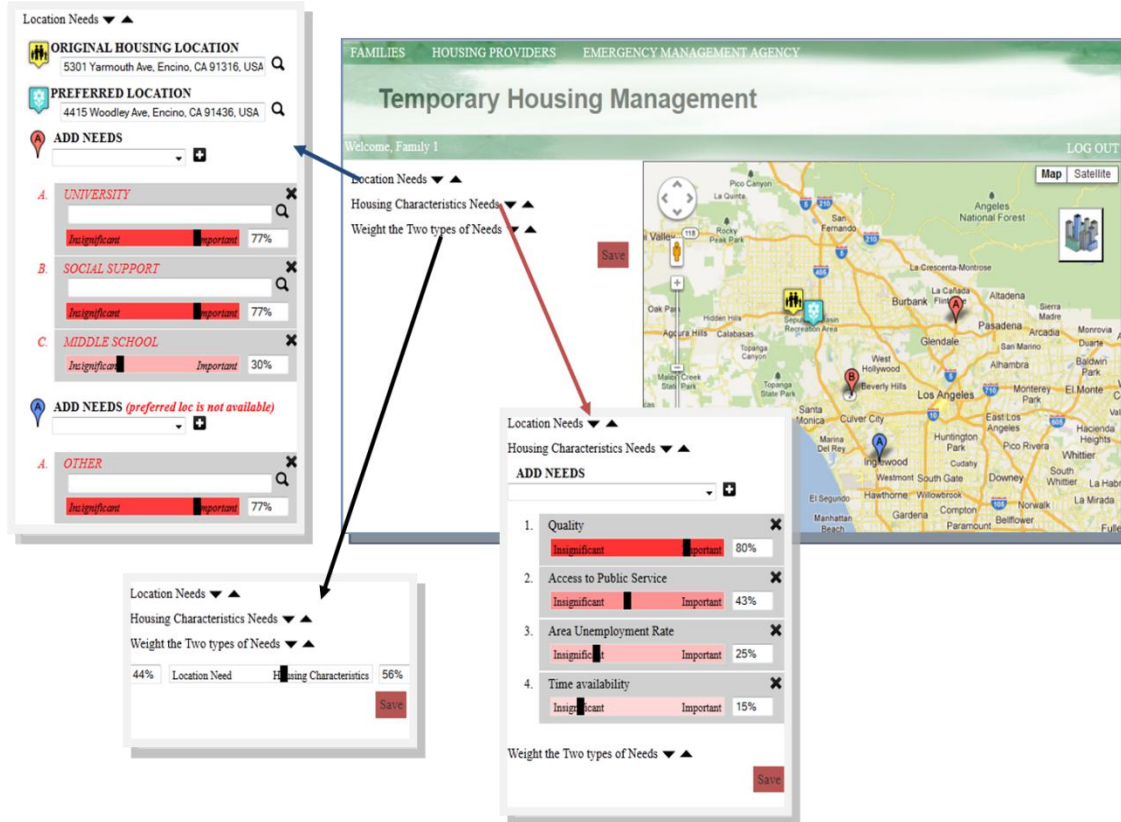


Figure 2.4. The Input Interface for Displaced Families

The input window for families is designed as a registration form. The location identification functions use Google Maps, where families can search the locations with partial address information (e.g., zip code) or using a drag-and-drop marker. The Google Map services are fast, simple, and very familiar to most of the families. It has the advantage of integrated satellite maps, the built in geocoding service provides excellent accuracy which is very important for the data analysis module.

2.3. Emergency Management Agency Portal

This portal allows emergency management agency planners to retrieve, edit families' and housing providers' data and define decision making parameters. As the administrator of the system, the planners have the authority to add and delete families and housing providers' record. By examining the situation, they can determine the priority of families and condition of housing alternatives. They also decide which housing information is to be viewed by the families and the specific types of needs can be selected in the Displaced Families Portal. The decision making parameters will be discussed more in the Data Analysis Module, changing those parameters will affect the assignments results.

2.4. Database

The database stores the data collected from three web portals as well as the assignment results when the final decisions are made. The database manages the data in a very efficient manner, which supports the data analysis module and multi-objective optimization module to retrieve data.

Figure 2.5 illustrates the overall relational database structure of the system. The “displaced_family” table contains the basic information of families. The location and housing characteristics needs of the families are stored in the “need_input” and “char_need_input” tables, respectively. The “housing” table contains the basic information of the housing alternatives, where the types of the housing characteristics are stored in the “housing_char” table. The final assignment table stores the optimization results, where each family will be assigned one housing unit.

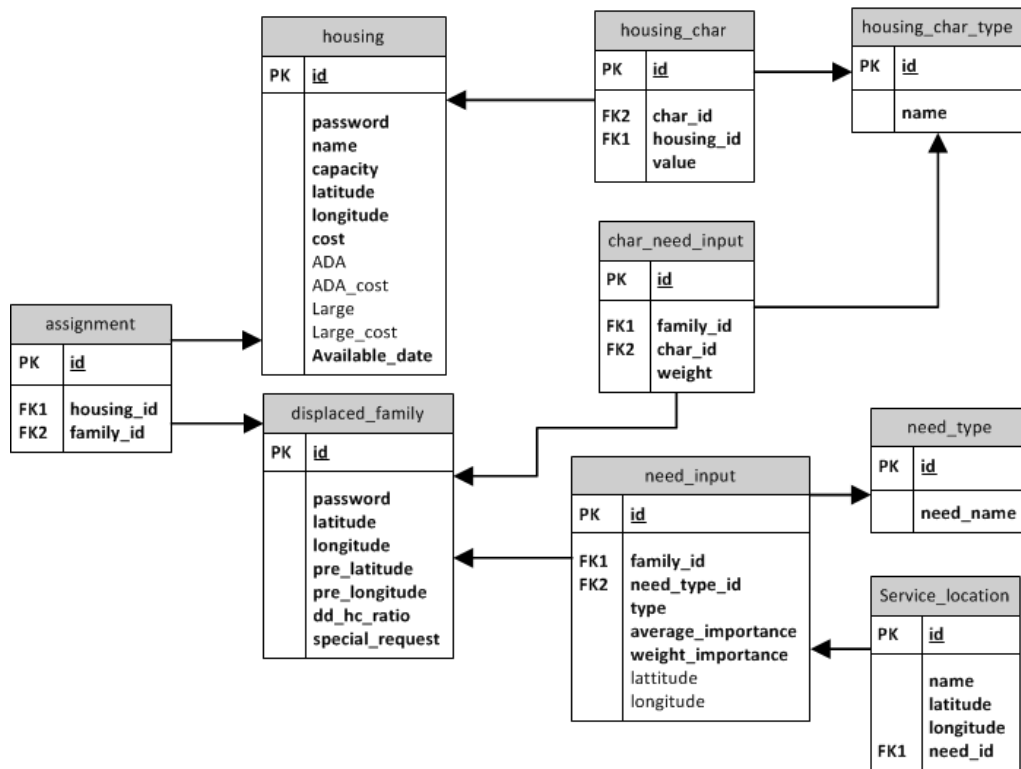


Figure 2.5. Database Structure

III. DATA ANALYSIS MODULE

The Data Analysis Module enables the system to use the collected families' needs to evaluate all housing alternatives where it calculates a socioeconomic index to represent the level to which each housing alternative satisfies a family's socioeconomic needs. The socioeconomic index will be used later as one of the objective function coefficients in the multi-objective optimization module.

Before the socioeconomic index can be calculated, it is worthwhile to study some key factors about temporary housing that can significantly affect the displaced families' socioeconomic recovery. Previous research suggested that the significant factors include housing quality, housing delivery time, access to public transportation and other essential utilities and services, neighborhood safety, proximity to jobs and schools, distance from pre-disaster location and social support networks, and proximity to healthcare and eldercare facilities (Bolin and Bolton 1986; Comerio 1997; El-Anwar et al. 2008; El-Anwar et al. 2010c; FEMA 2005a; FEMA 2005b; FEMA 2007; Friday 1999; Hidayat and Egbu 2010; Johnson 2002a; Johnson 2002b; Quercia and Bates 2002; Rakes et al. 2010; Shlay 1995). The Data Analysis Module classifies these socioeconomic factors under two main categories: (1) displacement distance category, which includes factors that are of specific interest to some families and are functions in the distance between the proposed housing and some locations, such as proximity to jobs and schools, distance from pre-disaster location and social support networks, and proximity to healthcare and eldercare facilities; and (2) housing characteristics category, which includes the general factors that are expected to be of interest to all displaced families, such as housing quality, housing delivery time, access to public transportation and other essential utilities and services, and neighborhood safety. The families' location needs collected in the Data Acquisition Module will be processed to evaluate housing under the displacement distance category, while the housing characteristics needs are used under the housing characteristics category.

There are three main phases to calculate the socioeconomic index: (1) identifying the location needs of displaced families using a displacement distance equivalent index; (2) computing a housing characteristics index to account for the families' preferences in housing characteristics as well as its location attributes; and (3) combining the two indices to evaluate the overall impact of the each available housing alternative on the family's social and economic recovery using a socioeconomic index. In addition to maximizing socioeconomic benefit, reducing cost is also a key objective of system. Hence, this module also accounts for the life cycle costs associated with developing each temporary housing project or procuring housing service. The general structure of this module is shown in the Figure 3.1.

