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Araştırma Makalesi Research Article

A COOPERATIVE GAME THEORETICAL MODEL IN TEMPORARY HOUSING FOR POST-DISASTER SITUATIONS

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Abstract
Turkey is among the countries that are especially vulnerable to natural disasters. Throughout history, many disasters have occurred in the geography where Turkey is located. Turkey is known that a country that is connects the continents and cultures. It is provide also interactions between several tectonic plates that including the Eurasian, African, and Arabian plates through the Anatolian plate. Interactions among the plates compose active seismic region that encompasses most of Turkey. As a result of this high seismicity region, earthquake has been significant natural disaster for Turkey. Numerous buildings collapse and have damage after the severe earthquakes and the victims need to shelter to provide their needs. In this process, temporary housing is using to solve this shelter needs hence temporary housing needing urgent attention. But there is a problem about number of temporary housing demand because it is not possible to say a certain number about temporary housing needed. In this study, game theory is used to solve this problem. Our study shows that cooperative interval game theory help us to define a fair cost allocation between private organizations for supporting the housing problem by using facility location games under uncertainty.

AFET SONRASI GEÇİCİ KONUTLAR İÇİN BİR KOOPERATİF OYUN TEORİSİ MODELİ

Anahtar Kelimeler
Geçici Konut,
Deprem,
Kooperatif Oyun Teorisi,
Belirsizlik,
Aralıklı Çözümler.

Öz
Türkiye, özellikle doğal afetlere karşı savunmasız olan ülkeler arasındadır. Tarih boyunca, Türkiye'nin bulunduğu coğrafyada birçok felaket meydana gelmiştir. Türkiye, kıtaları ve kültürleri birbirine bağlayan bir ülke olduğu biliniyor. Anadolu levhası üzerinden Avrasya, Afrika ve Arap levhalarını da içeren birçok tektonik levha arasında etkileşimler sağlar. Plakalar arasındaki etkileşimler, Türkiye'nin çoğunu kapsayan aktif sismik bölgeyi oluşturmaktadır. Bu yüksek deprem bölgelerinin bir sonucu olarak, Türkiye için deprem önemli bir doğal afet olmuştur. Çok sayıda bina, şiddetli depremlerin ardından çökmekte ve zarar görmektedir ve mağdurların ihtiyaçlarını karşılamak için barınmaları gerekmektedir. Bu süreçte geçici barınak, bu barınak ihtiyacını çözmek için kullanıyor, bu nedenle geçici dikkat gerektiren geçici konutlar. Ancak geçici konut talebinin sayısı konusunda bir sorun var çünkü ihtiyaç duyulan geçici konutlar hakkında belirli bir rakam söylemek mümkün değil. Bu çalışmada, bu problemi çözmek için oyun teorisi kullanılmıştır. Çalışmamız, kooperatif aralıklı oyun teorisinin belirsizlik altında tesis yeri oyunlarını kullanarak konut sorununu desteklemek için özel kuruluşlar arasında adil bir maliyet tahsisi tanımlamamıza yardımcı olduğunu göstermektedir.

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1. Introduction

Turkey faces frequent disasters due to its geological and topographical characteristics. Turkey is not a country facing with tornados or hurricanes. But, the most effective disasters in Turkey according to their severity rates are; earthquakes, landslides, floods, rocks fall, fires, avalanche, storm and rising of ground water, etc. According to these, the most devastating disaster is earthquakes for Turkey. The other disaster types are usually small-scaled, with relatively little or no death toll. Earthquakes are the most feared type of disaster in Turkey, as many lives are often lost (Limoncu and Celebioglu, 2006; Güneş, 2015). Turkey is located on one of the most active several tectonic plates called Alpine–Himalayan earthquake belt. This plate is still active, and many earthquakes occur each month (Erdogan et al, 2009).

Based on available resources and records, all natural disasters occurred in Turkey since the beginning of the 20th century resulted in 87.000 casualties, 210.000 injuries, and 651.000 heavily damaged or destroyed homes. Earthquakes were responsible for 76% of the damaged or destroyed homes, followed far behind by landslides (10%) and floods (9%) (Güneş, 2015). For example, the city of Izmir, lying in the first seismic zone of Turkey, is located in a seismically very active region in Western part of the Anatolian plate. Unexpected major earthquakes can occur frequently in this region and lead to severe damages on buildings (Tuna and Altun, 2014; Moberg, 2015). There have been many earthquakes with magnitude Ms C 4.9 that occurred between 1900 and 2005 near Izmir.

