Research Advances in Optimized Temporary Housing following Disasters

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Abstract
Recent years have witnessed large-scale population displacements following natural disasters, which necessitated the provision of adequate temporary housing solutions. These solutions needed to cater to the socioeconomic and psychological needs of displaced families, have minimal negative environmental impact, and be within available recovery budgets. During the last decade, there has been an intense research effort to develop models capable of optimizing temporary housing configurations in order to address this multifaceted problem. This paper examines the differences and similarities among these optimization models in terms of their objectives, integration of subsequent housing phases, approach to decision-making, optimization tools, and integration with impact assessment software systems.

Keywords
Temporary Housing, Optimization, Natural Disasters, Decision-Making

1. Introduction

Natural disasters can cause significant property damage and large-scale population displacements. After spending days or weeks in mass-care emergency shelters, the displaced families are in urgent need of temporary housing, where they can reestablish their household routines until permanent housing can be eventually obtained (Quarantelli 1985). Temporary housing can extend for months and even years and can take many forms, such as manufactured housing (e.g. travel trailers and mobile homes), leased hotels and motels, and public housing units. In the aftermath of natural disasters, emergency planners are confronted with critical and serious temporary housing challenges that are caused by (1) the social and economic disruptions inflicted on the displaced families; (2) the vulnerability of temporary housing to post-disaster hazards; (3) the negative environmental impacts of temporary housing on host communities; (4) the significant costs of temporary housing provision; and (5) the impacts of temporary housing decisions on permanent housing solutions and their sustainability (El-Anwar et al. 2009b).

In the last decade, there has been a noticeable research effort in developing temporary housing optimization models in order to address the aforementioned challenges. These research studies were conducted following a series of natural disasters worldwide; including the 2005 Hurricanes Katrina and Rita in the US (Oh et al. 2006; El-Anwar and El-Rayes 2007), the 2008 Wenchuan earthquake in China (Huang et al. 2011), and 2010 Darfield and the 2011 Christchurch earthquakes in New Zealand (Giovinazzi et al. 2013). Some studies analyzed historic large-scale disasters such as the 1994 Northridge earthquake in the US (El-Anwar et al. 2008) and potential disasters such as the New Madrid Earthquake in TN (El-Anwar et al. 2011) and an earthquake along the Mosha fault in Tehran, Iran (Hosseini et al. 2016). The objectives of this paper is to analyze the differences and similarities of these research studies and their developed models in terms of (1) optimization objectives; (2) integration of subsequent housing phases; (3) approach to decision making; (4) optimization tools; and (5) integration with impact assessment software systems.

2. Optimization Objectives

This section presents the main single and multi-objective optimization models developed to support temporary housing decisions. These models are categorized in the following subsections based on their objectives that focused on (1) displacement distances; (2) experienced socioeconomic disruptions; (3) spread of panic; (4) housing structural safety; (5) environmental impacts; and (6) public expenditures.

<u>Families' Displacement Distances</u>:

Displacement distance is an important factor affecting displaced families' post-disaster recovery and welfare. Accordingly, minimizing the families' displacement distances was among the objectives to be addressed by some of the early studies. However, studies used different definitions to displacement distances. First, El-Anwar and El-Rayes (2007) computed the displacement distance as the distance between the assigned temporary housing unit and the preferred location by families, which can be represented by the zip codes selected by displaced families. Accordingly, their optimization model focused on minimizing the summation of displacement distances for all families based on that definition.

Second, Rakes et al. (2014) developed an optimization model to assigning families to temporary housing locations based on their distance from the family's preferred location and the closest educational and healthcare facilities based on the family's needs. This model selected housing locations that address some defined needs for each family, but did not consider the family's preferences among those needs.

Third, El-Anwar and Chen (2013) formulated a displacement distance equivalency index that utilized the Analytical Hierarchy Process to evaluate the average distance of a proposed housing location based on two categories of individually specified needs. The first category represents the need to be close to specific services that can be available in various locations; such as public schools, healthcare facilities, and public transportation. The second category represents location-specific needs, such jobs and the pre-disaster housing location. Accordingly, the developed optimization model minimizes the displacement distance equivalency index for each family.

<u>Experienced Socioeconomic Disruptions:</u>

El-Anwar et al. (2010c) developed an optimization model capable of identifying the locations and types of temporary housing that would minimize the socioeconomic disruptions experienced by families. To this end, six socioeconomic disruption metrics were proposed, including (1) employment and educational opportunities; (2) displacement distance from preferred housing location; (3) temporary housing quality; (4) temporary housing delivery time; (5) capacity of the assigned temporary housing location to support the healthcare and safety needs for both the displaced families and host communities; and (6) access to essential utilities and services. It is noteworthy that the model adopted the displacement distance definition offered by El-Anwar and El-Rayes (2007). The model provided a comprehensive assessment to the housing location, but this assessment was not based on each family's specific needs and preferences.