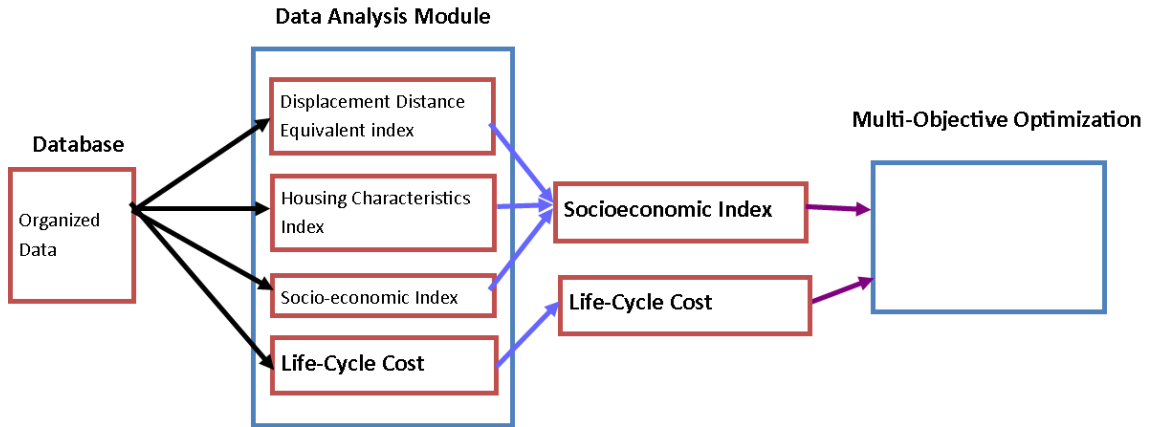


Figure 3.1. The Structure of Module 2

3.1. Displacement Distance Equivalent Index

Housing proximity to families' needs can significantly impact their socioeconomic recovery. The displacement distance category is designed to capture these proximity needs for each family, and it accounts for proximity to (1) location-specific needs, which are located at specific addresses such as jobs, colleges, kinship ties and other social support groups, religious facilities, and pre-disaster location; and (2) service-specific needs, which are offered at multiple facilities at different locations such as K-12 education facilities, hospitals, eldercare facilities, and clinics. This section briefly describes how the module computes a displacement distance equivalency index to evaluate the performance of housing alternatives in fulfilling the proximity needs of each family. There are three steps as discussed below:

First, the module computes the distances between each housing alternative and location-specific needs entered by each family (e.g., distance to job). Moreover, the module computes the distances between the housing alternatives and closest service-specific needs (e.g., closest elementary school). The module currently uses the Haversine Formula to calculate the shortest distance between each two locations (Sinnott 1984). However, future developments will include calculating travel distances for more accurate evaluations.

Second, the module retrieves the family specified preferred location for temporary housing (e.g., a zip code). If a housing alternative falls within that location, then it will fulfill a number of the pre-defined proximity needs. Accordingly, in this case the displacement distance equivalent will be calculated only for needs that do not fall within the preferred location. However, if a housing alternative is outside the preferred location area, then the module computes the displacement distance equivalent using all proximity needs. The module computes the displacement distance equivalent ($DDE_{f,h}$) by

aggregating the weighted distances between housing alternative h and the needs of family f .

In the third step, the module computes the displacement distance equivalency index ($DDEI_{f,h}$) for family f and housing alternative h , thus enabling emergency management agencies to build a utility function that can be applied to all temporary housing applications. As shown in Figure 3.2, the utility function is a function in the minimum displacement D_{min} , maximum displacement D_{max} , and a magnifying factor m . If $DDE_{f,h} \geq D_{max}$, then we set $DDEI_{f,h} = 0$. Similarly, if $DDE_{f,h} \leq D_{min}$, then set $DDEI_{f,h} = 1$. Accordingly, $DDEI_{f,h}$ ranges between 0 (lowest performance with maximum displacement) to 1 (highest performance with minimal or no displacement) and can be computed using Equation (3.1) below,

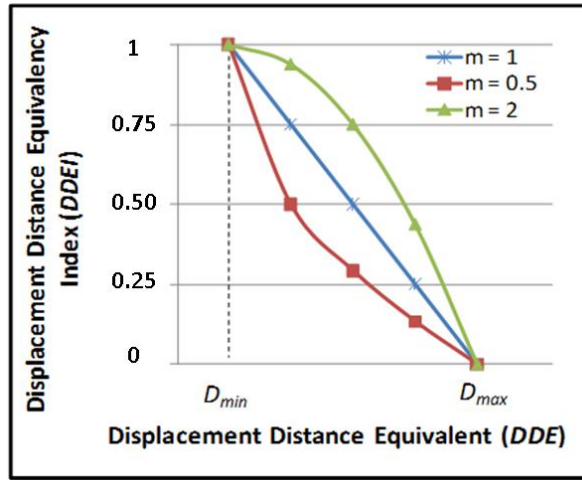


Figure 3.2. Utility Functions Used to Compute the Displacement Distance Equivalency Index for Three Different Magnifying Factors

$$DDEI_{f,h} = \begin{cases} 0, & \text{if } DDE_{f,h} \geq D_{max} \\ \left[\frac{D_{max} - DDE_{f,h}}{D_{max} - D_{min}} \right]^m, & \text{if } D_{min} < DDE_{f,h} < D_{max} \\ 1, & \text{if } DDE_{f,h} \leq D_{min} \end{cases}, \quad (3.1)$$

where,

$DDEI_{f,h}$ = displacement distance equivalency index for family f residing in housing alternative h ;

$DDE_{f,h}$ = displacement distance equivalent for family f residing in housing alternative h ;

D_{max} = maximum displacement defined by decision maker to represent the lowest performance for the location of a temporary housing with respect to fulfilling the proximity needs of displaced families;

D_{min} = minimum displacement defined by decision maker to represent the highest performance for the location of a temporary housing with respect to fulfilling the proximity needs of displaced families; and

m = magnifying factor to represent how the increase in displacement distance impacts the families socioeconomic welfare.

3.2. Housing Characteristics Index

This subsection briefly describes how the module computes a housing characteristics index to evaluate the performance of each housing alternative in fulfilling the socioeconomic needs represented by the factors in the housing characteristics category. To this end, the module performs three main steps, as follows.

Assessing housing characteristics

The module evaluates the performance of each housing alternative in five main socioeconomic factors that fall under the housing characteristics category, including (1) housing quality, which can be rated on a scale from 1 to 5 similar to the hotel rating system; (2) housing delivery time, which represents how long the displaced families will stay in mass-care shelters before they can move to temporary housing because of time needed for construction/installation activities (e.g., for pre-fabricated homes projects) or room availability (e.g., for motels); (3) level of access of housing location to public transportation, where decision makers can define five levels of accessibility starting from “no accessibility” to “highly accessible”; (4) access to other essential utilities and services, which can follow a similar rating system as access to public transportation and include access to public services, supermarkets, retail stores, entertainment and recreational activities; and (5) neighborhood safety, which can be evaluated using reported crime rates at the temporary housing location. The module normalizes these ratings using a scale from 0 (lowest performance) to 1 (highest performance) based on a pre-defined range of values input by the decision making authority for each factor.

Weighting socioeconomic factors

One of the unique features of the proposed module is its ability to capture the specific preferences of each displaced family among their socioeconomic needs. To this end, the module asks the families to assign the absolute weight (0-1) to each needs and normalize it for the five socioeconomic factors.

The module computes a housing characteristics index ($HCI_{f,h}$) that represents the performance of housing alternative h in fulfilling the housing characteristics needs of displaced family f . This index is computed by aggregating the weighted performance of the housing alternative in the five socioeconomic factors, as shown in Equation 3.2 below,

$$HCI_{f,h} = \sum_{i=1}^5 (w_{f,i} \times p_{h,i}) \quad (3.2)$$

where,

$HCI_{f,h}$ = housing characteristics index representing the evaluated performance of housing alternative h in fulfilling the housing characteristics needs of displaced family f , and it can range from 0% (lowest performance) to 100% (highest performance);

$w_{f,i}$ = relative weight of socioeconomic factor i computed based on the pair-wise comparisons performed by family f , where there are five factors under the housing characteristics category; and

$p_{h,i}$ = performance of housing alternative h in fulfilling socioeconomic need i .

3.3. Calculate Socioeconomic Index

The objective of this section is to evaluate the overall socioeconomic performance of candidate configuration of temporary housing assignments. To this end, the module first calculates a socioeconomic index ($SI_{f,h}$) to evaluate the combined social and economic impacts for each family if they reside in any of the available housing alternatives. The module computes $SI_{f,h}$ as the aggregate weighted performance of the temporary housing alternative in each of $HCI_{f,h}$ and $DDEI_{f,h}$, as shown in Equation (3.3),

$$SI_{f,h} = w_{f,HC} \times HCI_{f,h} + w_{f,DD} \times DDEI_{f,h} \quad (3.3)$$

where,

$SI_{f,h}$ = socioeconomic index of family f residing in temporary housing alternative h ;

$w_{f,HC}$ = relative weight of housing characteristics for family f ; and

$w_{f,DD}$ = relative weight of displacement distance for family f .

Second, in order to evaluate the configuration of all temporary housing assignments, the module computes an overall socioeconomic index (OSI) by averaging the computed socioeconomic indexes for all the displaced families, as shown in Equation (3.4),

$$OSI = \frac{1}{F} \times \sum_{f=1}^F \sum_{h=1}^H (SI_{f,h} \times x_{f,h}) \quad (3.4)$$

where,

OSI = overall socioeconomic index for a candidate configuration of temporary housing assignments;

F = number of displaced families applying for temporary housing;

H = number of housing alternatives; and

$x_{f,h}$ = binary decision variable that indicates whether family f is assigned to housing alternative h or not.

Both $SI_{f,h}$ and OSI have values that can range from 0 (lowest socioeconomic performance) to 1 (highest socioeconomic performance).

3.4. Compute Life Cycle Costs

This section describes the proposed methodology to compute a monthly equivalent cost for temporary housing development projects (El-Anwar 2009). Converting total life cycle costs into monthly costs is essential for comparing the costs of development projects to those of contracting with rental/lease housing businesses (such as hotels and motels). Life cycle costs include all costs incurred during the useable life time of the temporary housing alternative, such as costs of purchase (e.g. travel trailers), construction/installation, providing infrastructure and lifelines to the housing site, operation and maintenance, storage (when not in use), relocation to storage areas or other areas where needed, removal and site cleaning after period of use, and salvage which is deducted from costs. To this end, Equations 3.5 and 3.6 are formulated to support this cost conversion as follows,

$$C_h = \left(\sum_{u=0}^{ULT_h} \frac{\tilde{C}_{h,u}}{(1+r)^u} \right) \times \frac{r \times (1+r)^{PH}}{[(1+r)^{PH} - 1] \times cap_h} \quad (3.5)$$

$$TC = \sum_{h=1}^H (C_h \times \sum_{f=1}^F x_{f,h}) \quad (3.6)$$

where,

ULT_h = useable life time of temporary housing alternative h in months;

$\tilde{C}_{h,u}$ = net monthly cost of temporary housing alternative h during the u th month, which is equal to the summation of its costs minus its salvage value, if any during the u th month;

r = monthly interest rate;

PH = planning horizon in months;
 cap_h = capacity of temporary housing alternative h in number of units;
 C_h = equivalent monthly cost of temporary housing alternative h per unit;
 TC = total monthly public expenditures on temporary housing for a specific combination of temporary housing arrangements;
 H = number of available temporary housing alternatives;
 F = number of displaced families applying for temporary housing; and
 $x_{f,h}$ = binary decision variable that defines whether family f is assigned to housing alternative h or not.