Seismic zones map of Turkey and Izmir city is shown in Figure 1.

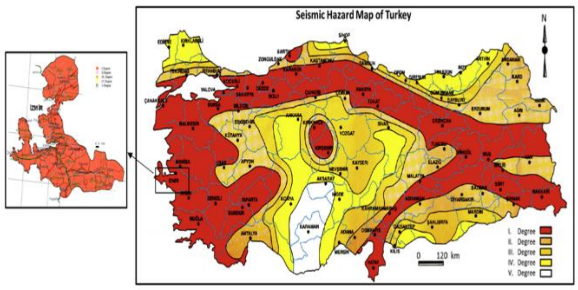

Figure 1. Seismic zones map of Turkey and Izmir city (Unal, 2015).

There are five different earthquake zones in Turkey. Figure 1 shows them ordered according to degrees, with the first being the most dangerous and the fifth the least dangerous. According to the literature; 44 percent of Turkey's population lives in the first-degree zones (Kılcı, et al., 2015).

Post-disaster housing recovery is quite important in the long-term reconstruction of communities affected by catastrophes. But, there is lack of a systematic framework for measuring post-disaster housing recovery (Chang, 2010; Ganapati, 2013).

There are four stages of sheltering and housing respectively; "emergency sheltering" (housing disaster victims temporarily, such as in stadiums and schools); "temporary sheltering" (e.g., tents); "temporary housing" (e.g., trailers); and "permanent housing" (new housing units built for disaster victims). We focus exclusively on permanent housing in the disaster recovery phase. Several of these stages may exist simultaneously in a disaster-stricken society (Ganapati, 2008).

According to the Quarantelli housing and sheltering should be considered separately. Sheltering involves normal daily activities, whereas housing involves the resumption of household responsibilities and activities like food preparation, laundry, socializing, work, school and recreation (Johnson, 2002).

Questions about temporary housing after disasters are still an extensive issue and debate in the scientific field. The number of natural disasters has increased dramatically in recent years, having a significant impact on the built environment. Many buildings collapse or have suffer damages after disasters and these situations causing high numbers of homeless people. After a disaster the needs for housing should have a quick response since temporary housing in helping affected communities to re-establish their normal life activities in a post-disaster situation. Hence, temporary housing would be immediately available after a disaster, offering a level of comfort consistent with the prevailing standard of living, at a cost proportional to intended length of use and easily eradicated or transformed once it is no longer needed (Johnson, 2007; Félix et al., 2013).

Temporary accommodation refers to disaster-affected families' interim lodging between the onset of the disaster and the period when they regain permanent housing. It fills the gap between the immediate relief stage and the later reconstruction stage. As a result, this is a significant stage in the disaster recovery process that is mostly overlooked by governments, for NGOs and aid organizations (Johnson, 2002; Chalinder, 1998).

Especially, five types of temporary accommodation (prefabricated temporary houses, wooden temporary houses, paper temporary houses, winterized tents, and self-built shelters) are utilized after the disaster.

In this paper, cooperative interval games are used to solve the temporary accommodation problem quickly and economically after the earthquake. The paper is having great importance in terms of disaster preparedness to avoid post disaster housing problem for Turkey and for other countries having a possibility to face with disaster like earthquake and etc. This research has a great importance to provide a solution to the post-earthquake housing problem.

Cooperative interval games and interval solution concepts are useful tools for modeling various management, engineering and Operational Research situations, where payoffs are affected with uncertainty. In different situations, decisions regarding whether (or not) to cooperate within the grand coalition rely on estimations of individual benefits/costs, between two bounds.

Cooperation between different responding entities is a critical element of effective intervention operations. Making a reasonable price decision is a significant problem for real estate companies and governments (Johnson, 2002).

Interval solutions for cooperative games reflect uncertainty about the payoff allocations in situations, where there is no uncertainty in the worth of coalitions. If there are some uncertainties about the payoff allocation then we cannot just assign a specific payoff to every player. Therefore, in this paper we propose some interval solutions for cooperative games. This uncertainty can have several reasons like number of temporary housing demand. Because it is not possible to say a certain number about temporary housing needed.

