Researcher

CILT/VOL **03**
SAYI/ISSUE **01**
YIL/YEAR **2023**

ANKARA BİLİM ÜNİVERSİTESİ

Researcher

CİLT/VOL **03** SAYI/ISSUE **01** YIL/YEAR **2023**

e-ISSN:2717-9494

Yayıncı / Publisher: Ankara Bilim Üniversitesi / Ankara Science University
Basım Tarihi / Date of Publication: Temmuz 2023/ July 2023
Yayın Türü / Publication Type: Uluslararası Süreli Yayın / International Periodical
İletişim Bilgileri / Contact Information: Maltepe Mahallesi Şehit Gönenç Caddesi No: 5 Çankaya Ankara
Web Sitesi / Website: https://dergipark.org.tr/tr/pub/researcher
E-posta / E-mail: researcher@ankarabilim.edu.tr

Researcher uluslararası, hakemli ve yılda iki sayı yayınlanan dergidir. İngilizce ve Türkçe dilindeki metinler kabul edilir.
The Researcher is a peer-reviewed, international journal publishing two issues a year. Manuscripts are accepted in English and Turkish languages.

ANKARA, TEMMUZ 2023 / JULY 2022

Önsöz

Yayın hayatına 2013 yılında başlamış olan "Researcher: Social Sciences Studies" (RSSS), 2020 Ağustos ayı itibariyle "Researcher" ismiyle Ankara Bilim Üniversitesi bünyesinde yayın hayatına devam etmektedir. Fen Bilimleri alanına katkıda bulunmayı hedefleyen özgün araştırma makalelerinin yayımlandığı bir dergidir. Dergi, özel sayılar dışında yılda iki kez yayımlanmaktadır.

Amaçları doğrultusunda dergimizin yayın odağında; Endüstri Mühendisliği, Bilgisayar Mühendisliği ve Elektrik Elektronik Mühendisliği alanları bulunmaktadır. Dergide yayımlanmak üzere gönderilen aday makaleler Türkçe ve İngilizce dillerinde yazılabilir. Dergiye gönderilen makalelerin daha önce başka bir dergide yayımlanmamış veya yayımlanmak üzere başka bir dergiye gönderilmemiş olması gerekmektedir. Bir makalenin dergide yayımlanabilmesi için en az iki hakem tarafından olumlu rapor verilmesi gerekir.

Değerlendirme sonucu kabul edilen çalışmalar sırasıyla; intihal kontrolünün yapılması, kaynakça düzenlemesi, gönderme ve atıf kontrolü, mizanpaj ve dizgisinin yapılması süreçlerinden geçer.

Researcher, Dergipark üzerinden bilimsel araştırmaların içeriğine anında açık erişim sağlamaktadır.

Researcher makale işlem ücreti (gönderme, değerlendirme veya basım ücreti) ve makalelere erişim için abonelik ücreti talep etmediği için ücretsiz yayın yapan dergi statüsündedir, Dergimiz herhangi bir kâr amacı gütmemekte ve hiçbir gelir kaynağı bulunmamaktadır.

Baş Editör

Prof. Dr. Hakan ÇAĞLAR

Editör

Doç. Dr. Yavuz Selim ÖZDEMİR

<u>İçindekiler / Index</u>

ANKARA SCIENCE UNIVERSITY, RESEARCHER
Vol. 3, No. 1 July 2023
e-ISSN: 2717-9494
Research Article/Araştırma Makalesi
Doi: https://doi.org/10.55185/researcher.1204631

Afet Durumları ve Tesis Kurma Oyunları

Medine DEMİR 1[1*], Pınar USTA[2], Sırma Zeynep ALPARSLAN GÖK[3]
[1]Süleyman Demirel Üniversitesi, Isparta, Türkiye; ORCID: 0000-0002-9543-0753
[2]Isparta Uygulamalı Bilimler Üniversitesi, Türkiye; ORCID: 0000-0001-9809-3855
[3]Süleyman Demirel Üniversitesi, Isparta, Türkiye; ORCID: 0000-0001-9435-0527

* Corresponding Author: medinemugla@hotmail.com

Received: 21 November 2022; Accepted: 23 December 2022

Reference/Atıf: M. Demir, P. Usta, S. Z. Alparslan Gök, “Afet Durumları ve Tesis Kurma Oyunları”, Researcher, vol.3, no.1, pp.1-12, July 2023, doi: 10.55185/researcher.1204631

Özet

Tarih boyunca, Türkiye’nin bulunduğu coğrafyada birçok doğal afet meydana gelmiştir. Bu doğal afetlerden Türkiye için en önemli olanların başında depremler gelmektedir. Bu depremlerde çok sayıda bina şiddetli deprem nedeniyle zarar görmüş hatta birçok ev yıkılarak yeniden kullanılamaz hale gelmiştir. Bu süreçte evlerini kaybeden depremzedelerin barınma ihtiyaçlarının çözülmesinde geçici konutlar kullanılmaktadır. Sözkonusu konutlar geçici yapılar olmasına rağmen, acil durumlarda üretilmesi, yeniden yapılanmaya katkı sağlaması ve kolay kaldırılması nedeniyle afet durumlarında kullanılan önemli ve etkin çözüm faktörlerinden biridir. Bu makalede, kooperatif oyun teorisi tesis kurma oyunlarının geçici konut sorununun desteklenmesinde ve kuruluşlar arasında adil bir maliyet payı oluşturulmasında yardımcı olabileceğini göstermek amaçlanmıştır. Bu makale çalışmasında 2011 yılında Van’da meydana gelmiş bir deprem ele alınmıştır. Bu deprem sonrasında Van (Merkez) ve Van (Erciş)’te bir dizi çadır inşa edilmiştir. Çadırları iki bölge arasında adil bir şekilde dağıtmak için iki şirket seçilmiştir. Kooperatif oyun teorisinin amacı, oyuncular arasında olası bir iş birliği sonucu elde edilecek maliyetin veya yararın uygun dağıtımlarını bulmak ve oyuncuları koalisyon yapmaya teşvik etmenin yollarını araştırmaktır. Bu amaçla tesis kurma durumlarını kullanarak geçici konut sorununu desteklemek ve kuruluşlar arasında adil bir maliyet dağılımı tanımlamak için kooperatif oyun teorisi kullanılmıştır.