Furthermore, the formulation proposed by El-Anwar and Chen (2013) was later incorporated in the community-based housing response pool online system developed by El-Anwar and Chen (2016). This system enables (1) housing providers to register their housing units in a pre-disaster phase and update their units availability and rental costs following the disaster occurrence; (2) displaced families to apply for temporary housing and define their socioeconomic needs and their preferences among those needs;

and (3) emergency planners to define additional housing resources and optimize the temporary housing configurations with the objective of minimizing the overall socioeconomic disruptions.

Spread of Panic:

Hu et al. (2014) developed a model capable of minimizing the spread of panic among victims, cost of psychological intervention, as well as transportation and shelter building costs. The model utilized an objective function that assigned a penalty cost for each objective into a weighted single objective. The model utilized the susceptible-infective-removal model to account for the increase in the number of victims to be evacuated due to panic spread.

Temporary Housing Structural Safety:

El-Anwar et al. (2010a) developed an optimization model to quantify and maximize the safety of temporary housing in the presence potential post-disaster hazards, such as earthquake aftershocks. The proposed safety analysis considers a number of important factors, including (1) post-disaster hazard type and magnitude; (2) distance between temporary housing and potential hazard; and (3) housing type.

Environmental Impacts:

There are two main reported studies that aimed at optimizing temporary housing decisions in order to account for their environmental impacts. In the first study, El-Anwar et al. (2009b) developed a model that is capable of minimizing the adverse environmental impacts of building and maintaining temporary housing projects on host communities. The environmental impact model is designed to enable emergency management agencies to assess and minimize the environmental impacts of temporary housing plans, in compliance with the FEMA environmental review process (FEMA 2005). In the second study, Huang et al. (2011) developed a model to optimize the direction of the temporary house length in relation to the airflow field to improve the thermal environment of the housing settlement. To this end, they used computational fluid dynamics (CFD).

Public Expenditures:

Minimizing public expenditures is a common objective in most of the aforementioned models, which utilized multi-objective optimization to account for the total cost of providing temporary housing in addition to the other objectives. The model developed by Hu et al. (2014) accounted as well for the cost of psychological intervention, because of the unique nature of their overarching objective of controlling the spread of panic among disaster victims. Furthermore, El-Anwar and Chen (2016) proposed a comprehensive cost model to compute and minimize total public expenditures by taking into account all costs related to providing and sustaining temporary housing projects during their life cycle.

It is noteworthy that El-Anwar et al. (2009a and 2009b) and Hosseini et al. (2016) proposed methodologies to incorporate most of the aforementioned objectives, including (1) minimizing socioeconomic disruptions; (2) maximizing structural safety; (3) minimizing environmental impacts; and
(4) minimizing public expenditures. The following section discusses further research efforts that aimed at incorporating the longer-term permanent housing phase in the optimization problem.

3- Integration of Subsequent Housing Phases

A number of studies accounted for the long-term impacts of post-disaster short-term housing decisions. These studies offered a unique perspective to the temporary housing phase and added new optimization objectives related to the subsequent long-term housing and development phases. The first study was conducted by Oh et al. (2006) and investigated the use of agent technologies for pre-disaster temporary housing location selection. The objective was to identify the suitable location to meet the short-term need while avoiding conflicts with long-term development plans in the host communities. Agents in their model represent three stakeholder groups: government officials, disaster victims, and property owners.

The second study by El-Anwar et al. (2010b) aimed at evaluating and maximizing the sustainability of integrated housing recovery efforts under the Alternative Housing Pilot Program (AHPP). AHPP is a program funded by the US Congress in 2006 to evaluate the efficacy of non-traditional short and intermediate-term housing alternatives in case of large-scale disasters. AHHP intended to encourage housing solutions that will facilitate sustainable, permanent, quickly deployable, and affordable housing in lieu of the existing temporary housing solutions. The developed optimization model by El-Anwar et al. (2010b) incorporated a set of important metrics, which have significant impacts on the sustainability of post-disaster housing during the temporary and permanent housing phases, including (1) environmental performance; (2) social welfare; (3) life cycle cost; and (4) structural safety.

While the model developed by El-Anwar et al. (2010b) focused on the AHPP, a later model was developed by El-Anwar (2013a; 2013b) to quantify and optimize the impacts of substituting temporary housing by quickly deployable permanent housing on the social and economic welfare of displaced families as well as the required additional costs associated with these substitutions. The model identifies the optimal configurations of hybrid housing arrangements (including both temporary and permanent housing developments) to maximize the overall net socioeconomic benefit.

4- Approach to Decision-Making

A number of the aforementioned models incorporated multiple social and economic metrics when identifying the optimal configuration of temporary housing alternatives that would satisfy the displaced families' needs. However, these models adopted different decision-making approaches regarding who defines the families' needs as well as their preferences among those needs. The first approach is top-down, where the decision-making authority lies with the emergency management agency. In this case, emergency planners assume all families share the same need to be close to work and educational opportunities, healthcare facilities, public transportation, etc. Furthermore, emergency planners also define the relative importance weights among those metrics (El-Anwar et al. 2009b).