This paper is organized as follows is organized as follows: We give some basic notions and solution concepts from Cooperative Game Theory in Section 2. Our cooperative facility location game based on cooperative interval game model constructed after an earthquake as a natural disaster is presented in Section 3. In Section 4, we give some interpretations related with our solutions. Finally, Section 5 ends this paper with a conclusion and an outlook to future studies.

2. Preliminaries

In this section, in order to provide the readers with all the necessary background to follow this paper, we formally give some basics from cooperative interval games and related interval solution concepts. Facility location situations which is necessary to construct our model is also given .

2.1. Cooperative Interval Games

A *cooperative game* in characteristic function form is an ordered pair (N, c) where N is a finite set of players and c is a characteristic function $c: 2^N \to \mathbb{R}_+$ that associates to each set $S \subset N$ a real value $c(S)$ satisfying $c(\emptyset) = 0$. This value $c(S)$ shows the joint gain which the players in S can guarantee by themselves if they cooperate independently of what the agents in $N \setminus S$ could do. Hence, $c(S)$ measures the worth of a coalition S. The family of all cooperative games are denoted by G^N (Tijs, 2003).

The payoffs to coalitions of players are known with uncertainty in cooperative interval game theory. A *cooperative interval game* (Alparslan Gök, 2009) is an ordered pair $\langle N, c \rangle$, where $N = \{1,2,\ldots,n\}$ is the set of players, and $c: 2^N \to I(\mathbb{R})$ is the characteristic function such that $c(\emptyset) = [0,0]$, where $I(\mathbb{R})$ is the set of all nonempty, compact intervals in $\mathbb{R}$. For each $S \in 2^N$, the worth set $c(S)$ of the coalition S in the interval game $\langle N, c \rangle$ is of the form $[\underline{c}(S), \overline{c}(S)]$. The family of all interval games with player set N is denoted by IG^N. Similarly, we identify an interval game $\langle N, c \rangle$ with its characteristic function c.

Let $A, B \in I(\mathbb{R})$ with $A = [\underline{A}, \overline{A}]$, $B = [\underline{B}, \overline{B}]$, $|A| = \overline{A} - \underline{A}$ and $\alpha \in \mathbb{R}_+$. Therefore, we can say that $A + B = [\underline{A}, \overline{A}] + [\underline{B}, \overline{B}] = [\underline{A} + \underline{B}, \overline{A} + \overline{B}]$ and $\alpha A = \alpha[\underline{A}, \overline{A}] = [\alpha\underline{A}, \alpha\overline{A}]$.

We also need to show the using of partial subtraction operator. $A - B$ can be defined, only if $|A| \geq |B|$, by $A - B := [\underline{A}, \overline{A}] - [\underline{B}, \overline{B}]$=$[\underline{A} - \underline{B}, \overline{A} - \overline{B}]$.

A game $\langle N, c \rangle$ is called *size monotonic* if$\langle N, |c| \rangle$ is *monotonic*, i.e., $|c|(S) \leq |c|(Z)$ for all $S, Z \in 2^N$ with $S \subset T$. For further use, the class of size monotonic interval games with player set N is denoted by $SMIG^N$.

2.2. Interval Solutions

Now, let us introduce the definition of the interval solution which are necessary in this study.

2.2.1. Interval Shapley value

Let $\pi(N)$ be the set of all permutations $\sigma : N \to N$. The set $P^\sigma(i) = \{r \in N \mid \sigma^{-1}(r) < \sigma^{-1}(i)\}$ consists of all predecessors of i with respect to the permutation σ. Let $c \in G^N$ and $\sigma \in \pi(N)$. The *marginal vector* $m^\sigma(c) \in \mathbb{R}^n$ with respect to σ and v has as i-th coordinate $m_i^\sigma(c) = c(P^\sigma(i) \cup \{i\}) - c(P^\sigma(i))$ for each $i \in N$.

Given a game (N, c) the *marginal contribution* $m^\sigma(c)$ of player i to coalition S $(i \notin S)$ is given by $c(S \cup i) - c(S)$.