Anahtar Kelimeler: kooperatif oyun teorisi, tesis kurma durumları, yöneylem araştırması, artanların eşit dağıtım kuralları, Shapley değeri

Abstract

Throughout history, many natural disasters have occurred in the geography where Turkey is located. Earthquakes are among the most important natural disasters for Turkey. In these earthquakes, many buildings are damaged due to the severe earthquake, and many houses are destroyed and become unusable again. Temporary residences are used to meet the shelter needs of earthquake victims who lost their homes in this process. Although the mentioned houses are temporary structures, they are one of the important and effective solution factors used in disaster situations because they are produced in emergencies, contribute to reconstruction and are easily removed. In this article, it is aimed to show that cooperative game theory facility location games can be helpful in supporting the temporary housing problem and establishing a fair cost share among organizations. In this article, an earthquake that occurred in Van in 2011 is discussed. After this earthquake, a series of tents are built in Van (Center) and Van (Erciş). Two companies are chosen to distribute the tents fairly between the two regions. The purpose of cooperative game theory is to find appropriate distributions of the cost or benefit that would result from possible cooperation between players and to explore ways to encourage players to form coalitions. For this purpose, cooperative game theory is used to support the temporary housing problem by using facility location situations and to define a fair cost distribution among organizations.

Keywords: cooperative game theory, facility location situations, Operations Research, equal surplus sharing solutions, Shapley value

1. Giriş

Türkiye sahip olduğu jeolojik ve topolojik karakteri sebebiyle özellikle doğal afetlere karşı savunmasız ülkeler arasında yer almakta ve sık sık doğal afetlerle karşılaşmaktadır. Tarih boyunca, Türkiye'nin bulunduğu coğrafyada birçok doğal afet meydana gelmiştir. Bu afetlerden Türkiye'de en etkili olanlar depremler, heyelanlar, seller ve yangınlar olmakla birlikte, bu afetler içerisinde Türkiye için en yıkıcı ve en korkutucu olanının deprem olduğu söylenebilir [1]–[2].

Çok sayıda bina, şiddetli depremlerin ardından zarar görmekte hatta yıkılmaktadır ve birçok depremzede evsiz kalmaktadır ve bu durum barınma sorununu depremzedelerin en önemli sorun ve ihtiyaçlarından biri haline getirmektedir. Geçici konutlarda bu süreçte barınma ihtiyacını çözmek için kullanılmaktadır. Şiddetli ve yıkıcı depremlerden sonra oluşturulan geçici konutlar, afetzedelerin normal yaşam aktivitelerini yeniden kurmalarına, rutin hayatlarına dönmeye yardımcı olduğundan konut ihtiyaçları hızlı bir şekilde yanıtlanmalıdır [3]–[4].

Sel ve deprem gibi büyük ölçekli doğal afetlerin ardından acil durum yönetim kurumları, afetzedelere kalıcı konut sağlanıncaya kadar hane halkının günlük faaliyetlerine yeniden dönmelerini sağlamak için yaşadığı konutları kaybetmiş ailelere geçici konut çözümlerinin sağlanması için baskı yaparlar [5]–[6].

Depremler sonrasında insanlar ihtiyaç ve yaşam tarzlarına bağlı olarak barınma ihtiyaçlarını farklı şekillerde gidermektedir. Fakat deprem sonrasında artçı depremler olması ve hasar görmüş evlerinde yeniden yıkılma risk ve ihtimaline karşı konut alanları bir süre kullanılamamaktadır. Dolayısıyla afet sonrasında ortaya çok sayıda hasarlı veya yıkılmış bina çıkmakta ve bu durum afetzedeler için acilen çözülmesi gereken büyük bir konut sorununa yol açmaktadır [7]. Bu nedenle kalıcı konutlar için uygun koşullar beklenmeden geçici konutlarla barınma ihtiyacının acilen giderilmesi gerekmektedir [8].

Nitekim son yıllarda ülkemizde yaşanan doğal felaket sayısının dramatik bir şekilde artmasına bağlı olarak sıklıkla yaşanmaya başlayan felaketler ve sonrasında yaşananlar konut sorunun önemini ortaya koymuştur [3]–[4].

Bu çalışmada afet sonrası geçici konut acil yardım sorununu hızlı ve ekonomik olarak ortadan kaldırmak için tesis kurma durumları, kooperatif oyun teorisi ile modellenip çözüm teknikleri geliştirilmiştir.

Tesis kurma durumları yöneylem araştırması problemlerinden olup, gerçek yaşam problemlerinde kullanılan birçok uygulamaya sahiptir. Bu tip problemlerde bir tesisin inşası için verilen bir toplam maliyet vardır. Bu maliyet, hem her bir kuruluşun tesise uzaklığından hem de her bir tesisin inşasından meydana gelmektedir. Burada amaç toplam maliyeti minimize etmektir.

Kooperatif oyun teorisinin amacı, oyuncular arasındaki iş birliği sonucunda oluşan maliyetin veya faydanın adil bir biçimde dağıtılmasının yollarını araştırmaktır. Bu çalışmada ana amaç tesis kurma durumlarını kooperatif oyun teorisi ile modellemeye ve elde edilen maliyeti adil bir şekilde paylaştırmaya dayanmaktadır [9]–[10].

Çalışmada tesis durumlarından olan ve kooperatif oyun teorisi ile modellenebilen acil yardım problemleri için bir karar destek çerçevesinin geliştirilmesine yönelik bir başlangıç yaklaşımı sunulmaktadır. Bu çalışma kooperatif oyun teorisinin kuruluşlar arasında adil bir maliyet dağılımının belirlenmesinde yardımcı olabileceğini göstermektedir.

Genel veya yerel yönetimler yangın, sel ve deprem felaketleri sonucu oluşan acil durumlara müdahale etmekle sorumludur. Son zamanlarda afet sonrası projelerin planlanmasında devlet kurumlarının yanısıra özel kuruluşlar da yer almaktadır [11].

Bu çalışmada afet sonrasında acil ihtiyaç duyulan çadır kentlerin seçimi ve geliştirilmesi konusunda acil yardım problemlerinde karar vericileri hızlı ve ekonomik olarak desteklemek ve yönlendirmek için bir yaklaşım önerilmektedir. Farklı yanıt veren kuruluşlar arasındaki iş birliği, etkili müdahale operasyonlarının önemli bir bileşenidir [12].

Çalışmanın kapsamı göz önüne alındığında, kurulacak tesislerin toplam maliyetini en aza indirmek ve müşterilere mal veya hizmet ulaştırılması için bazı tesislerin sürekli veya ayrı bir alana yerleştirilmesi konusunda tesis kurma durumlarının kooperatif oyun teorisi ile modellenmesi uygundur [13]–[14].

Bu çalışmada, deprem sonrasında acil ihtiyaç duyulan çadır kentlerin ihtiyaç sahiplerine ulaştırılmasında çadırların temini, dağıtımı ve kurulumu süreçlerindeki maliyetin belirlenmesinde kooperatif oyun teorisi modellerinin potansiyel varlığı araştırılmıştır. Çalışma, tesis kurma oyunlarının çeşitli kuruluşlar arasında adil bir maliyet dağılımı sağlayacağını göstermektedir.

2. Literatür Özetleri

Kooperatif oyun teorisinin özellikleri ve temel kavramları 1944 yılında Von Neumann ve Morgenstern tarafından geliştirilmiştir [10]. Von Neumann ve Morgenstern'nın "Theory of Games and Economic Behavior" isimli kitabında, çok kompleks stratejik davranış modellerini daha basit modellere indirgemeyi denemiş, bunu başarmak için de karakteristik fonksiyon modelini çıkarmışlardır.