IV. MULTI-OBJECTIVE OPTIMIZATION MODULE

This chapter provides a detailed description of the multi-objective optimization module design. The first section introduces the general setup of the module, including the design of decision variables, objective function and constraints. The development of a customized Hungarian algorithm is explained in the second section; the algorithm provides good computational efficiency in the optimization module. The last section briefly describes the implementation of a case example and demonstrates the computational saving. The structure of the module is shown in Figure 4.1.

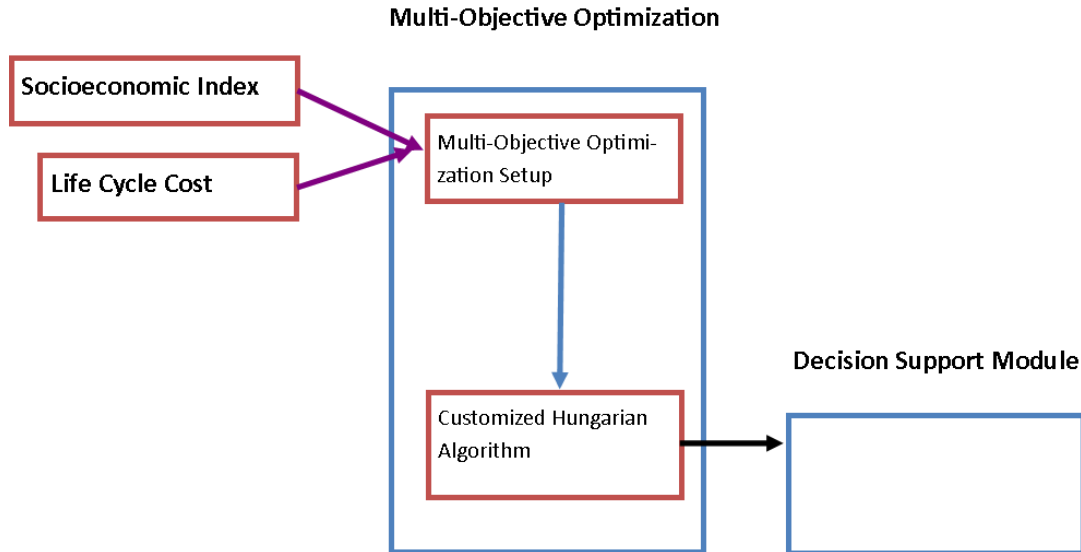


Figure 4.1. General Structure of Module 3

4.1. General Optimization Setup

This section introduces the general formulation of the optimization model. The design of decision variables, objective function and constraints are explained in detail. The decision variables represent all the possible assignments solutions. The objective function integrates the two separate objectives, socioeconomic and life cycle cost, into one. And the constraints make sure each family will have exactly one housing unit assigned.

Decision Variables

The decision variables are designed to represent all possible assignments of displaced families in housing alternative alternatives. To this end, $x_{f,h}$ is a binary decision variable that defines whether family f is assigned to housing alternative h (i.e., $x_{f,h} = 1$) or not (i.e., $x_{f,h} = 0$). The advantage of this design is that it enables the optimization model to identify the optimal housing assignment for each family considering its own socioeconomic needs which supports the objective of the customized formulation. The number of decision variables needed to support this formulation is equal to the total number of housing alternatives (H) multiplied by the total number of displaced families (F). The significantly large number of decision variables in this formulation, however, increases the computational complexity of the optimization problem considerably.

Objective Functions

There are two main objectives for this temporary housing problem; (1) to maximize the socioeconomic welfare of displaced families; and (2) to minimize total public expenditures on temporary housing. Both of the objectives are computed using the data processed by the Data Analysis Module. The first objective can be computed using Equation (3.4). The second objective can be calculated using the Equation (3.7). The two objectives are,

$$\text{Maximize:} \quad OSI(x) = \frac{1}{F} \times \sum_{f=1}^F \sum_{h=1}^H (SI_{f,h} \times x_{f,h})$$

$$\text{Minimize:} \quad TC(x) = \sum_{h=1}^H (C_h \times \sum_{f=1}^F x_{f,h}) .$$

To solve this temporary housing optimization problem, the module adopts the method of finding multiple trade-off Pareto-optimal solutions with a wide range of values for the two objectives, as shown in Figure 4.2. Moreover, to find the Pareto-optimal solutions, the module uses the weighted-sum approach to scalarize the two objectives into a single objective by pre-multiplying each objective with weights. The weights are varied to explore the Pareto-optimal front. In order to be able to search the full Pareto-optimal solutions, the Pareto-optimal front must be convex. Luckily, in this problem, the

objective functions are linear, and the feasible region is also convex since this is a transportation problem and the constraint coefficient matrix is totally unimodular.

The implementation of the weight-sum method takes three main steps; (1) identifying the range of Pareto optimal solutions; (2) normalizing each of the two optimization objectives, i.e., normalizing $OSI(x)$ and $TC(x)$; and (3) aggregating the weighted normalized values.

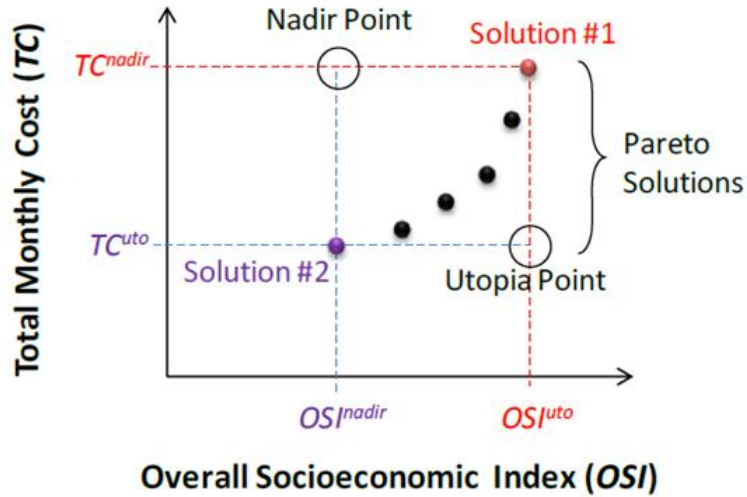


Figure 4.2. Pareto Optimal Solutions

First, the module identifies the range of Pareto optimal solutions by identifying (1) the solution that provides the absolute maximum socioeconomic welfare and its corresponding cost, as represented by solution #1 in Figure 4.2; and (2) the solution that provides absolute minimum total cost and its corresponding socioeconomic welfare, as represented by solution #2 in Figure 4.2. Solution #1 is identified by optimizing the temporary housing problem only for the first objective (i.e., maximizing socioeconomic welfare) using Equation (3.4), while solution #2 is identified by optimizing the problem only for the second objective (i.e., minimizing total cost) using Equation (3.7).

Second, the two optimization objectives need to be normalized in order to avoid scale effects when computing the model's single objective function (which aggregates the performance in achieving both objectives). In order to normalize each of the two objectives, the model generates two hypothetical solution vectors. The first vector is the utopia objective vector that corresponds to an ideal solution that would achieve the absolute maximum socioeconomic welfare (OSI^{uto}) and absolute minimum total cost (TC^{uto}), simultaneously. Although such solution typically does not exist, it represents the ideal case that the optimization model should try to converge to. The second vector is the nadir objective vector (OSI^{nadir} , TC^{nadir}) that represents the least performances in the

two objectives among the set of Pareto optimal solutions, as shown in Figure 4.2. The module then normalizes the two objectives based on each solution's distance from the utopia and nadir points, as shown in Equations (4.1) and (4.2),

$$OSI(x)^{norm} = \frac{OSI(x) - OSI^{nadir}}{OSI^{uto} - OSI^{nadir}} \quad (4.1)$$

$$TC(x)^{norm} = \frac{TC^{nadir} - TC(x)}{TC^{nadir} - TC^{uto}} \quad (4.2)$$

where,

$OSI(x)^{norm}$ and $TC(x)^{norm}$ are the normalized socioeconomic index and total cost, respectively, for the candidate configuration of temporary housing arrangements (x), which can range from 0 (at nadir point) to 1 (at utopia point);

$OSI(x)$ and $TC(x)$ are the overall socioeconomic index and total cost, respectively, for the candidate configuration of temporary housing arrangements (x);

OSI^{nadir} and TC^{nadir} are the overall socioeconomic index and total cost, respectively, at nadir point; and

OSI^{uto} and TC^{uto} are the overall socioeconomic index and total cost, respectively, at utopia point;

The third step computes the model's combined objective function as the weighted-sum of the two optimization objectives, as shown in Equation (4.3),

$$\text{Maximize:} \quad OP(x) = w_{OSI} \times OSI(x)^{norm} + w_{TC} \times TC(x)^{norm} \quad (4.3)$$

where,

OP = the objective value of the model, overall performance of the candidate configuration of temporary housing arrangements and family assignments; and

w_{OSI} and w_{TC} = relative importance weights of maximizing socioeconomic welfare and minimizing total costs, respectively.

Accordingly, solving the temporary housing problem for any unique combination of weights (w_{OSI}, w_{TC}) will generate one of the optimal solutions in the Pareto front, as shown in Figure 4.2.

Optimization Constraints

In order to ensure the practicality of the model, four sets of constraints are developed.

The first set of constraints requires that each family is provided one housing unit, as shown in Equation (4.4). The second set ensures that the capacity of each housing alternative is not exceeded by over-allocating families, as shown in Equation (4.5). The

third set of constraints requires that families with ADA needs are only offered housing units that accommodate their needs, as shown in Equation (4.6). It should be noted that each housing alternative location can offer up to four housing alternatives based on its units' sizes and ADA compatibility. These four housing alternatives include (1) housing units that can accommodate up to four family members and cannot accommodate families with ADA needs; (2) units that can accommodate larger families with more than four members and cannot accommodate ADA needs; (3) units that can accommodate up to four family members and can accommodate ADA needs; and (4) units that can accommodate more than four family members and ADA needs. Therefore for simplicity, the model currently accounts for two categories of family sizes; these are (1) families with up to four members and (2) larger families. This assumption can be easily changed based on the decision makers' requirements. The fourth set of constraints requires that large families with more than four members are only offered housing units that can accommodate them, as shown in Equation (4.7). A fifth set of constraints is introduced using Equation (4.8) to define the decision variable ($x_{f,h}$) as a binary variable that can take values of only 0 or 1. The constraints are,

Each family must be assigned one housing unit:
$$\sum_{h=1}^H x_{f,h} = 1, \forall f \quad (4.4)$$

Housing capacity should not be exceeded:
$$\sum_{f=1}^F x_{f,h} \leq Cap_h, \forall h \quad (4.5)$$

ADA needs must be accommodated:

$$x_{f,h} = 0, \forall \{f \in F_{ADA}, h \notin H_{ADA}\} \quad (4.6)$$

Larger family sizes must be accommodated:

$$x_{f,h} = 0, \forall \{f \in F_{>4}, h \notin H_{>4}\} \quad (4.7)$$

Decision variables are binary:

$$x_{f,h} = 0 \text{ or } 1 \forall f, h \quad (4.8)$$

where,

$x_{f,h}$ = binary decision variable that defines whether family f is assigned to housing alternative h or not;

F = number of displaced families applying for temporary housing;

H = number of available temporary housing alternatives;

Cap_h = capacity of temporary housing alternative h in number of available units;

F_{ADA} = set of displaced families with ADA needs;

H_{ADA} = set of available temporary housing alternatives that can accommodate ADA needs;

$F_{>4}$ = set of displaced families with more than four family members; and

$H_{>4}$ = set of available temporary housing alternatives that can accommodate families with more than four family members.