For $\sigma_1 = (1,2,3)$ we calculate the marginal vectors of

Example 2.1 are as follows:

$$m_1^{\sigma 1}(c) = c(\{1\}) = [5,7],$$
$$m_2^{\sigma 1}(c) = c(\{1,2\}) - c(\{1\}) = [2,3],$$
$$m_3^{\sigma 1}(c) = c(\{1,2,3\}) - c(\{1,2\}) = [3,3].$$

The other marginal vectors can be calculated similarly. Based on this concept, for $c \in SMIG^N$ the *interval Shapley value* $\Phi(c)$ of a game $c \in I(\mathbb{R})^N$ is defined (Alparslan Gök, 2014). For each player the interval Shapley value is the average of each player's possible marginal contributions. The mathematical expression of the Shapley value is the following:

$$\Phi(c) := \frac{1}{n!}\sum_{\sigma\epsilon\pi(N)} m^{\sigma}(c) \quad (2).$$

The interval Shapley value assignes a payoff vector to each cooperative interval game. It should not forgetten that the Shapley value is defined and axiomatically characterized for arbitrary cooperative games but the interval Shapley velues is defined only for a subclass of cooperative interval games called size monotonic games, and it is axiomatically characterized only on a strict subset of size monotonic games (Alparslan Gök, 2014; Shapley, 1953).

2.2.2. The interval Banzhaf value

The Banzhaf value arises from the subjective belief that each player is equally likely to join any coalition. On the other hand, the Shapley value arises from the belief that for every player, the coalition he joins is equally likely to be of any size and that all coalitions of a given size are equally likely (Palancı et al, 2015).

The interval Banzhaf value $\beta: SMIG^N \rightarrow I(\mathbb{R})^N$, $\forall c \in SMIG^N$ is defined as

$$\beta(c) = \frac{1}{2^{|N|-1}}\sum_{i\in S}(c(S) - c(S\backslash\{i\}) \quad (3).$$

2.2.3. The interval *ICIS*-value

The CIS-value (Driessen and Funaki, 1991) assigns to every player its individual worth, and distributes the remainder of the worth of the grand coalition N equally among all players (Palancı et al, 2015).

The interval *ICIS*-value assings every player to its individual interval worth, and distributes the remainder of the interval worth of the grand coalition N equally among all players (Palancı et al, 2015). The ICIS-values is defined by

$$ICIS_i(c) = c(\{i\}) + \frac{1}{|N|}\left(c(N) - \sum_{j\in N} c(\{j\})\right) \quad (4).$$

.

2.2.4. The interval *ENSC*-value

The interval *ENSC*-value (IENSC-value) assigns to every game c the ICIS-value of its dual game, i.e.

$$IENSC_i(c) = ICIS_i(c^*) = \frac{1}{|N|}\left(c(N) + \sum_{j\in N} c(N\{j\}) - c(N\{i\}\right) \quad (5).$$

The *IENSC*-value assigns to every player in a game its interval marginal contribution to the "grand coalition" and distributes the remainder equally among the players (Palancı et al, 2015; van den Brink and Funaki, 2009).

2.2.5. The interval IED-solution

The interval *ED*-solution (*IED*-solution) is given by

$$IED_i(c) = \frac{c(N)}{|N|} \text{ for all } i \in \mathrm{N} \quad (6).$$

(Palancı et al, 2015; van den Brink and Funaki, 2009).

2.3. Facility Location Situations

A given cost for constructing a facility is existed in *facility location situations*. A player is expected to connect to this facility with a minimim the total cost. There are two cases in these kind of situations. The first one is the case of public facilities (such as hospitals, fire stations, etc.) and the second one is the case of private facilities (such as distribution centers, some stations, etc.) (Palanci and Alparslan Gök, 2017).

Each facility is constructed to please the players in a facility location situation, Here, the problem is to minimize the total cost. This cost is composed of both the player distance and the construction of each facility. A facility location game is constructed from a facility location situation.

In a *facility location game*, a set A of agents (knowns as cities), a set F of facilities, a facility opening cost f_i for every facility $i \in F$, and a distance d_{ij} between every pair (i,j) of points in $A \cup F$ indicating the cost of connecting j *to* i are given. It is assumed that the distances come from a metric space (they are symmetric and obey the triangle inequality). For a set $S \subseteq A$ of agents, the cost of this set is defined as the minimum cost of opening a set of facilities and connecting every agent in S to an open facility. The cost of each coalition for the game c is defined by

$$c(S) = min_{F^*\subseteq F}\{\sum_{i\in F^*} f_i + \sum_{j\in S} min_{i\in F^*} d_{ij}\} \quad (7).$$

Now, we give an example of a facility location game.