Shapley, 1953 yılında Shapley değerini bularak bilime önemli katkıda bulunmuştur. Daha sonra Shapley değeri ile ilgili çeşitli karakterizasyonlar yapılmıştır.

Kooperatif oyun teorisinde kullanılan çözüm kavramlarından biri de Banzhaf değeridir. Banzhaf değerine, [15] ilk olarak Banzhaf tarafından oylama oyunlarında bahsedilmiştir.

Banzhaf değeri her oyuncunun herhangi bir koalisyona eşit olasılıkla girmesini dikkate alırken, Shapley değeri her oyuncunun aynı boyuttaki herhangi bir koalisyona ve aynı boyuttaki tüm koalisyonlara eşit olasılıkla girmesini dikkate almaktadır.

Kooperatif oyunlar için CIS-değeri (kısıt kümesinin ağırlık merkezi çözümü), ENSC-değeri (eşitlikçi bölünemeyen katkı değeri), ED-değeri (eşit bölme değeri) çözümleri 1991 yılında Driessen ve Funaki tarafından tanımlanmıştır [16]–[17].

Müşterilere hizmet sağlamak için kullanılan tesis kurma oyunları yöneylem araştırması son zamanlarda literatürde sıklıkla çalışılan bir problemdir [18-24]. Tesis kurma durumlarında, bir tesis açmanın ve müşteriyi söz konusu tesise bağlamanın önceden tanımlanmış bir maliyeti vardır[13]. Burada hedeflenen temel amaç, müşterilere dağıtılabilecek toplam maliyeti adil bir şekilde minimize etmektir.

3. Kooperatif Oyun Teorisi

Kooperatif oyun teorisi ile ilgili temel kavramlardan bu bölümde bahsedilecektir [25, 27]–[10] referanslarında kooperatif oyun teorisi ile ilgili olarak detaylı bilgiler yer almaktadır.

Bu modelde oyuncu kümesi ve oyuncuların kazanç ya da maliyetlerini belirten bir karakteristik fonksiyon söz konusudur. Oyuncular arasında iş birliği yapılmaktadır ve oyun kurulduktan sonra elde edilen kazancın/maliyetin nasıl adil dağıtılacağına bakılmaktadır.

Tanım 3.1 n-kişilik bir kooperatif oyun $< N,c >$ ikilisinden oluşur. Burada N={1,…,n} oyuncu kümesi c:2N → R karakteristik fonksiyondur. Karakteristik fonksiyon ∀ S⊂N koalisyonunu bir reel sayıya götürür yani ∀ S∈ 2N için c(s) koalisyonunun değerini belirtir ve c(∅)=0 olarak tanımlıdır.

Örnek 3.1 (Eldiven Oyunu) Oyuncuların kümesi N={1,2,3} olmak üzere L={1} ve R={2,3} olsun. L kümesinin elemanlarının sol el eldiven imal ettiği R kümesinin elemanlarının ise sağ el eldiven imal ettiği bilinmektedir. Tek el eldiven imal etmenin maliyeti sıfır iken, çift eldiven imalatının bedeli ise 10 TL olduğu bilindiği üzere $< N,c >$ oyunu

S	$\emptyset$	$\{1\}$	$\{2\}$	$\{3\}$	$\{1,2\}$	$\{1,3\}$	$\{2,3\}$	$\{1,2,3\}$
$c(S)$	0	0	0	0	10	10	0	10

şeklinde modellenir [10].

Kooperatif oyun teorisindeki en temel problemlerden biri de tüm koalisyonlar oluşturulmasını takiben, elde edilen kazancın veya maliyetin nasıl paylaştırılacağıdır. Bu çözüm kavramlarına; von Neumann (1928) tarafından bulunan "von Neumann çözümü" [28], von Neumann (1944) tarafından bulunan "kararlı kümeler" [29], Shapley(1953) tarafından bulunan "Shapley değeri" [25] örnek olarak gösterilebilir. Bu şekilde kooperatif oyun teorisindeki bir çözüm kavramı, asgari olarak bir x ödeme vektörüne karşılık gelir. Kooperatif oyun teorisinde çözüm kavramından bahsetmek için aşağıdaki tanımlara değinilmelidir.

Shapley değeri için önce marjinal katkı vektörünün tanımı verilmelidir.

Tanım 3.2 (Marjinal Katkı) $c \in G^N$ ve $\sigma \in \pi(N)$ olsun. $m^{\sigma}(c) \in \mathbb{R}^N$ marjinal katkı vektörü, $\forall\, i \in N$ için,

$$m_i^{\sigma}(c) \coloneqq c(P^{\sigma}(i) \cup \{i\}) - c(P^{\sigma}(i)) \tag{1}$$

ile gösterilir.

Tanım 3.3 (Shapley değeri) $c \in G^N$ oyununun Shapley değeri olan $\Phi(c)$, bir oyunun marjinal vektörlerinin ortalamasıdır. Yani, $\Phi(c) = \frac{1}{n!}\sum_{\sigma\in\pi(N)} m^{\sigma}(c)$ dir.

$$\Phi(c) = \frac{1}{n!}\sum_{\sigma\in\pi(N)} m^{\sigma}(c) \tag{2}$$

Bu denkleme bakarak, Shapley değerinin olasılık yorumunu yapabilir. $\pi(N)$**'**nin elemanlarının içinde olduğu bir torbadan bir permütasyonu $\frac{1}{n!}$ olasılıkla çekebilir. O zaman, oyuncular odaya σ permütasyonu sırasında bir bir girer ve her oyuncu odaya marjnal katkısını verir. Shapley değeri

$$\Phi\,(c) = \frac{1}{n!}\sum_{\sigma\in\pi(N)} (c(P^{\sigma}(i) \cup \{i\}) - cP^{\sigma}(i)) \tag{3}$$

formülü ile de ifade edilir.

Örnek 3.2 Üç kişilik $< N, c >$ oyunu ve oyunun. Karakteristik fonksiyonları aşağıda gösterildiği gibi olsun.

S	∅	{1}	{2}	{3}	{1,2}	{1,3}	{2,3}	{1,2,3}
$c(S)$	0	0	0	0	2	6	1	6

Bu durumda Shapley değeri hesabı için önce marjinal katkı vektörleri Tablo 1'de gösterilmiştir.

Tablo 1: Marjinal vektörler

σ	$m_1^{\sigma}(c)$	$m_2^{\sigma}(c)$	$m_3^{\sigma}(c)$
σ_1=(1,2,3)	0	4	16
σ_2=(1,3,2)	0	13	7
σ_3=(2,1,3)	4	0	16
σ_4=(2,3,1)	5	0	15
σ_5=(3,1,2)	7	13	0
σ_6=(3,2,1)	5	15	0

$\Phi(c) = \frac{1}{3!}\sum_{\sigma\in\pi(3)} m^{\sigma}(c) = \frac{1}{6}(21,45,54)$ olarak bulunur.