4.2. Customized Hungarian Algorithm

This temporary housing optimization is a special case of a transportation problem. The general transportation problem is concerned with distributing any commodity (housing unit) from sources (housings) to destinations (families), in such a way as to minimize or maximize the total distribution weight (cost). It takes advantage of total unimodularity of its Constraint Coefficients Matrix and applies algorithms, such as the Hungarian Algorithm, to achieve tremendous computational savings (these algorithms are polynomial time solvable). Moreover, these algorithms can be easily implemented in the weight (cost) table format which saves memory consumption significantly (Nemhauser and Wolsey, 1988). Table 4.1 shows an example of a weight table, where w_{ij} is the weight (cost) of transporting the unit item from i th source to the j th destination.

Destination Source	1	2	...	n
1	w_{11}	w_{12}	...	w_{1n}
2	w_{21}	w_{22}	...	w_{2n}
...
m	w_{m1}	w_{m2}	...	w_{mn}

Table 4.1. Weight Table

Now in order to use the Hungarian Algorithm, one must transform the temporary housing problem to the weight table format. In addition, each family in the problem can only

accept one housing unit, while the housings provide multiple housing units. To address this issue and to be able to maximize the computational efficiencies by using the Hungarian algorithm, a customized version of the Hungarian algorithm is developed. The following subsections present (1) a customized formulation of the objective function to be solvable using the Hungarian algorithm; (2) the newly developed variant of the Hungarian algorithm; and (3) a case example to illustrate the advantage of the algorithm. It should be noted that a description of the original formulation of the Hungarian algorithm can be found at Schrijver (2003).

Modified Formulation of the Objective Function

To reformulate the temporary housing problem in a weight table, the weight ($w_{f,h}$) for each assignment needs to be defined. This weight should represent the contribution of each assignment in the objective function formulated as Equation (4.3). The objective function (OP) needs to be formulated as a function of the temporary housing decision variables ($x_{f,h}$) with the assignments weights ($w_{f,h}$). First, OP can be formulated by applying some algebra transformation to Equations (3.4) to (4.3). Accordingly, the new formulation of OP is developed as shown in Equation (4.9),

$$OP = \sum_{f=1}^F \sum_{h=1}^H \left[\left(w_{OSI} \times \frac{SI_{f,h}}{F \times (OSI^{uto} - OSI^{nadir})} - w_{TC} \times \frac{C_h}{TC^{nadir} - TC^{uto}} \right) \times x_{f,h} \right] - w_{OSI} \times \frac{OSI^{nadir}}{OSI^{uto} - OSI^{nadir}} + w_{TC} \times \frac{TC^{nadir}}{TC^{nadir} - TC^{uto}} \cdot \quad (4.9)$$

Moreover, the assignments weights ($w_{f,h}$) can be computed for each family f and housing alternative h , as shown in Equation (4.10),

$$w_{f,h} = w_{OSI} \times \frac{SI_{f,h}}{F \times (OSI^{uto} - OSI^{nadir})} - w_{TC} \times \frac{C_h}{TC^{nadir} - TC^{uto}} \cdot \quad (4.10)$$

Housing Family	1	2	...	H
1	w_{11}	w_{12}	...	w_{1H}
2	w_{21}	w_{22}	...	w_{2H}
...
F	w_{F1}	w_{F2}	...	w_{FH}

Table 4.2. Weight Table for Temporary Housing Problem

Table 4.2 shows the resulting weight table for this temporary housing problem. Therefore, OP can be formulated as a function in $x_{f,h}$ and $w_{f,h}$, as shown in Equation (4.11),

Maximize:

$$\sum_{f=1}^F \sum_{h=1}^H (w_{f,h} \times x_{f,h}) - \frac{w_{OSI} \times OSI^{nadir}}{OSI^{uto} - OSI^{nadir}} + \frac{w_{TC} \times TC^{nadir}}{TC^{nadir} - TC^{uto}} \quad (4.11)$$

It should be noted that since the term $-\frac{w_{OSI} \times OSI^{nadir}}{OSI^{uto} - OSI^{nadir}} + \frac{w_{TC} \times TC^{nadir}}{TC^{nadir} - TC^{uto}}$ in Equation (4.9) is a constant, it can be omitted from the maximization function with no impact on the generated optimal solutions.

Proposed Variant of Hungarian Algorithm

The Hungarian Algorithm handles constraints (4.4), (4.5) and (4.8), however, it cannot easily incorporate constraints (4.6) and (4.7). For this reason, we move the constraints into the objective function by setting the weights $w_{f,h}$ equal to negative infinity for the appropriate f and h combinations identified in (4.6) and (4.7). And to better explain the algorithm, the symbols used in this section are changed slightly from the previous part of the thesis, the index for families is i instead of f , and the i th family is denoted by f_i ; the index for housing is j and the j th housing is denoted by h_j .

The Algorithm Procedures are explained as follow:

0. There are F displaced families $\{f_i\}$ and H housing alternatives $\{h_j\}$. The housing alternative h_j has the number of housing units equal to Cap_j . One housing unit can only allow one family to live in it, and the housing units of all housings can guarantee every family has a place to live, i.e., $\sum_{j=1}^H Cap_j \geq F$.

As discussed earlier, assigning family f_i to housing alternative h_j results in a benefit equal to weight w_{ij} . The objective of problem is to maximize the overall benefit. However, the algorithm is implemented for minimization, so the value of each weight is redefined as $w_{ij} \leftarrow W - w_{ij}$, where W = the largest value among all weights. The decision variables are denoted as x_{ij} , where $x_{ij} = 1$ indicates that family f_i is assigned to housing h_j , and $x_{ij} = 0$ means f_i is not assigned to h_j . During the implementation of the

algorithm, x_{ij} can have the value of 2 to represent a special condition, but this will not last to the end and affect the final results. The initial condition is that no family is assigned to any housing, i.e., $x_{ij} = 0$ for all i, j ; and all families and housings are uncovered.

1. For each $i = 1, \dots, F$, identify the set of indices $\mathbf{j}^i = \arg \min_{n=1, \dots, H} \{w_{in}\}$ (\mathbf{j}^i can have several elements due to tied weight values), let j^i be the smallest index in \mathbf{j}^i . If $\sum_{k=1}^i x_{kj^i} \leq \text{Cap}_{j^i}$, let $x_{ij^i} = 1$.
2. For each $i = 1, \dots, F$, if $\exists j$ such that $x_{ij} = 1$, we say family f_i is covered. If all the families are covered, terminate the algorithm with the optimal solution. Otherwise, go to Step 3.
3. For each $i = 1, \dots, F$, identify the set $\mathbf{j}^i = \arg \min_{n=1, \dots, H} \{w_{in}\}$ using the current weights. Find the first pair (i', j') such that $j' \in \mathbf{j}^i$, and both $f_{i'}$ and $h_{j'}$ are uncovered. If there is no such pair, go to Step 6. If there is a pair (i', j') , let $x_{i'j'} = 2$. If the number of elements in the set $\mathbf{i}^{j'} = \{i | x_{ij'} = 1\}$ equals to $\text{Cap}_{j'}$, uncover all of the families $f_i, i \in \mathbf{i}^{j'}$, and cover the housing $h_{j'}$, go back to the start of step 3. Otherwise, go to Step 4.
4. In order to create an assignment for an additional family and update prior assignments to maintain feasibility, perform the following steps:
 - 4.1. Let $k = 1, r_k = i'$ and $c_k = j'$, go to Step 4.2.
 - 4.2. Find the index \tilde{j} such that $x_{r_k \tilde{j}} = 1$, if there is no such \tilde{j} , go to step 4.4, otherwise, go to Step 4.3.
 - 4.3. Set $k \leftarrow k + 1, r_k = r_{k-1}, c_k = \tilde{j}$, and there must be a \tilde{i} such that $x_{\tilde{i} c_k} = 2$, Increment k again, and let $r_k = \tilde{i}, c_k = c_{k-1}$. Then return to Step 4.2.
 - 4.4. Build ordered list $\{(r_k, c_k)\}$ with all k . Then for each k , if $x_{r_k c_k} = 1$, set $x_{r_k c_k} = 0$, and if $x_{r_k c_k} = 2$, set $x_{r_k c_k} = 1$ ($x_{r_k c_k} \neq 0$ in the list), go to Step 5.
5. Uncover all families and housings, and for all the elements in $\{x | x_{ij} = 2\}$ (not all $x_{ij} = 2$ are used in the ordered list $\{(r_k, c_k)\}$ in Step 4), let them be zero again, go back to Step 2.
6. Find $(i'', j'') = \arg \min_{i,j} \{w_{ij} | f_i \text{ is uncovered}, h_j \text{ is uncovered}\}$. For every covered family, we increase its weights by $w_{i''j''}$, for every uncovered housing, we decrease its weights by $w_{i''j''}$. Then go back to Step 3.

An example to illustrate the algorithm is shown in Figure 4.3, with twelve tables and the following explanations:

Table (1): This specific problem has 3 displaced families and 2 housing alternatives. The first housing has only 1 housing unit, the second has 3 units. Table (1) shows the original weights that the algorithm needs to maximize.

Table (2): The weights in Table (2) are recalculated in Step 0 of the algorithm, the weights $w_{ij} \leftarrow W - w_{ij}$, where $W = 0.9$. Step 1 of the algorithm finds the set of indices indicating the smallest weights for each family, $\mathbf{j}^1 = \{1, 2\}$, $\mathbf{j}^2 = \{1\}$ and $\mathbf{j}^3 = \{1\}$. Under the constraints of housing capacity, the algorithm gives the first assignments $x_{11} = 1$. In Step 2, the algorithm covers only the first family f_1 (indicated by pink shading), and the algorithm goes to Step 3.