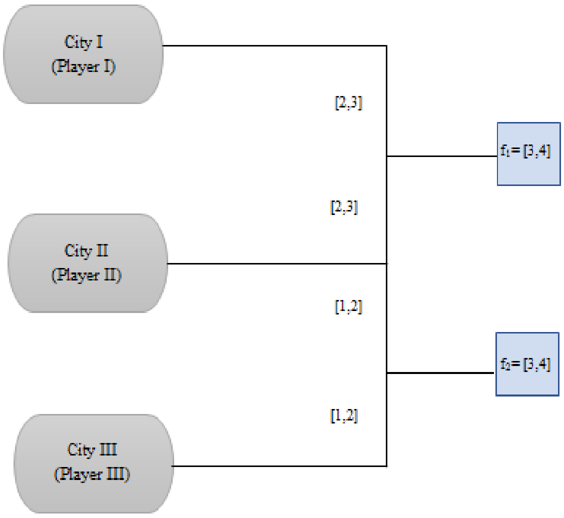

Figure 2. An example of a facility location game.

Example 2.3., Figure 2 shows a facility location game with 3 cities {City 1 (Player 1), City 2 (Player 2), City 3 (Player 3)} in Turkey and 2 hospitals {f1, f2}. The costs of each coalitions are calculated by using (1) as follows:

$$c(\{1\}) = [5,7];\ c(\{2\}) = [4,6];\ c(\{3\}) = [4,6];$$
$$c(\{1,2\}) = [7,10];\ c(\{2,3\}) = [5,8];\ c(\{1,3\}) = [9,15];$$
$$c(\{1,2,3\}) = [10,17].$$

The gathered cost can be shared out to the different purchasers in a equitable way for cost allocation problems. For example, provinces would pay for the building of libraries or sports, but they do not desire to pay more than their fair share of the gathered cost, whatever that means. Justice means that no group of customers, or coalitions, has any encouraging to disunify and acquire the service on their own, in applications of cooperative game theory (Mallozzi, 2011; Goemans and Skutella 2004).

A facility location game has two aims: the first one is to define a applicable position for the facility according to some given facility location rule; the second one deals instead with the problem of how to deal out the total cost among the members of the coalition, where the dispersion of total cost is worked with cooperative game theoretic solution concepts, such as interval solutions.

3. Case Study: Tent City Development After The Earthquake In İzmir

After the severe Earthquake, a huge emergency sheltering and temporary sheltering demand occurred, since the effects are very huge. So, the need for housing after the disaster was very large, which could be said that thousands of dwellings were needed urgently. In this period Turkish government began to evaluate the rehabilitation of the districts and to build post disaster housing (permanent housing). However, it was clear that all the needs could not be met in a single region, so the government firstly started to study on finding suitable districts for building post-disaster housing settlements. It took some time to solve all these problems (Ozden, 2005).

Our case study is based on a possible facility location after an earthquake in İzmir, Turkey. Consider that there is an earthquake in İzmir and after the earthquake, nearly 14000 tents are distributed. Three tent cities are established in Aydın, Uşak and Balıkesir which are near İzmir. There are nearly 8000 tents in the hands of the Kızılay that is the beneficiary of Turkey. The distribution of the approximately remaining 6000 tents is undertaken by one local and one foreign company. The cost of bringing services to the people living in the tent cities belongs to these companies.

Almost 50 percent of the 6000 tents are built in Aydın, almost 35 percent of the 6000 tents are built in Uşak, and the approximately rest of the tents are built in Balıkesir. Three kinds of tent types are distributed (Table 1). In Aydın, one tent is between 500 and 700 Turkish Liras (TL) and is for 8 or 10 persons. In Uşak, one tent is between 850 and 1050 TL and is for 15 or 17 persons. In Balıkesir, one tent is between 650 and 850 TL and is for 10 or 12 persons.

Table 1. The costs of building tent cities and some properties.

Tent city no	**Tent city name**	**Property of tent**	**Number of tents established by companies**	**Total**
1	Aydın	1 tent=[500,700] TL and for [8,10] persons	[3000,3200] (by local company)	[1500000,2240000] TL for [24000,32000] persons
2	Uşak	1 tent=[850,1050] TL and for [15,17] persons	[500,700] (by local company) [1600,1800] (by foreign company)	[6375000,12495000] TL for [7500,11900] persons (by local company) [20400000,32130000] TL for [24000,30600] persons (by foreign company)
3	Balıkesir	1 tent=[650,850] TL and for [10,12] persons	[900,1100] (by foreign company)	[585000,935000] TL for [9000,13200] persons

Additionally, the bringing services for facility location problems must be given, too. In our case study, the service cost per person is between 50 and 70 TL. In Table 2, the costs of bringing services of companies are given.