Tanım 3.4 (Banzhaf değeri) 1965 yılında Banzhaf tarafından bulunmuştur. β(c) ile gösterilir. $\forall\, i \in N$ ve $c \in G^N$ için β: $G^N \to I\,(\mathbb{R}^N)$ olmak üzere

$$\beta_i\,(c) = \frac{1}{2^{|N|-1}} \sum_{i\in S} c(S) - c(S\backslash\{i\}) \tag{4}$$

ile tanımlanır.

Uyarı: Bundan sonraki kısımlarda kolaylık açısından c({i,j}) notasyonu yerine c(ij) notasyonu kullanılacaktır.

Örnek 3.3 Oyuncuların kümesi $N = \{1,2,3\}$, $c \in G^N$ olmak üzere koalisyon değerleri de

S	$\emptyset$	{1}	{2}	{3}	{1,2}	{1,3}	{2,3}	{1,2,3}
$c(S)$	0	7	0	0	17	7	0	29

olarak verilsin. Buna göre bu oyunun $\beta(c)$ değeri;

$\beta_i(c)= \frac{1}{2^{|N|-1}} \sum_{i \in S}(c(s) - c(s\backslash\{i\}))$

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

$= \frac{1}{2^2}(c(1) + c(12) - c(2) + c(13) - c(3) + c(123) - c(23))$

$=15$

$\beta_2(c)= \frac{1}{2^2} \sum_{2 \in S}(c(s) - c(s\backslash\{2\}))$

$= \frac{1}{2^2}(c(2) + c(12) - c(1) + c(23) - c(3) + c(123) - c(13))$

$=8$

$\beta_3(c)= \frac{1}{2^2} \sum_{3 \in S}(c(s) - c(s\backslash\{3\}))$

$= \frac{1}{2^2}(c(3) + c(13) - c(1) + c(23) - c(2) + c(123) - c(12))$

$=3$

$\beta(c)=(15,8,3)$ olarak bulunur.

Tanım 3.5 (Kısıt kümesinin ağırlık merkezi çözümü) CIS değeri 1991 yılında Driessen ve Funaki tarafından bulunmuştur.

$\forall c \in G^N$, $\forall i \in N$ için $CIS : G^N \rightarrow I(\mathbb{R}^N)$ olmak üzere

$$CIS_i(c)= c(\{i\}) + \frac{1}{|N|}(c(N) - \sum_{j \in N} c(\{j\})) \tag{5}$$

olarak tanımlanır.

Örnek 3.4 Oyuncuların kümesi $N = \{1,2,3\}$, $c \in G^N$ olmak üzere koalisyon değerleri de

S	$\emptyset$	{1}	{2}	{3}	{1,2}	{1,3}	{2,3}	{1,2,3}
$c(S)$	0	1	1	0	4	1	3	5

olarak verilsin. Bu oyunun $CIS(c)$ değeri;

$CIS_i(c)= c(\{i\}) + \frac{1}{|N|}(c(N) - \sum_{j \in N} c(\{j\}))$

$CIS_1(c)= c(1) + \frac{1}{3}(c(123) - (c(1) + c(2) + c(3)))$

$= 2$

$CIS_2(c)= c(2) + \frac{1}{3}(c(123) - (c(1) + c(2) + c(3)))$

$=2$

$CIS_3(c)= c(3) + \frac{1}{3}(c(123) - (c(1) + c(2) + c(3)))$

=1

$CIS(c)$=(2,2,1) olarak bulunur.

Tanım 3.6 (Eşitlikçi Bölünemeyen katkı değeri) $ENSC$-değeri 1991 yılında Driessen ve Funaki tarafından bulunmuştur. Bu değer CIS-değerinin duali olarak tanımlanır. Yani $\forall\, c, c* \in G^N$ ve $c*$, c nin dual oyunu olsun.

$$ENSC(c) = CIS(c*) \tag{6}$$

olur.

$c*$, c nin duali olsun. Bu durumda $c, c* \in G^N$ ve $\forall\, S \in 2^N$ için,

$$c*(S) = c(S) - c(N \setminus S) \tag{7}$$

olur.

Önerme: $\forall\, S \in 2^N$ için $ENSC$: $G^N \rightarrow I(\mathbb{R}^N)$ olup $\forall\, i \in N$ için,

$$ENSC_i(c) = -c(N\setminus\{i\}) + \frac{1}{|N|}\left(c(N) + \sum_{j\in N} c(N\setminus\{j\})\right) \tag{8}$$

olur.

Örnek 3.5 Oyuncuların kümesi $N = \{1,2,3\}$, $c \in G^N$ ve koalisyon değerleri de

S	$\emptyset$	{1}	{2}	{3}	{1,2}	{1,3}	{2,3}	{1,2,3}
$c(S)$	0	2	2	0	7	4	5	9

olarak verilsin.

Buna göre $ENSC(c)$ değeri;

$ENSC_i(c) = -c(N\setminus\{i\}) + \frac{1}{|N|}\left(c(N) + \sum_{j\in N} c(N\setminus\{j\})\right)$

$ENSC_1(c) = -c(23) + \frac{1}{3}(c(123) + c(12) + c(13) + c(23))$

$= \frac{10}{3}$

$ENSC_2(c) = -c(13) + \frac{1}{3}(c(123) + c(12) + c(13) + c(23))$

$= \frac{13}{3}$

$ENSC_3(c) = -c(12) + \frac{1}{3}(c(123) + c(12) + c(13) + c(23))$

$= \frac{4}{3}$

$ENSC(c) = (\frac{10}{3}, \frac{13}{3}, \frac{4}{3})$ olarak bulunur.

Örnek 3.6 Oyuncuların kümesi $N = \{1,2,3\}$ ve koalisyon değerleri de

S	$\emptyset$	{1}	{2}	{3}	{1,2}	{1,3}	{2,3}	{1,2,3}
$c(S)$	0	2	2	0	7	4	5	9

olsun. Bu oyunun ED -değeri

$\mathrm{EDi(c)} = \frac{1}{|\mathrm{N}|}\mathrm{c(N)}$

$\mathrm{ED_1(c)} = \frac{1}{3}\mathrm{c}(\{1,2,3\}) = 3$

$\mathrm{ED_2(c)} = \frac{1}{3}\mathrm{c}(\{1,2,3\}) = 3$

$\mathrm{ED_3(c)} = \frac{1}{3}\mathrm{c}(\{1,2,3\}) = 3$ olup

$\mathrm{ED(c)} = (3,3,3)$ olarak bulunur.

4. Tesis Kurma Oyunu

Tesis kurma durumlarında, bir tesis inşa etmek için gereken bir maliyet vardır. Tesis kurma durumlarında biri kamu tesisleri (hastaneler, itfaiye istasyonları vb.), diğeri özel tesisler (dağıtım merkezleri, bazı istasyonlar vb.) olmak üzere iki durum bulunmaktadır.