A second approach allows displaced families to define their proximity needs to healthcare and k-12 education (Rakes et al. 2014). However, emergency planners still define the relative importance weights among those needs. The third approach is bottom-up, where each family defines its specific needs as well as its preferences among those needs (which is translated into relative weights in the optimization model). Accordingly, the third approach has the ability to offer customized housing solutions tailored to the needs of displaced families (El-Anwar and Chen 2013). However, that approach results in a significantly larger optimization problem, because each family is represented using a set of unique decision variables. At such scale, more effective optimization tools and model formulations are needed. The following section discusses the different optimization tools used with each of the proposed optimization models.

5- Optimization Tools

Various tools have been used to optimize temporary housing decisions according to the nature and scale of the optimization problem. Table 1 lists the tools used with each of the optimization models. Genetic algorithms were first introduced because of their modeling flexibility. However, as the scale of the temporary housing problem and its associated search space increased, more efficient tools were needed. To this end, linear formulations to the temporary housing assignment problem were introduced, which include the use of mixed integer-linear programming and the modified Hungarian algorithm. This is attributed to the reported effectiveness and efficiency of these formulations (Kandil et al. 2010), where the model effectiveness refers to the quality of generated solutions and its efficiency refers to the required computational time. With these modeling advancements, the computational time to solve large-scale problem was reduced from days to minutes (El-Anwar and Chen 2014). It is noted that enumeration was used but with much smaller search spaces (Huang et al. 2011) and agent-based simulation was used to address the unique modeling needs of the formulation proposed by Oh et al. (2006).

Table 1: Utilized Optimization Tools

Optimization Tools	Research Studies
Agent-Based Simulation	Oh et al. (2006)
Genetic Algorithms	El-Anwar and El-Rayes (2007); El-Anwar (2013b)
Enumeration (CFD Simulation)	Huang et al. (2011)
Linear, Integer, and Mixed Integer-Linear Programming	El-Anwar et al. (2008; 2009b; 2010a, b, c); Rakes et al. (2014); El-Anwar (2013a, b); El-Anwar and Chen (2013); Hu et al. (2014)
Hungarian Algorithm	El-Anwar and Chen (2014, 2016)

6- Integration with Impact Assessment Software Systems

In order to suppot the ulimate use of temporary housing optimization models by emergency management agencies, the comprehensive model proposed by El-Anwar et al. (2009b) was incorporated in MAEviz, which is seismic risk assessment open-source software developed by the Mid America Earthquake Center in cooperation with the National Center for Supercomputing Applications (El-Anwar et al. 2009a; MAEviz 2008). The optimization model is intergated in two modules within MAEviz for temporary housing analysis and temporary housing optimization. MAEviz can estimate housing losses and displacements following earthquakes, which is then used as input to the temporary housing modules.

7- Discussion

In the last decade there has been significant advancements in temporary housing optimization models, whether in terms of the incorporated optimization objectives or the scale of the optimization problems to be solved (represented by the number of temporary housing alternatives and the number of housing assignments to be made). These breakthroughs, however, could not have been possible without the corresponding innovations in problem formulations. The ability to model the temporary housing optimization problems using linear equations enabled the use of mixed integer linear programming, which enabled the models to address cases of large-scale displacement. This linear formulation later facilitated the use of the modified Hungarian algorithm, which enabled the development of exponentially larger models capable of offering customized solutions for each family based on their individual needs and preferences. It is noteworthy that the computational speed of these models is essential to facilitate their practical use in disaster response. Furthermore, the linear formulations enabled the development of more robust optimization models that are less sensitive to the values of input parameters, which is a common drawback with the use of evolutionary algorithms.

8- Conclusions and Future Work

The management of temporary housing has a significant impact on displaced families, host communities, and the limited recovery budgets. Accordingly, there has been a serious effort to develop effective optimization models to address the multifaceted aspects of temporary housing. This effort included quantifying and consequently optimizing multiple objectives, creating innovative formulations to the optimization problem, and empowering the displaced families with more decision-making authorities.

More research is still needed to address a number of issues related to temporary housing optimizations. First, there is a need to be able to quickly confirm the structural and functional performance of existing housing facilities (e.g. hotels, motels, and other rental units) following disasters and to assess the environmental impacts of proposed temporary housing communities. This is a prerequisite to including these housing alternatives in the temporary housing optimization process. Second, more research should be dedicated to enable displaced families to select from a number of offered temporary housing solutions. This entails the use of phased optimization techniques, which can run the optimization model efficiently after each applicant makes a selection. Third, there is a need to integrate the various components of post-disaster recovery instead of focusing on temporary housing as an isolated problem, such as optimizing the recovery of transportation networks and community services and infrastructure. Fourth, similar research effort is needed to offer optimized housing solutions to displaced families due to wars and internal conflicts based on the specific needs in these situations.

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