Table 2. The costs of bringing services of companies

Tent city no	**Tent city name**	**The costs of bringing services of local company**	**The costs of bringing services of foreign company**
1	Aydın	[1200000, 2240000] TL for [3000,3200] tents	-
2	Uşak	[375000,833000] TL for [500,700] tents	[1200000,2142000] TL for [1600,1800] tents
3	Balıkesir	-	[450000,924000] TL for [900,1100] tents

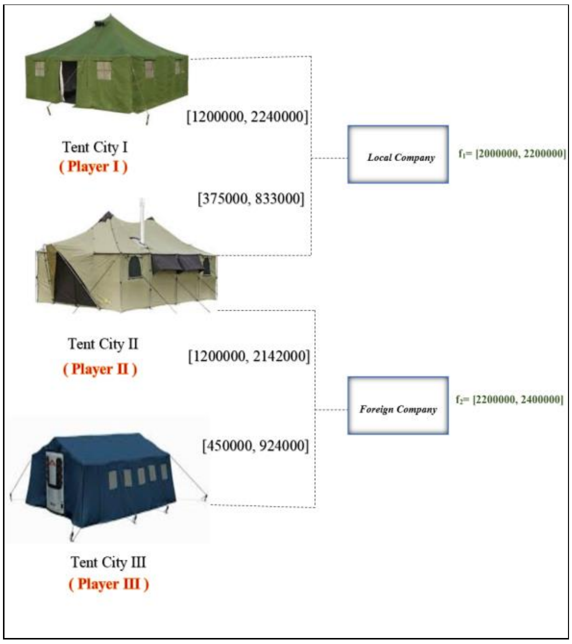

Figure 3. The illustration of our case study

Figure 3 shows a facility location game with 3 cities (Aydın (Player 1), Uşak (Player 2), Balıkesir (Player 3) in Turkey and 2 companies. The costs for each coalition are calculated by using (1) as follows:

$$c(\{1\}) = [3200000,4440000],$$
$$c(\{2\}) = [2375000,3033000],$$
$$c(\{3\}) = [2650000,3324000],$$
$$c(\{1,2\}) = [3575000,5273000],$$
$$c(\{1,3\}) = [5850000,7764000],$$
$$c(\{2,3\}) = [3850000,5466000],$$
$$c(\{1,2,3\}) = [6225000,8597000].$$

Table 3 shows the marginal vectors of our model, where $\sigma: N \to N$ consists of three components with the order $(\sigma(1), \sigma(2), \sigma(3))$.

Table 3. The marginal vectors of our model.

σ	$m_1^{\sigma}(c)$	$m_2^{\sigma}(c)$	$m_3^{\sigma}(c)$
$\sigma_1 = (1,2,3)$	[3200000,4440000]	[375000,833000]	[2650000,3324000]
$\sigma_1 = (1,3,2)$	[3200000,4440000]	[375000,833000]	[2650000,7320000]
$\sigma_1 = (2,1,3)$	[1200000,2240000]	[2375000,3033000]	[2650000,3324000]
$\sigma_1 = (2,3,1)$	[2375000,3131000]	[2375000,3033000]	[1475000,2433000]
$\sigma_1 = (3,1,2)$	[3200000,4440000]	[375000,833000]	[2650000,3324000]
$\sigma_1 = (3,2,1)$	[2375000,2298000]	[1200,2142000]	[2650000,3324000]

The average of the six marginal vectors is the interval Shapley value of this game which can be calculated as:

$$\Phi(c) = ([2591666.67,3498166.67], [1179166.67,1784500], [2454166.67,3841500]).$$

Now, Let us look at how the interval Banzhaf value for this game. For player 1 we have:

$$\beta_1(c) = \frac{1}{2^2}\sum_{1\in S}(c(S) - c(S\backslash\{1\})$$

$$= \frac{1}{4}(c(\{1\}) + c(\{1,2\}) + c(\{1,2,3\}) + c(\{1,3\}) - c(\{2\}) - c(\{3\}) - c(\{2,3\}))$$
$$= [2493750,3562750].$$