Table (3): Table (3) shows the results processed by Step 3 in the algorithm. In Step 3, the weights are not changed, so $\mathbf{j}^1 = \{1, 2\}$, $\mathbf{j}^2 = \{1\}$ and $\mathbf{j}^3 = \{1\}$, the algorithm finds the first uncovered pair $(i', j') = (2, 1)$, let $x_{21} = 2$. Set $\mathbf{i}^1 = \{1\}$, the number of its elements equals Cap_1 , so uncover family f_1 and cover housing h_1 . Go back to the start of Step 3.

Table (4): In Step 3, no weights are changed, the sets \mathbf{j}^i stay the same, the algorithm finds the first uncovered pair $(i', j') = (1, 2)$, let $x_{12} = 2$. The set $\mathbf{i}^2 = \emptyset$, and $Cap_2 = 3$, so housing h_2 still has open housing units. Go to Step 5.

Table (5):

In Step 4.1, let $k = 1, r_k = i' = 1, c_k = j' = 2$, go to Step 5.2.

In Step 4.2, we find $x_{r_k 1} = 1$, so $\tilde{j} = 1$, go to Step 5.3.

In Step 4.3, set $k = 2, r_k = 1, c_k = 1$, and identify $x_{2c_k} = x_{21} = 2$. Then let $k = 3$, so $r_k = 2, c_k = 1$, go back to Step 4.2.

Back in Step 4.2, there is no such \tilde{j} for $r_k = 2$, so go to Step 4.4

In Step 4.4, the ordered list $\{(r_k, c_k)\} = \{(1, 2), (1, 1), (2, 1)\}$ (indicated by dark blue shading), let $x_{11} = 0, x_{12}$ and $x_{21} = 1$. Go to Step 5.

Table (6): In Step 5, uncover all families and housing alternatives, and go to Step 2 to check optimality. In Step 2, families 1 and 2 are covered but the problem is not optimized yet, because not all three families are covered in Step 2. Go to Step 3.

Table (7): In Step 3, the sets \mathbf{j}^i stay unchanged, $(i', j') = (3, 1)$ is discovered as the first uncovered pair, so $x_{31} = 2$. The number of elements in \mathbf{i}^1 equals Cap_1 , so uncover f_2 and cover h_1 , return to the start of Step 3. There are no uncovered pairs (i', j') found in Step 3, the algorithm goes to Step 6.

Table (8): In Step 6, the smallest uncovered weight is $w_{22} = 0.2$ (indicated by dark green shading), so $(i'', j'') = (2, 2)$.

Table (9): The weights of all covered families are increased by 0.2, the weights of all uncovered housings are decreased by 0.2. Go back to Step 3.

Table (10): In Step 3, using the current weights, the sets are updated to $\mathbf{j}^1 = \{2\}, \mathbf{j}^2 = \{2\}$ and $\mathbf{j}^3 = \{2\}$, $(i', j') = (2, 2)$ is the first uncovered pair, and $\mathbf{i}^2 = \{1\}$, its number of elements is less than Cap_2 , so h_2 still has open housing units. Go to Step 4.

Table (11):

In Step 4.1, let $k = 1, r_k = i' = 2, c_k = j' = 2$, go to Step 4.2.

In Step 4.2, we find $x_{r_k 1} = 1$, so $\tilde{j} = 1$, go to Step 4.3.

In Step 4.3, set $k = 2, r_k = 2, c_k = 1$, and identify $x_{3c_k} = x_{31} = 2$. Then let $k = 3$, so $r_k = 3, c_k = 1$, go back to Step 4.2.

In Step 4.2, there is no such \tilde{j} for $r_k = 2$, then go to Step 4.4

In Step 4.4, the ordered list $\{(r_k, c_k)\} = \{(2, 2), (2, 1), (3, 1)\}$ (indicated by dark blue shading), let $x_{21} = 0, x_{22}$ and $x_{31} = 1$. Go to step 6.

Table (12): In Step 6, uncover all families and housing alternatives and go to Step 2 to check optimality. In Step 2, we cover families 1, 2, and 3, and since all the families are covered, terminate the algorithm. The solution is $x_{11} = 0, x_{12} = 1, x_{21} = 0, x_{22} = 1, x_{31} = 1$ and $x_{32} = 0$. The overall weight of the original problem is $w_{12} + w_{22} + w_{31} = 0.9 + 0.7 + 0.7 = 2.3$.

The example illustrates how the algorithm obtaining an optimal solution. To explore other solutions on the Pareto-optimal front, the user would modify w_{OSI} and w_{TC} and calculate the weights $w_{f,h}$ according to Equation (4.10).

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0.9	0.9
f_2	0.8	0.7
f_3	0.7	0.6

(1)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0*	0
	$x_{11}=1$	$x_{12}=0$
f_2	0.1*	0.2
	$x_{21}=0$	$x_{22}=0$
f_3	0.2*	0.3
	$x_{31}=0$	$x_{32}=0$

(2)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0*	0
	$x_{11}=1$	$x_{12}=0$
f_2	0.1'	0.2
	$x_{21}=2$	$x_{22}=0$
f_3	0.2*	0.3
	$x_{31}=0$	$x_{32}=0$

(3)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0*	0'
	$x_{11}=1$	$x_{12}=2$
f_2	0.1'	0.2
	$x_{21}=2$	$x_{22}=0$
f_3	0.2*	0.3
	$x_{31}=0$	$x_{32}=0$

(4)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0*	0'
	$x_{11}=1$	$x_{12}=2$
f_2	0.1'	0.2
	$x_{21}=2$	$x_{22}=0$
f_3	0.2*	0.3
	$x_{31}=0$	$x_{32}=0$

(5)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0	0*
	$x_{11}=0$	$x_{12}=1$
f_2	0.1*	0.2
	$x_{21}=1$	$x_{22}=0$
f_3	0.2*	0.3
	$x_{31}=0$	$x_{32}=0$

(6)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0	0*
	$x_{11}=0$	$x_{12}=1$
f_2	0.1*	0.2
	$x_{21}=1$	$x_{22}=0$
f_3	0.2'	0.3
	$x_{31}=2$	$x_{32}=0$

(7)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0	0*
	$x_{11}=0$	$x_{12}=1$
f_2	0.1*	0.2
	$x_{21}=1$	$x_{22}=0$
f_3	0.2'	0.3
	$x_{31}=2$	$x_{32}=0$

(8)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0.2	0*
	$x_{11}=0$	$x_{12}=1$
f_2	0.1*	0
	$x_{21}=1$	$x_{22}=0$
f_3	0.2'	0.1
	$x_{31}=2$	$x_{32}=0$

(9)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0.2	0*
	$x_{11}=0$	$x_{12}=1$
f_2	0.1*	0'
	$x_{21}=1$	$x_{22}=2$
f_3	0.2'	0.1
	$x_{31}=2$	$x_{32}=0$

(10)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0.2	0*
	$x_{11}=0$	$x_{12}=1$
f_2	0.1*	0'
	$x_{21}=1$	$x_{22}=2$
f_3	0.2'	0.1
	$x_{31}=2$	$x_{32}=0$

(11)

	h_1	h_2
	$Cap_1=1$	$Cap_2=3$
f_1	0.2	0*
	$x_{11}=0$	$x_{12}=1$
f_2	0.1	0*
	$x_{21}=0$	$x_{22}=1$
f_3	0.2*	0.1
	$x_{31}=1$	$x_{32}=0$

(12)

Figure 4.3. Algorithm Case Example

Case Example

This subsection presents an application example in order to demonstrate the big computational and memory savings associated with the proposed implementation. The following parts briefly describe the application example input data, compare the optimization results obtained using each of the traditional Branch and Bound algorithm and the customized Hungarian algorithm, and discuss the computational performance. Moreover, the last part of this subsection demonstrates the generation of Pareto optimal solutions.

The purpose of this application example is to represent the optimization of a large-scale temporary housing optimization problem. To this end, this application example utilized the collected data for the temporary housing case study presented by El-Anwar et al. (2008). The case study involved simulating the reoccurrence of the 1994 Northridge earthquake using HAZUS®-MH V1.1. This simulation generated the expected distribution of displaced families in Los Angeles County, CA by census tracts. In this application example, 5,000 of those families were assumed to be in need of temporary housing. The socioeconomic needs of those families were randomly generated within practical ranges. Furthermore, housing data were obtained from the database of available temporary housing alternatives generated for the aforementioned Northridge earthquake case study. This data was generated using a detailed online search of available temporary housing alternatives in Los Angeles County. These alternatives consist of campsites for travel trailers, hotels, inns, motels, as well as other lodges. A total of 178 housing alternatives from this database were included in this application example with a total capacity of 34,768 housing units. This database also provided other needed data about these housing alternatives, such as their addresses, housing capacities, time availability, housing quality rating, neighborhood safety, area unemployment rate, and access to public services and transportation. Moreover, the authors complemented this data by identifying samples of the available services within the cities of these housing alternatives, such as public K-12 schools and healthcare facilities. Any other needed data for running the model was reasonably assumed.

Using the aforementioned data, a pool of 5,000 displaced families and 178 temporary housing alternatives is created. This pool was used to develop 13 temporary housing problems ranging in size from small-scale problems (e.g., housing 500 families and 15 housing alternatives) to large-scale problems (e.g., housing 5,000 families and 178 housing alternatives), as shown in Table 4.3. These 13 problems are ordered based on their computational complexity as a function in the number of decision variables, which

is equal to the number of displaced families (F) multiplied by the number of available housing alternatives (H).

Problem #	Number of Families (F)	Number of Housing alternatives (H)	Number of Decision Variables ($F \times H$)	Running Time(s)	
				Customized Hungarian	Branch & Bound
1	500	15	7,500	0.016	15
2	500	30	15,000	0.006	104
3	600	30	18,000	0.047	129
4	500	40	20,000	0.006	305
5	700	30	21,000	0.101	328
6	800	30	24,000	0.154	Out of Memory
7	500	50	25,000	0.178	Out of Memory
8	1000	30	30,000	0.269	Out of Memory
9	1000	60	60,000	1.83	Out of Memory
10	2000	60	120,000	20.0	Out of Memory
11	2000	120	240,000	46.0	Out of Memory
12	4000	120	480,000	461.0	Out of Memory
13	5000	178	890,000	1,534.0	Out of Memory

Table 4.3. Algorithm Performance

The Branch and Bound algorithm and customized Hungarian algorithm were run on a 2.8 GHz Intel Pentium D processor with 3 GB of random access memory and a 64-bit operating system using MATLAB®. The Branch and Bound algorithm used the “bintprog” function from the MATLAB® Optimization Toolbox. The customized Hungarian algorithm follows the procedure explained in the last section (See the Appendix for the MATLAB code “Hungarian_Housing.m”), and the code is modified from the original Hungarian algorithm written by Melin (2006). Table 4.3 shows the computational efficiency for the 13 temporary housing problems using the two implementations. The customized Hungarian algorithm outperforms a general Branch and Bound algorithm in this problem.