Her tesis, mevcut konumdaki oyuncuları memnun etmek için inşa edilmiştir. Burada amaç maliyeti minimize etmektir. Minimize edilmek istenilen maliyet oyuncunun tesise olan mesafesinden ve tesisin yapımından oluşmaktadır.

Bir tesis kurma oyununda, A şirketlerin kümesi, tesislerin kümesi F, bir tesisin açma maliyeti f_i, her tesis için $i \in F$ ve bir mesafe d_{ij} her çift nokta arasında (i, j), j'yi i'ye bağlamanın maliyetini gösteren $A \cup F$ verilir. Mesafelerin bir metrik uzaydan geldiği varsayılır (simetriktirler ve üçgen eşitsizliğine uyarlar).

Bir $S \subset A$ şirketler kümesi için, bu kümenin maliyeti, bir dizi tesis açmanın ve S'deki her aracıyı açık bir tesise bağlamanın minimum maliyeti olarak tanımlanır. Maliyet fonksiyonu c ile tanımlanır [14].

$\mathrm{c(S)} = \min\{\sum_{i\in F^*} f_i + \sum_{j\in S} \min d_{ij}\}$

Tesis kurma oyununa Van depremi örnek verilirse; 23 Ekim 2011 tarihinde 7,2 büyüklüğünde Van'ın merkeze bağlı Tabanlı Köyü'nde ve 9 Kasım 2011 tarihinde 5,6 büyüklüğünde Van'ın Edremit İlçesi'nde olmak üzere iki adet büyük deprem meydana gelmiştir. Van'da meydana gelen ikinci depremin ardından 644 kişi yaşamını yitirmiş, 650.000 kişi ise doğrudan veya dolaylı olarak depremden etkilenmiştir. Deprem sonrasında şehirde Merkez'de 31, Erciş'te 4 olmak üzere toplam 35 konteynerkent kurulmuştur. Şubat 2012 tarihinde çadır kentler kapatılarak depremzedeler geçici konutlara yerleştirilmiştir. Van depremi sonrası konteyner kent bilgileri Tablo 2 de verilmiştir [30].

Tablo 2: Van depremi sonrası kurulan geçici konut bilgileri

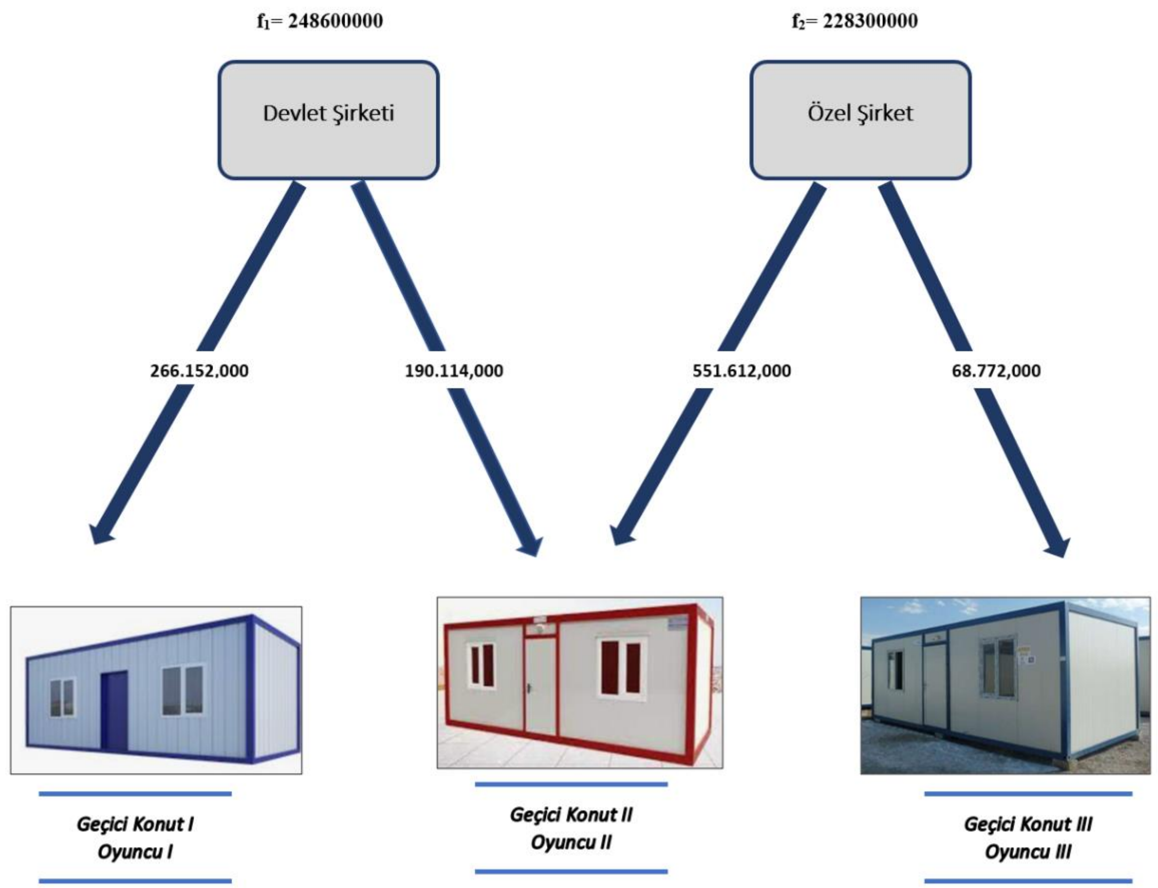
İl	Konteynerkent	Konteyner (adet)	Nüfus
Van (Merkez)	31	24.014	147.319
Van (Erciş)	4	5.472	27.71
Toplam	35	29.486	175.070

Bu çalışmada gerçek verilerden yararlanılarak Van depremi sonrasında kurulan geçici konteyner kent için Tesis durumu ele alınmıştır. Van merkez ve Erciş'te kullanılmak üzere toplamda 29.486 adet geçici konut dağıtımı yapılmıştır. Bu dağıtım Devlet ve özel olmak üzere iki ana kaynak üzerinden yapılmıştır. Tablo 3'te geçici konutların sayısı ve maliyet durumu verilmiştir.

Tablo 3: Van depremi geçici konutların sayısı ve maliyet durumu

Temporary House No, Name	**Ev sayısı**	**Her bir ev için devlete bağlı şirketin maliyeti**	**Her bir ev için özel şirketin maliyeti**	**Devlet şirketinin toplam maliyeti**	**Özel şirketin toplam maliyeti**
1, Van Merkez	14.008	19.000 TL	22.000 TL	266152000 TL	-
2, Van Merkez	10.006	19.000 TL	22.000 TL	190114000 TL	551612000 TL
3, Van Erciş	5.472	-	22.000 TL	-	68772000 TL

Tesis kurma durumuna ait kooperatif oyun modeli Şekil 1'de verilmiştir.