The interval Banzhaf values of other players can be examined similarly as follows:

$$\beta_2(c) = [1081250,1710250], \beta_3(c) = [2356250,3101250].$$

At that rate, the interval Banzhaf value is

$$\beta(c) = ([2493750,3562750], [1081250,1710250], [2356250,3101250]).$$

Now, we want to calculate *ICIS*-value, *IENSC*-value and *IED*-solution. We calculate the *ICIS*-value of our game as follows:

$$ICIS_1(c) = c(\{1\}) + \frac{1}{3}(c(\{1,2,3\}) - (c(\{1\}) + c(\{2\}) + c(\{3\})) = [2533330,3720000],$$

$$ICIS_2(c) = c(\{2\}) + \frac{1}{3}(c(\{1,2,3\}) - (c(\{1\}) + c(\{2\}) + c(\{3\})) = [1708330,2313000],$$

$$ICIS_3(c) = c(\{3\}) + \frac{1}{3}(c(\{1,2,3\}) - (c(\{1\}) + c(\{2\}) + c(\{3\})) = [1983330,2604000].$$

Then, the *ICIS*-value is obtained by

$$ICIS(c) = \left([2533330,3720000], [1708330,2313000], [1983330,2604000]\right).$$

We calculate the *IENSC*-value of our game as follows:

$$IENSC_1(c) = -c(\{2,3\}) + \frac{1}{3}\left(c(\{1,2,3\}) + c(\{2,3\}) + (\{1,3\}) + (\{1,2\})\right) = [966666.6,985333.3],$$

$$IENSC_2(c) = -c(\{1,3\}) + \frac{1}{3}\left(c(\{1,2,3\}) + c(\{2,3\}) + (\{1,3\}) + (\{1,2\})\right) = [-1033333.4,-1312666.67],$$

$$IENSC_3(c) = -c(\{1,2\}) + \frac{1}{3}\big(c(\{1,2,3\}) + c(\{2,3\}) + (\{1,3\}) + (\{1,2\})\big)$$
$$=[1241666.6,1178333.3].$$

Then, the *IENSC*-value is obtained by

$$IENSC(c) = \begin{pmatrix} [966666.6,985333.3], \\ [-1033333.4,-1312666.67], \\ [1241666.6,1178333.3] \end{pmatrix}.$$

Finally, we calculate the *IED*-solution of our game as follows:

$$IED_1(c) = IED_2(c) = IED_3(c) = \frac{c(\{1,2,3\})}{3} = [2075000,2865666.66].$$

Table 4 illustrates the results of this application.

Table 4. The interval solutions of our model

Interval Solutions	Player 1	Player 2	Player 3
Interval Shapley value	[2591666.67,3498166.67]	[1179166.67,1784500]	[2454166.67,3841500]
Interval Banzhaf value	[2493750,3562750]	[1081250,1710250]	[2356250,3101250]
ICIS-value	[2533330,3720000]	[1708330,2313000]	[1983330,2604000]
IENSC-value	[966666.6,985333.3]	[−1033333.4, −1312666.67]	[1241666.6,1178333.3]
IED-solution	[2075000,2865666.66]	[2075000,2865666.66]	[2075000,2865666.66]

These values can be used in different application areas such as Operational Research, economic and management situations.

4. Conclusion And Outlook

Research for efficiently planning and responding to natural disasters is of vital interest due to devastating effects and loses caused by their occurrence, including facility deficiency, lack of services related to disasters, building damage.

Some uncertainties are occurred in facility location situations because of several limitations. Moreover, data may not be available or may not be easy to communicate in large-scale if emergencies in casualty. The basic aim of Cooperative Interval Game Theory is to study ways to enforce and sustain cooperation between players to cooperate under uncertainty. The most important question in this area is how the total cost can be allocated among players in a fair way.

This paper has presented for a novel facility location planning after natural or societal disasters, responding to the urgent housing problem of the affected areas. In this study, we handle a housing problem after the earthquake in İzmir. Based on the case study, we construct the cooperative facility location game between three cities that the tent cities are built in and we give some interval solution concepts such as interval Shapley value, interval Banzhaf value, *ICSI*- value, *IENSCI*- value, *IED*- value.

We believe that the response phase of post-earthquake relief has been researched most extensively, and future research could be directed toward to other phases of disaster management such as mitigation, preparedness, recovery, housing and health problems.

Conflict of Interest

No conflict of interest was declared by the authors.

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