In order to demonstrate the proposed model’s capabilities in identifying the optimal tradeoffs between maximizing socioeconomic welfare and minimizing total costs, the customized Hungarian algorithm is applied to the full scale problem. This problem includes optimizing temporary housing assignments for 5,000 families with 178 housing alternatives, resulting in 890,000 decision variables ($5,000 \times 178$). In order to identify the Pareto solutions that represent those optimal tradeoffs, different combinations of relative weights should be assigned to OSI and TC . To this end, the full scale housing problem was solved for four combinations of weights; (1,0), (0.75, 0.25), (0.5, 0.5), and (0,1).

Table 4.4 shows the Pareto-optimal solutions for the (w_{OSI}, w_{TC}) weight combination as well as the Utopia and Nadir points with the associated function values of OSI and TC . The points are graphed in Figure 4.4. The tradeoffs for the objective functions are easily interpreted. These results show that only four combinations of weights were enough to draw a relatively accurate Pareto front for this case. The weight combinations of $(0.75, 0.25)$ and $(0.5, 0.5)$ could generate optimal solutions that are very close to the Utopia point. The OSI values of 89.8% and 90.9% are very close to the Utopia values of 92.2%. And the TC values of 6,802 and 7,163 are very close to the Utopia value of 6,666.

The results inform a decision maker about the relative weights (w_{OSI}, w_{TC}) that are good values to implement in the systems, and provide a range on the total monthly cost to anticipate. The detailed assignments can also be compared to explore which housing alternatives are likely to be filled to capacity.

(w_{OSI}, w_{TC})	Time (s)	OSI	TC($\times 1,000$ USD)
(1, 0)	1533.728	92.2%	12,261
(0.75, 0.25)	2620.837	90.9%	7,163
(0.5, 0.5)	3221.85	89.8%	6,802
(0, 1)	1099.436	67.0%	6,666
Utopia Point		92.2%	6,666
Nadir Point		67.0%	12,261

Table 4.4 Optimization Results

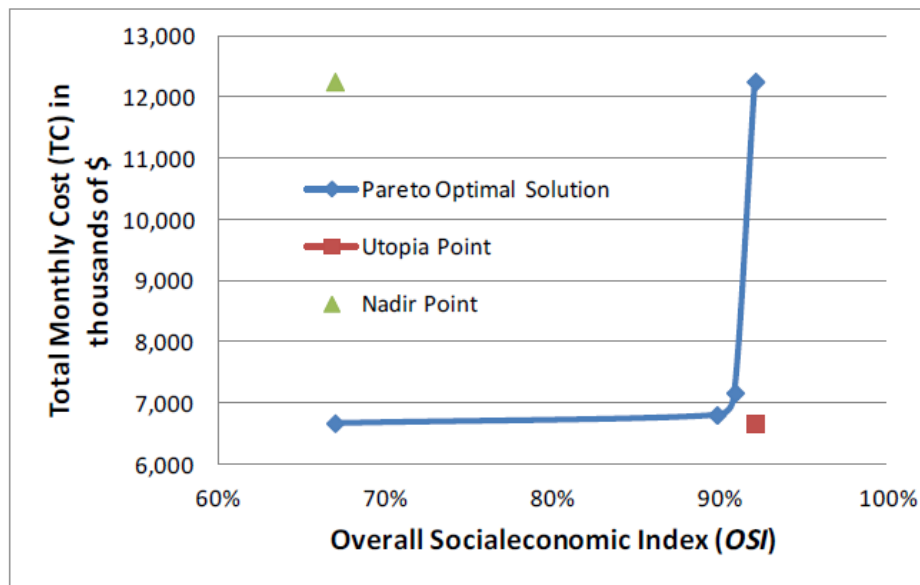


Figure 4.4. Pareto Optimal Solution

V. DECISION SUPPORT MODULE

This chapter introduces two tools to support Emergency Management Agency in decision making. The cost-socioeconomic tradeoff tool allows the Emergency Management Agency to look at the total cost and overall family socio-economic benefit among different Pareto-optimal solutions. The potential housing cost-benefit analysis tool gives the agency the capability to virtually add potential housing alternatives in the system, and test whether the housing alternatives benefit families in an acceptable cost. The general structure of this module is shown in Figure 5.1.

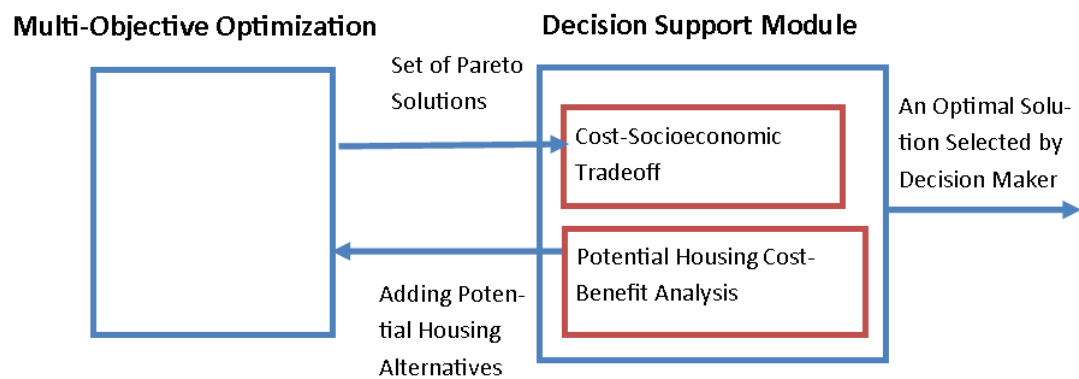


Figure 5.1. General Structure of Module 4

5.1. Cost-Socioeconomic Tradeoff

As discussed in the last chapter, the Optimization module provides a set of Pareto solutions. The Cost-Socioeconomic Tradeoff tool first displays all the solution in a scatter graph, such as Figure 4.4, but without the Nadir and Utopia Points. Figure 5.2 illustrates the Pareto-optimal front, contrasting the Overall Socio-economic Index versus the Monthly Total Cost. When clicking on any solution, the Tradeoff tool can show the detail number of both objectives to help Emergency Management Agency to evaluate the trade-off and make the final selection.

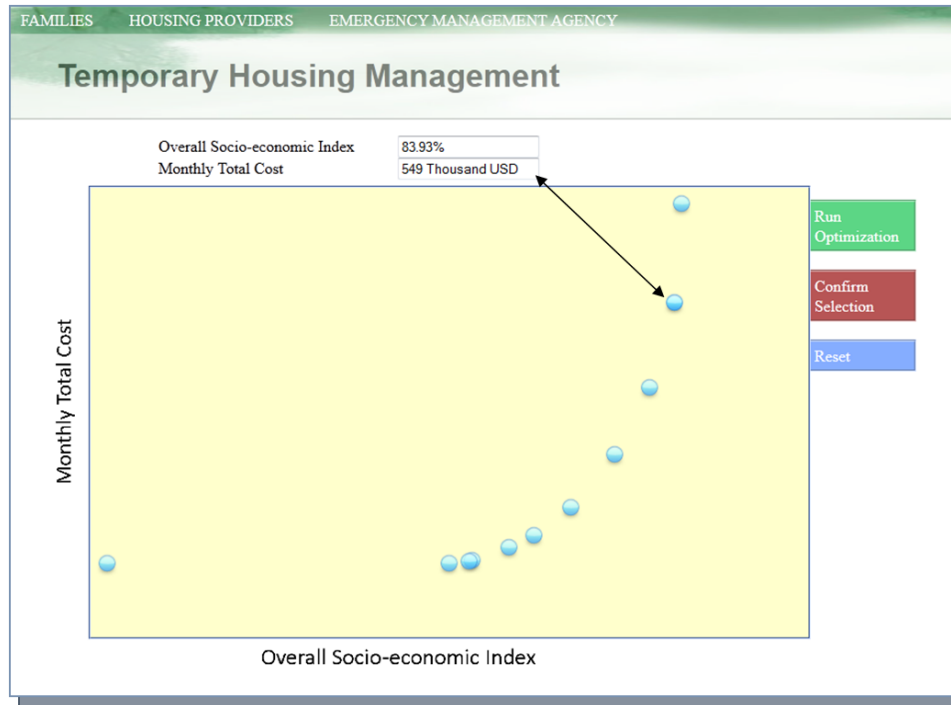


Figure 5.2. Cost-Benefit Analysis

5.2. Cost-Benefit Analysis for Potential Housing

In many cases, the Emergency Management Agency likes to see if it is worthwhile that, by adding a potential housing alternative, the overall performance of the new assignments will be improved. As shown in Figure 5.3, the potential housings can be trailer homes, constructed temporary housing or military buildings, all of which requires substantial cost to set them up. The Potential Housing Analysis function allows Emergency Management Agencies to virtually add the potential housing in the system, put estimated costs associated with it and go back to the optimization, checking whether the housing fulfills families' needs. The system will not directly suggest a potential housing. Instead, it shows how many families will be assigned to this potential housing if it is built, leaving Emergency Management Agency to make the decision.



Figure 5.3. Potential Housing Analysis
(three different types of potential housing alternatives are added to the system)

VI. OUTPUT REPORTING MODULE

This chapter presents the last module of the system, the output reporting. After the solution is selected by the Emergency Management Agency, the information is automatically generated for different users. Once they re-log into their portals, the results/assignments are available. Families have the right to refuse the offer and look for their own housings. The system will collect their feedback and put the refused housing unit back into the housing pool for later assignments.