Şekil 1: Tesis kurma durumuna ait kooperatif oyun modeli

Bu modelin koalisyon değerleri,

c (1)= 514752000; c (2)= 438714000; c (3)= 297072000; c (12)= 704866000; c (23)= 848684000; c (13)= 811824000; c (123)= 1001938000 şeklindedir.

İlgili oyuna ait marjinal vektörler Tablo 4'te gösterilmiştir.

Tablo 4: Marjinal vektörler

σ	$m_1^{\sigma}(c)$	$m_2^{\sigma}(c)$	$m_3^{\sigma}(c)$
σ_1=(1,2,3)	514752000	190114000	297072000
σ_2=(1,3,2)	514752000	190114000	297072000
σ_3=(2,1,3)	266152000	438714000	297072000
σ_4=(2,3,1)	153254000	438714000	409970000
σ_5=(3,1,2)	514752000	190114000	297072000
σ_6=(3,2,1)	153254000	551612000	297072000

Yukarıdaki oyuna ait sırasıyla Shapley değeri, Banzhaf değeri, CIS değeri, $ENSC$ değeri ve ED çözümünü bulalım.

Shapley değeri:

$\Phi(c)=\frac{1}{3!}\sum_{\sigma\in\pi(3)} m^{\sigma}(c)$

$=\frac{1}{3}(1058458000,999691000,947665000)$ olarak bulunur.

Banzhaf değeri:

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

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

$=\frac{1}{2^2}(c(1)+c(12)-c(2)+c(13)-c(3)+c(123)-c(23))$

$=362227500$

$\beta_2(c)=\frac{1}{2^2}\sum_{2\in S}(c(s)-c(s\backslash\{2\}))$

$=\frac{1}{2^2}(c(2)+c(12)-c(1)+c(23)-c(3)+c(123)-c(13))$

$=342638500$

$\beta_3(c)=\frac{1}{2^2}\sum_{3\in S}(c(s)-c(s\backslash\{3\}))$

$=\frac{1}{2^2}(c(3)+c(13)-c(1)+c(23)-c(2)+c(123)-c(12))$

$=399564500$

$\beta(c)=(362227500, 342638500, 399564500)$ olarak bulunur.

CIS değeri:

$CIS_i(c)=c(\{i\})+\frac{1}{|N|}(c(N)-\sum_{j\in N}c(\{j\}))$

$CIS_1(c)=c(\{1\})+\frac{1}{3}(c(\{123\})-(c(\{1\})+c(\{2\})+c(\{3\})))$

$=\frac{780904000}{3}$

$CIS_2(c)=c(\{2\})+\frac{1}{3}(c(\{123\})-(c(\{1\})+c(\{2\})+c(\{3\})))$

$=\frac{552790000}{3}$

$\text{CIS}_3(c) = c(\{3\}) + \frac{1}{3}\left(c(\{123\}) - \left(c(\{1\}) + c(\{2\}) + c(\{3\})\right)\right)$

$= \frac{127864000}{3}$

CIS(c)=$\left(\frac{780904000}{3}, \frac{552790000}{3}, \frac{127864000}{3}\right)$ olarak bulunur.

$ENSC$ değerini hesaplayalım:

$\text{ENSC}_i(c) = -c(N\backslash\{i\}) + \frac{1}{|N|}\left(c(N) + \sum_{j\in N} c(N\backslash\{j\})\right)$

$\text{ENSC}_1(c) = -c(\{23\}) + \frac{1}{3}\left(c(\{123\}) + c(\{12\}) + c(\{13\}) + c(\{23\})\right)$

$= \frac{821260000}{3}$

$\text{ENSC}_2(c) = -c(\{13\}) + \frac{1}{3}\left(c(\{123\}) + c(\{12\}) + c(\{13\}) + c(\{23\})\right)$

$= \frac{931840000}{3}$

$\text{ENSC}_3(c) = -c(\{12\}) + \frac{1}{3}\left(c(\{123\}) + c(\{12\}) + c(\{13\}) + c(\{23\})\right)$

$= \frac{1252714000}{3}$

ENSC(c)=$\left(\frac{821260000}{3}, \frac{931840000}{3}, \frac{1252714000}{3}\right)$ olarak bulunur.

ED çözümü;

$\text{EDi}(c) = \frac{1}{|N|} c(N)$

$\text{ED}_1(c) = \frac{1}{3} c(\{1,2,3\}) = \frac{1001938000}{3}$

$\text{ED}_2(c) = \frac{1}{3} c(\{1,2,3\}) = \frac{1001938000}{3}$

$\text{ED}_3(c) = \frac{1}{3} c(\{1,2,3\}) = \frac{1001938000}{3}$ bulunur.

$\text{ED}(c) = \left(\frac{1001938000}{3}, \frac{1001938000}{3}, \frac{1001938000}{3}\right)$ olarak bulunur.

Tesis kurma durumuna ait kooperatif oyun modeli tüm çözümlere ait değerler Tablo 5'te verilmiştir.

Tablo 5: Tesis kurma durumuna ait kooperatif oyun modeli çözüm sonuçları

Çözümler	**Van Merkez 1**	**Van Merkez 2**	**Van Erciş**	**Vektörel Gösterim**
Shapley değeri	$\frac{105845000}{3}$	$\frac{999691000}{3}$	$\frac{947665000}{3}$	(352819333,333230333,315888333)
Banzhaf değeri	362227500	342638500	399564500	(362227500,342638500,399564500)
CIS-değeri	$\frac{780904000}{3}$	$\frac{552790000}{3}$	$\frac{127864000}{3}$	(260301333,184263333,426213333)
$ENSC$-değeri	$\frac{821260000}{3}$	$\frac{931840000}{3}$	$\frac{1252714000}{3}$	(273753333,310613333,417571333)
ED-çözümü	$\frac{1001938000}{3}$	$\frac{1001938000}{3}$	$\frac{1001938000}{3}$	(333979333,333979333,333979333)

5. Sonuç

Şiddetli depremlerden etkilenen birçok ülkede, öncelikli ve en önemli sorun deprem sonrası konut sorununun hızlı ve etkili olarak çözülmesi, depremzedelerin hayatlarını normale döndürmek ve barınmaları için gerekli geçici konutların sağlanmasıdır. Bu nedenle afetlerden sonra ortaya çıkan barınma ile ilgili sorunlar bilimsel alanda hala geniş bir araştırma ve tartışmaya sahiptir.

Gerekli tasarım ve yönetmeliklere uygun olarak yapılmamış binaların birçoğu deprem yükleri etkisinde büyük hasar almaktadırlar. Dolayısıyla özellikle kötü yapı stoğuna sahip şehirlerde yaşanan şiddetli depremlerde binalar kendilerinden beklenen performansı sergileyememekte ve yıkılmaktadırlar. Bu durumda geçici konutların deprem bölgelerine temini öncelikli ihtiyaç olarak karşımıza çıkmaktadır. Burada temel amaç geçici konutların en kısa sürede sahiplerine ulaştırılmasıdır.