Families' Output Portal

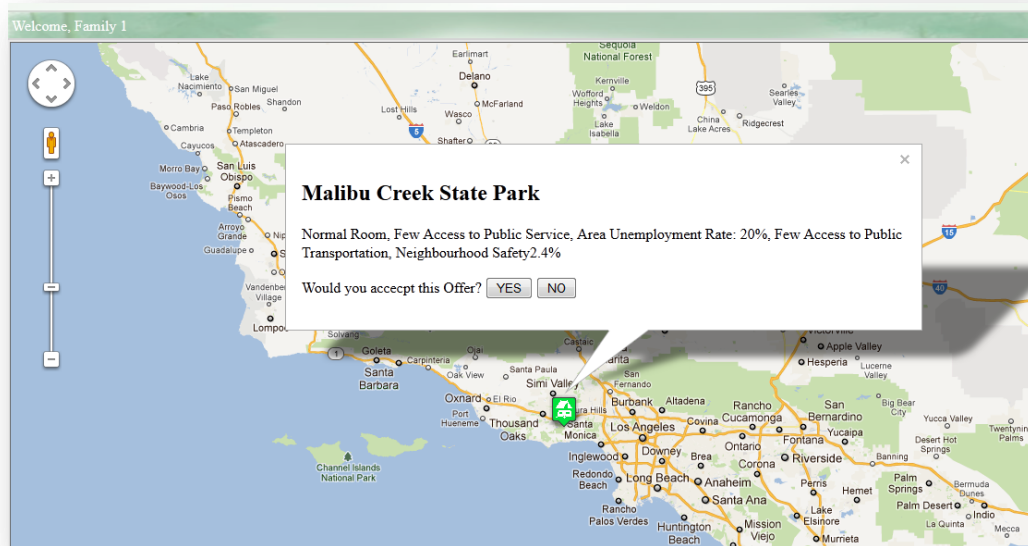


Figure 6.1. Families' Output Portal

As shown in Figure 6.1, when a family re-logs into the system, the portal will generate one marker in the center, which indicates the location of the housing that has been assigned to them. Google Map can provide the street view of the location, so without visiting, the family can have a general idea of what the building looks like. In addition, by clicking the marker, an information window will pop up: it tells the room type, neighborhood safety, access to public transportation, unemployment rate, etc.

At the end of the information window, the family needs to decide whether to accept this offer. If family decides to refuse the offer, the information window will become a comment board; the family can leave the reason why this housing unit does not fulfill its socioeconomic needs. All the messages are stored in the database for developers and Emergency Management Agency to improve the system.

Housing Providers' Output Portal

The Output Portal for a Housing Provider contains the list of families that will live in its housing units. The information only includes each family's id. Figure 5.2 presents the assignment table for housing #62. Once a family in the list turned down the offer, the family will be automatically erased from the list.

family_id	housing_id
691	62
851	62
961	62
1301	62
1311	62
1581	62
1631	62
1781	62
2331	62

Figure 6.2. Family List for Housing Provider #62

Emergency Management Agency's Output Portal

The Output Portal for Emergency Management Agency is designed in a database browser like format. The Emergency Management Agency can use queries to view different information on the assignment table. He can request for a specific family's housing assignment or check the list of families assigned in a motel. Some sample reports are shown in Figure 6.3.

Assignment For Family1041

family_id	housing_id	ADA	Large
1041	172	N	N

Families assigned to Housing units with ADA Facility

family_id	housing_id	ADA
1	172	Y
31	97	Y
61	142	Y
91	177	Y
121	72	Y
151	172	Y
181	97	Y
211	177	Y
241	177	Y
271	177	Y

Assignment For Housing62

family_id	housing_id
691	62
851	62
961	62
1301	62
1311	62
1581	62
1631	62
1781	62
2331	62

Figure 6.3. Output Tables for Emergency Management Agency

VII. CONCLUSIONS

Current post-disaster temporary housing programs have limited capability to fulfill the unique family's socioeconomic needs. The inadequate strategic planning and lack of decision support tools increasingly resulted in issues such as high overall cost, late delivery and frequent family complaints. This thesis presented a new web-based Post Disaster Temporary Housing Management system to transform the current inefficient practice. Its new framework effectively collects families' specific socioeconomic needs, leverages available housing stock in impacted areas, matches housing offerings to displaced families specific needs, maximizes the cost effectiveness of temporary housing plans, provides support tools to decision makers and automates the process of housing services procurement. Accordingly, the main contribution of this thesis is to transform the current practice of post disaster temporary planning and execution. Furthermore, some of the developed tools and methodologies can also be applied to other fields.

The system aims at achieving two main objectives: (1) matching families' socioeconomic needs to the characteristics and location of each housing alternative; and (2) minimizing the life cycle costs of temporary housing. The implementation of the system adopts a comprehensive methodology that consists of five main modules, including (1) Data Acquisition Module; (2) Data Analysis Module; (3) Multi-Objective Optimization Module; (4) Decision Support Module; and (5) Output reporting Module. The first two modules are capable of providing customized temporary housing assistance tailored to the specific social, economic, and psychological needs of displaced families as compared to the one-size-fits-all current approach. The multi-objective optimization was implemented using a customized Hungarian Algorithm. It is proposed because of its effectiveness in identifying Pareto-optimal solutions and the efficiency of its computational requirements. Two decision support tools leverage available housing stock following disasters and conduct cost-benefit analysis on the provision of other temporary housing forms such as travel trailers and mobile homes.

This thesis has resulted in three peer-evaluated journal articles, one of which has been accepted in the ASCE Journal of Construction Engineering and Management, and the other two are still under review for publication. Further investigations are currently underway to identify methods that are capable of capturing and improving displaced families satisfaction with offered housing units as well as methods of enabling the automation of a negotiation scheme between emergency management agencies and housing providers. The final product will also include a special interface for mobile devices such as smart phones.

Bibliography

Bolin, R. (1982). "Long-term family recovery from disaster." Institute of Behavioral Science Monograph 36, University of Colorado, Boulder.

Bolin, R. (1993). "Post-earthquake shelter and housing: Research findings and policy implications." 1993 National Earthquake Conference Monograph 5: Socioeconomic Impacts, Committee on Socioeconomic Impacts, ed., Central United States Earthquake Consortium, Memphis, Tenn., 107–131.

Bolin, R. C. and Bolton, P. (1986). Race, religion, and ethnicity in disaster recovery, Boulder, CO: Institute of Behavioral Science, University of Colorado.

Comerio, M. C. (1997). "Housing repair and reconstruction after Loma Prieta." National Information Service for Earthquake Engineering, University of California Berkeley, 1997, http://nisee.berkeley.edu/loma_prieta/comerio.html.

Comerio, M. C. (1998). Disaster Hits Home: New Policy for Urban Housing Recovery. Berkeley: University of California Press, Berkeley, CA.

Deb, K., Agrawal, S., Pratap, A., and Meyarivan, T. (2001). "A Fast Elitist Non-Dominated Sorting Genetic Algorithm for Multi-objective Optimization," KANGAL Report 200001, Genetic Algorithm Laboratory, Indian Institute of Technology, Kanpur, India.

El-Anwar, O. (2009) "MULTI-OBJECTIVE OPTIMIZATION FOR TEMPORARY HOUSING ARRANGEMENTS AFTER NATURAL DISASTERS", Doctoral Dissertation, University of Illinois at Urbana-Champaign.

El-Anwar, O. and Chen, L. (2012) (a) "Computing a Displacement Distance Equivalent to Support Planning for Post-Disaster Temporary Housing Projects," Journal of Construction Engineering and Management, ASCE, accepted.

El-Anwar, O. and Chen, L. (2012) (b) "Maximizing the Computational Efficiency of Temporary Housing Decision Support following Disasters," Journal of Computing in Civil Engineering, ASCE, in review.

El-Anwar, O. and Chen, L. (2012) (c) “Customized Development of Temporary Housing Projects to Meet Displaced Populations Needs,” *Journal of Urban Planning and Development*, ASCE, in review.

El-Anwar, O. and K. El-Rayes (2007). “Post-Disaster Optimization of Temporary Housing Efforts,” *Proc., ASCE Construction Research Congress, Island of Grand Bahamas*. 6–8 May.

El-Anwar, O., El-Rayes, K., and Elnashai, A. (2008). “Multi-Objective Optimization of Temporary Housing for the 1994 Northridge Earthquake.” *Journal of Earthquake Engineering*, 12(1), 81- 91.

El-Anwar, O., El-Rayes, K., and Elnashai, A. (2009) (a). “An Automated System for Optimizing Post-Disaster Temporary Housing Allocation,” *Journal of Automation in Construction*, 18(7), 983-993.

El-Anwar, O., El-Rayes, K., and Elnashai, A. (2009) (b). “Optimizing Large-Scale Temporary Housing Arrangements after Natural Disasters,” *Journal of Computing in Civil Engineering*, ASCE, 23(2), 110 - 118.

El-Anwar, O., El-Rayes, K., and Elnashai, A. (2010) (a). “Maximizing Temporary Housing Safety after Natural Disasters,” *Journal of Infrastructure Systems*, ASCE, 16(2), 138-148.

El-Anwar, O., El-Rayes, K., and Elnashai, A. (2010) (b). “Maximizing the Sustainability of Integrated Housing Recovery Efforts,” *Journal of Construction Engineering and Management*, ASCE, 136(7), 794-802.

El-Anwar, O., El-Rayes, K., and Elnashai, A. (2010) (c). “Minimization of Socioeconomic Disruption for Displaced Population Following Disasters,” *Disasters*, 34(3), 865–883.

Elnashai, A., Hampton, S., Karaman, H., Lee, J.S., McLaren, T., Myers, J., Navarro, C., Sahin, M., Spencer, B., and Tolbert, N. (2008) (a). “Overview and Applications of MAEviz – HAZTURK 2007,” *Journal of Earthquake Engineering*, 12(1), 100 — 108.

Elnashai, A., Hampton, S., Lee, J.S., McLaren, T., Myers, J., Navarro, C., Spencer, B., and Tolbert, N. (2008) (b). “Architectural Overview of MAEviz – HAZTURK,” *Journal of Earthquake Engineering*, 12(1), 92 — 99.

FEMA (2005) (a). "All Temporary Housing Options Being Considered," Federal Emergency Management Agency, Release number: 1603-004. <<http://www.fema.gov/news/newsrelease.fema?id=18820>>, (December 18, 2011).

FEMA (2005) (b). "Disaster Recovery Officials Work to Get People Closer to Home," Federal Emergency Management Agency, Release number: 1604-074. <<http://www.fema.gov/news/newsrelease.fema?id=19781>>, (December 18, 2011).

FEMA (2005) (c). "Programmatic environmental assessment: Temporary housing for disaster victims of Hurricane Katrina." FEMA-DR-1604-MS, September 2005.

FEMA (2006). "Alternative Housing Pilot Program - Guidance and Application Kit," Department of Homeland Security, Federal Emergency Management Agency, September 15, 2006 <http://www.fema.gov/pdf/government/grant/ahpp_guidance.pdf>, (October 27, 2008).

FEMA (2007). "Emergency Temporary Group Housing Site Selection Guidelines: Minimizing Environmental/Historic/Safety Problems," Federal Emergency Management Agency, FEMA HQ Regions 4 and 6. <<http://www.fema.gov/pdf/plan/ehp/thsiteselection.pdf>>, (December 18, 2011).

Friday, B. E. (1999). "Rebuilding shelter after natural disasters: Three decades of USAID experience in Latin America and the Caribbean." Prepared for United States Agency for International Development, Contract No. PCE-I-00-96-00008-00, Delivery Order Number 3, PADCO, Inc.

Golec, J. (1983). "A contextual approach to the social psychological study of disaster recovery," *Journal of Mass Emergencies and Disasters*, 1, August, 255-276.

Hidayat, B and Egbu, C (2010). "A literature review of the role of project management in post-disaster reconstruction," In: Egbu, C. (Ed), Proc., 26th Annual ARCOM Conference, 6-8 September 2010, Leeds, UK, Association of Researchers in Construction Management, 1269-1278.

Johnson, C. (2002) (a) "Planning consideration for temporary accommodation after disasters: An example of the 1999 Turkish earthquake." Proc., i-Rec Conference on Improving Post-Disaster Reconstruction in Developing Countries, University of Montreal, Montreal, Canada, 23-25 May, 2002.

Johnson, C. (2002) (b) “What's the big deal about temporary housing? Types of temporary accommodation after disasters: An example of the 1999 Turkish earthquake.” Proc., TIEMS 2002 International Disaster Management Conference, University of Waterloo, 14-17 May, 2002. TIEMS, Canada.

Johnson, C. (2007). “Impacts of prefabricated temporary housing after disasters: 1999 earthquakes in Turkey.” *Habitat International*, 31(1), 36-52.

Kruglanski, A. W. and Icek A. (1983). “Bias and Error In Human Judgment.” *European Journal of Social Psychology* 13, 1-44.

Kandil, A., El-Rayes, K., and El-Anwar, O. (2010). "Optimization Research: Enhancing Robustness of Large-Scale Multi-Objective Optimization in Construction," *Journal of Construction Engineering and Management*, ASCE, 136(1), 17-25.

Lizarralde, G. and Johnson, C. (2003). “Houses of candied sugar: Comparative research on controversial temporary housing after earthquake disasters in Colombia and Turkey.” Proc., International Association for Housing Science World Congress on Housing Process and Product, Montreal, Canada, 23–27 June, 2003. Montreal: IAHS.

Melin, A. (2006). “Hungarian Algorithm.” Matlab File Exchange.
<<http://www.mathworks.com/matlabcentral/fileexchange/11609-hungarian-algorithm/content/Hungarian.m>>.

MAEviz (2008). “MAEviz Software.” Mid-America Earthquake Center.
<http://mae.ce.uiuc.edu/software_and_tools/maeviz.html>, (Febraury 12, 2008).

McLaren, T., Myers, J., Lee, J.S., Tolbert, N., Hampton, S., and Navarro, C. (2008). “MAEviz: An Earthquake Risk Assessment System.” Proc. of the 16th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, Irvine, California.

McLaren, T., Navarro, C., Lee, J.S., Hampton, S., Tolbert, N., Spencer, B.F., and Elnashai, A. (2009). “Coupling Network Analysis using MAEviz Building Blocks.” Proc. of 2009 NSF Engineering Research and Innovation Conference, Honolulu, Hawaii.

Newhauser, G. and Wolsey, L. (1988). “Integer and Combinatorial Optimization”, Wiley, New York.

Quercia, R. G. and Bates, L. K. (2002). "The Neglect of America's Housing: Consequences and Policy Responses," Working Paper 2002-02. Center for Urban and Regional Studies, The University of North Carolina at Chapel Hill.

Rakes, T., Fetter, G., Deane, J., and Rees, L. (2010). "An assignment model for the interim housing of disaster victims," Proc., 2010 Southeast Decision Sciences Institute Conference, Wilmington, NC, 2010.

Saaty, T. L. (1980). *The analytic hierarchy process*, McGraw-Hill, New York.

Schrijver, A. (2003). *Combinatorial optimization, Polyhedra and Efficiency*, Springer, Verlag, Germany.

Shlay, A. B. (1995) "Housing in the Broader Context in the U.S." *Housing Policy Debate*, 6(3).

Sinnott, R.W. (1984). "Virtues of the Haversine," *Sky and Telescope*, 68(2), p. 159.

Tomioka, T. (1997). "Housing Reconstruction Measures from the Great Hanshin-Awaji Earthquake." In *Proceedings of the 5th United States/Japan Workshop on Earthquake Hazard Reduction*, Pasadena, California, January 15–17, 1997 (pp. 37–57). Oakland: Earthquake Engineering Research Institute.

White, J. A., Case, K. E., Pratt, D. B., and Agee, M. H. (1998). "Comparison of alternatives." *Principles of engineering economic analysis*, fourth edition, John Wiley and Sons, Inc., 143-255.

APPENDIX: MATLAB Code for the Customized Hungarian Algorithm

```
function[solution, solution_weights]=Hungarian_Housing(weight, capacity)
%
% The Hungarian_housing(weight, capacity) is modified from the original
% Hungarian Algorithm 'Hungarian(Perf)' function written by Alex Melin(2006)
% at http://www.mathworks.com/matlabcentral/fileexchange/11609-hungarian-
% algorithm/content/Hungarian.m
%
% The Hungarian_Housing assumes there are F families and H housing
% alternatives. Each housing alternative has certain amount of housing
% units and one housing unit can only allow one family to live in it.
% The housing units of all housing alternatives can guarantee every family
% has a place to live.
%
% The objective of this algorithm is to maximize the overall assignment
% weights
%
% Inputs:
% weight is a F * H Matrix
% capacity is a vector containing the number of housing units of each
% housing alternative
%
%
% Initial condition for the main program.
exitflag = 1;
weight_org = weight;
stepnum = 0;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                               MAIN PROGRAM                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

while exitflag
    switch stepnum
        case 0
            [weight,W_size,f_cov,h_cov,stepnum] = step0(weight);
        case 1
            [weight,M,W_size,stepnum] = step1(weight,capacity,W_size);
        case 2
            [f_cov,stepnum] = step2(M,W_size);
        case 3
            [M,f_cov,h_cov,rk,ck,stepnum] =
            step3(weight,f_cov,h_cov,M,capacity);
        case 4
            [M,stepnum] = step4(M,rk,ck);
        case 5
            [M,f_cov,h_cov,stepnum] = step5(M,f_cov,h_cov);
        case 6
```

```

        [weight,stepnum] = step6(weight,f_cov,h_cov);
    case 7
        % Algorithm Terminated with OPTimal Solution
        exitflag = 0;
    end
end

% Calculate the sum of the assignment weights using the optimal solution
solution = M;
solution_weights=sum(sum(weight_org(solution==1)));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Step 0: Setup the initial condition for the algorithm %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [weight,W_size,f_cov,h_cov,stepnum] = step0(weight)

% The algorithm is implemented for minimization,
weight = max(max(weight)) - weight;
W_size = size(weight);

% A vector that shows if a family is covered
% f_cov[i] = 1 indicates the ith family is covered
% Families are initaially uncovered.
f_cov = zeros(W_size(1),1);

% A vector that shows if a housing alternative is covered
% h_cov[j] = capacity[j] indicates the jth housing alternative is covered
% Housing alternatives are initially uncovered
h_cov = zeros(W_size(2),1);

stepnum = 1;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Step 1: Calculate the smallest weights for each family.
% Build the first assignments under the Capacity Constraints
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [weight,M,W_size,stepnum] = step1(weight, capacity,W_size)

% Find the smallest weight for each family
for i = 1:W_size(1)
    fmin = min(weight(i,:));
    weight(i,:) = weight(i,)-fmin;
end

% Initialize the Assignment Matrix
M = zeros(W_size);

temp_f_cov = zeros(W_size(1),1);

```

```

temp_h_cov = zeros(W_size(2),1);

% Build the first assignments under the capacity constraints
for i = 1:W_size(1)
    for j = 1:W_size(2)
        if weight(i,j) == 0 && temp_f_cov(i) == 0 && temp_h_cov(j) <
capacity(j)
            M(i,j) = 1;
            temp_f_cov(i) = 1;
            temp_h_cov(j) = temp_h_cov(j)+1;
        end
    end
end

stepnum = 2;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Step 2: Cover the families that has assignments, if all families are
% covered, terminate the algorithm with the optimal solution
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [f_cov,stepnum] = step2(M, W_size)

f_cov = sum(M,2);
if sum(f_cov) == W_size(1)
    stepnum = 7;
else
    stepnum = 3;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Step 3: Find the uncovered smallest weights for the families, change
% the covers to cover all the smallest weights with minimum
% number of covers.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [M,f_cov,h_cov,rk,ck,stepnum] = step3(weight,f_cov,h_cov,M,capacity)

W_size=size(weight);
zflag = 1;

while zflag

    % The row and cololumn index of the first uncovered smallest weight
    row = 0; col = 0; exitflag = 0;

    % Find the first uncovered smallest weight of a family
    for i = 1:W_size(1)
        for j= 1:W_size(2)
            if weight(i,j) == 0 && f_cov(i) == 0 && h_cov(j) == 0
                row = i;
            end
        end
    end
end

```



```

else
    % If there is no assigned housing for this family, finish the path
    zflag = 0;
end

if zflag == 1;
    % Find the family that has the smallest uncovered weight for the
    % housing (ck)
    rindex = find(M(:,ck(k))==2);
    k = k+1;
    ck(k,1) = ck(k-1);
    rk(k,1) = rindex;
end
end

% For the complete M-augmenting path, assign the families to the housings
% not assigned to them on the path and unassign the families that assigned
% to the housing on the path.
for i = 1:length(ck)
    if M(rk(i),ck(i)) == 1
        M(rk(i),ck(i)) = 0;
    else
        M(rk(i),ck(i)) = 1;
    end
end
end

stepnum = 5;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Step 5: Uncover the families and housing alternatives, unmark the
% uncovered smallest weights that left from step 4
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [M, f_cov, h_cov, stepnum] = step5(M, f_cov, h_cov)

f_cov = f_cov.*0;
h_cov = h_cov.*0;
M(M==2) = 0;
stepnum = 2;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Step 6: Find the smallest weight that is not covered, add it to all
% the covered families, and deducted it from all the uncovered
% housing alternatives.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [weight,stepnum] = step6(weight,f_cov,h_cov)

minval = min(min(weight(f_cov == 0,h_cov ==0)));

weight((f_cov == 1),:) = weight((f_cov == 1),:) + minval;

```

```
weight(:, (h_cov == 0)) = weight(:, (h_cov == 0)) - minval;  
stepnum = 3;
```