Bu çalışmada depremden etkilenen bölgelerin geçici konut sorununa yanıt verecek bir tesis yerleşim planlaması sunulmuş ve Van ilinde deprem sonrasında ortaya çıkan geçici konut sorunu ele alınmıştır. Geçici konutların inşa edildiği üç yer arasında kooperatif tesis kurma oyunu kurulmuş ve kooperatif oyun teorisi kullanılarak çözümler elde edilmiştir.

Çalışmamız sonucu elde ettiğimiz Tablo 5'i değerlendirirsek Shapley değeri, Banzhaf değeri, CIS-değeri, $ENSC$- değeri ve ED-çözümüne ait sonuçlar birbirine yakındır. Shapley değeri'nin, Banzhaf değeri'nin, CIS-değeri'nin, $ENSC$- değeri'nin ve ED-çözümü'nün 1. ve 2. bileşeni maliyet olarak alınabilir fakat 3. bileşeni alınamaz. Çünkü 3. bileşenlerin değeri yüksektir. Genel anlamda çözüm sonuçlarının hepsi kullanılabilir ve hepsi iyi sonuç verir diyebiliriz.

Verimlilik, koalisyonel bağımsızlık ve bireysel bağımsızlık açısından bakarsak, Shapley değeri verimliliği sağlar fakat koalisyonel bağımsızlığı ve bireysel bağımsızlığı sağlamaz. Banzhaf değeri verimliliği, koalisyonel bağımsızlığı ve bireysel bağımsızlığı sağlamaz. CIS-değeri de verimliliği, koalisyonel bağımsızlığı ve bireysel bağımsızlığı sağlamaz, $ENSC$- değeri verimliliği sağlar fakat koalisyonel bağımsızlığı ve bireysel bağımsızlığı sağlamaz. ED-çözümü de verimliliği sağlar fakat koalisyonel bağımsızlığı ve bireysel bağımsızlığı sağlamaz. Dolayısıyla Shapley değeri, $ENSC$- değeri ve ED-çözümü çözüm sonuçları daha iyi sonuç verir.

Tesis kurma durumlarında amaç maliyeti minimize etmektir. Dolayısıyla minimize edilmek istenilen maliyet oyuncunun tesise olan mesafesinden ve tesisin yapımından oluşmaktadır. Beş çözüm sonucu birbirine yakın olduğu için beşi de kullanılabilir ve güzel sonuçlar verir. Eğer verimlilik, koalisyonel bağımsızlık ve bireysel bağımsızlık açısından bakarsak da, Shapley değeri, $ENSC$- değeri ve ED-çözümü çözüm sonuçlarını kullanmak daha faydalıdır.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

Kaynaklar

[1] Limoncu, S., Celebioğlu, B., "Post-Disaster sustainable housing system in Turkey," *In Proceedings of the I-Rec 2006 International Conference on Post-Disaster Reconstruction:Meeting Stakeholder Interests*, 2006.

[2] Güneş, O., "Turkey's grand challenge:Disaster-proof building inventory within 20 years," *Case Studies in Construction Materials*, vol. 2, pp. 18-34, 2015.

[3] Johnson, C., "Impacts of prefabricated temporary housing after disasters: 1999 earthquakes in Turkey,"*Habitat International*, vol. 31, no. 1, pp. 36-52, 2007.

[4] Félix, D., Branco, J.M., Feio, A., "Temporary housing after disasters: A state of the art survey,"*Habitat International*, vol. 40, pp. 136-141, 2013.

[5] Arslan, H., Cosgun, N., "Reuse and recycle potentials of the temporary houses after occupancy:Example of

Duzce,Turkey,"*Building and Environment*, vol. 43, no. 5, pp. 702-709, 2008.

[6] El-Anwar, O., El-Rayes, K., Elnashai, "An automated system for optimizing post-disaster temporary housing allocation", *Automation in Construction*, vol. 18, no.7, pp. 983-993, 2009.

[7] Limoncu, S., Bayülgen, C., "Housing Issues After Disaster in Turkey", *Megaron*, vol.3, no.1, 2008.

[8] Özata, Ş., Limoncu, S., "Analysing Post-Earthquake Housing Practices in İstanbul and Its Surroundings Between 16th and 20th Centuries," *Megaron*, vol. 9, no. 3, pp. 217-227, 2014.

[9] Puerto, J., Tamir, A., Perea, F., "Cooperative location games based on the minimum diameter spanning Steiner subgraph problem," *Discrete Applied Mathematics*, vol.160, no. 7, pp. 970-979, 2012.

[10] Tijs, S. H., "Introduction to game theory," *India: SIAM Hindustan Book Agency*, 2003.

[11] Coles, J., Zhuang, J., "Decisions in disaster recovery operations: A game theoretic perspective on organization cooperation,"*Journal of Homeland Security and Emergency Management,*vol.8, no.1, 2011.

[12] Mu,L., Ma, J., "Game theory analysis of price decision in real estate industry," *International Journal of Nonlinear Science*, vol.3, no. 2, pp.155-160, 2007.

[13] Goemans, M. X., Skutella, M., "Cooperative facility location games," *Journal of Algorithms*, vol.50, no.2, pp. 194-214, 2004.

[14] Mallozzi, L., "Cooperative games in facility location situations with regional fixed costs", *Optimization Letters*, vol. 5, no.1, pp. 173-181, 2011.

[15] Banzhaf, J.F., "Weighted Voting Doesn.t Work: A Mathematical Analysis," *Rutgers University Law Review,* vol. 19, pp. 317-343, 1965.

[16] Driessen, T.S.H., Funaki, Y., "Coincidence of and collinearity between game-theoretic solutions," *OR Spectrum*, vol.13, no.1, pp.15-30, 1991.

[17] van den Brink R., Funaki Y., "Axiomatizations of a Class of Equal Surplus Sharing Solutions for TU-Games," *Theory and Decision,* Vol. 67, no.3, pp. 303-340, 2009.

[18] Aardal, K., van den Berg, P. L., Gijswijt, D., and Li, S.,"Approximation algorithms for hard capacitated k-facility location problems,"*European Journal of Operational Research,* vol. 242 no.2, pp. 358–368, 2015.

[19] Kulturel-Konak, S., and Konak, A., "A large-scale hybrid simulated annealing algorithm for cyclic facility layout problems," *Engineering Optimization*, vol. 47, no.7, pp. 963–978, 2015.

[20] Akgün, İ., Gümüşbuğa, F., and Tansel, B., "Risk based facility location by using fault tree analysis in disaster management," *Omega*, vol. 52, pp. 168–179, 2015.

[21] Current, J., Min, H., Schilling, D., "Multiobjective analysis of facility location decisions," *European Journal of Operational Research*, vol. 49, no. 3, pp. 295-307, 1990.

[21] Johnson, L. A., Montgomery, D. C., "Operations research in production planning, scheduling, and inventory control," vol.6, New York: Wiley, 1974.

[23] Luss, H., "Operations research and capacity expansion problems: A survey," *Operations Research,* vol.30, no.5, pp. 907-947, 1982.

[24] Francis, R. L., McGinnis, L. F., and White, J. A., "Facility layout and location:an analytical approach," *Pearson College Division*, 1982.

[25] Shapley, L.S., "A value for n-person games," *Annals of Mathematics Studies,* vol. 28, pp. 307-317, 1953.

[26] Curiel, I., "Cooperative Game Theory and Applications," *Springer-Verlag*, 194p, USA, 1997.

[27] Branzei, R., Dimitrov, D., Tijs, S., "Models in Cooperative Game Theory," *Springer-Verlag*, 204p, Berlin, 2008.

[28] von Neumann, J., "Zur theorie der gesellschaftsspiele," *Mathematische Annalen,* vol.100, no.1, pp. 295-320, 1928.

[29] von Neumann, J., Morgenstern, O., "Theory of Games and Economic Behavior," *Princeton University Press,* 776p, Princeton, 1944.

[30] Çınar, A. K., Akgün, Y., and Maral, H., "Afet sonrası acil toplanma ve geçici barınma alanlarının planlanmasındaki faktörlerin incelenmesi: İzmir-Karşıyaka örneği," *Planlama*, vol. *28*, no.2, pp. 179-200, 2018.

[31] Palanci, O., Alparslan Gok, S.Z., "Facility Location Situations and Related Games in Cooparation Spatial İnteraction Models Volume 118 of the series," *Springer Optimization and Its Applications*, pp. 247-260, 2017.

[32] Usta, P., Ergun, S., and Alparslan Gok, S.Z., "A cooperative game theory approach to post disaster housing problem," *Handbook of Research on Emergent Applications of Optimization Algorithms Chapter 14 IGI Global*, pp. 314-325, USA, 2018

[33] Tüzün S., "Oyun Teorisindeki Eşit Dağıtım Kuralları Üzerine," Yüksek Lisans Tezi, Süleyman Demirel Üniversitesi, 2021.

[34] Qasim, E., Alparslan Gok, S.Z., Palanci, O., "An Application of Cooperative Grey Games to Post-Disaster Housing Problem," *International Journal of Supply and Operations Management (IJSOM)*, Vol. 6, no.1, pp. 57-66, 2019.

ANKARA SCIENCE UNIVERSITY, RESEARCHER
Vol. 3, No. 1 July 2023
e-ISSN: 2717-9494
Research Article/Araştırma Makalesi
Doi: https://doi.org/10.55185/researcher.1208237

Estimating Medical Waste Generation Utilizing Penalized Regression Models

Burcu DEVRİM İÇTENBAŞ[1,*]
[1]Ankara Science University, Faculty of Engineering and Architecture, Department of Industrial Engineering, Ankara, Türkiye; ORCID: 0000-0002-8148-4945
* Corresponding Author: burcu.ictenbas@ankarabilim.edu.tr

Received: 21 November 2022; Accepted: 27 December 2022

Reference/Atıf: B.D. İçtenbaş, "Estimating Medical Waste Generation Utilizing Penalized Regression Models", Researcher, vol.3, no.1, pp.13-18, July 2023, doi: 10.55185/researcher.1208237

Abstract

Medical Waste (MW) amount that has a significant impact on health and environment is increasing as a result of industrialization as well as population density. There is a need an accurate estimation waste generation amount that will be useful information to select the appropriate disposal methods and to organize the recycling and storage. Some researchers have applied conventional statistical algorithms and many kinds of Machine Learning (ML) algorithms to predict MW amount. However, to the best of our knowledge, penalized regression methods such as Ridge, Lasso, and Elastic Net regressions have not been used to predict the MW amount. 18-years real data were obtained from İstanbul Metropolitan Municipality Department Open Data Portal with the input variables namely number of hospitals, number of health personal, number of bed available at the hospital, crude birth rate and gross domestic product per capita. 80% of the total database being used for developing the models, whereas the rest 20% were used to validate the models. In order to compare their performances, 5-fold cross-validation was applied and performance measures (MAE, RMSE and R-squared) were calculated in this study. Of the penalized regression methods, the Lasso regression provided better performance than those of other models with RMSE, MAE, and R-squared of 349.56, 596.52, 0.96, respectively, whereas the second-best Ridge regression poorer accuracy with RMSE, MAE, and R-squared 1039.091, 878.25,0.88, respectively. Thus, in our case, Lasso regression can be considered better than the Ridge regression and Elastic Net regression due to the lowest RMSE and MAE values and highest R-squared. The results reveal that the proposed Lasso regression is better than the other penalized regression models to predict the MW amount.

Keywords: medical waste, penalized regression models, prediction, sustainability

1. Introduction

Medical Waste (MW) amount is increasing as a result of industrialization as well as population density [1,2]. All the medical institutions from the hospitals to veterinary centers cause the MW. The management of the MW is a critical problem that it may yield public health risks and environmental pollution risks since it is accepted as a hazardous waste type [2,3,4]. Selecting appropriate disposal methods and organizing recycling and storage is a prominent issue especially in developing countries so there is a need an accurate estimation of this type of waste generation that will be useful information for these processes [1,5-8].

There have been several studies to estimate the MW generation such as Multiple Linear Regression [1,9-13], time series methods [1,14] and machine learning algorithms [2,3,15,16]. Multiple Linear Regression (MLR) is the most commonly methods by the researchers to estimate the MW generation. Their models reached higher model performance (R-squared>0.80) using the critical key factors number of hospitals, number of total patients, occupancy rate but MLR has assumptions that are not easy to meet in real life. The previous studies that utilized machine learning algorithms gave better results than MLR because of managing the non-linearity between input and output variables [8,15]. On the other hand, because of the lack of historical MW database, most of the studies for estimating MW generation based on surveys and questionnaires but this may yield misleading results [3,8,9,15,17,18]. Some researchers used machine learning algorithms such as Support Vector Machine (SVM) and Artificial Neural Networks (ANN) and compared the traditional statistical techniques such as MLR [2,315,16]. Machine learning algorithms outperformed statistical techniques because of its ability to better model non-linear relationships but they have disadvantages related to poor performance on small data [15]. Since some MW data is time-based, different ARIMA models as time series models have been used to predict the MW amount [1,14,19,20]. Requiring long time data to detect seasonality and not robust for outlier and missing value are the weaknesses of time series analysis methods [20,21].

İstanbul has strong influence on the environment and the health since it has Over the 15 million population, but MW generation database is still lacking the other factors that may affect the MW generation like medical waste type, social economic and health institutions type [1,22]. Penalized regression methods that extensions of linear regression models can be an effective tool for estimating the MW generation to discover the relations between the input and output parameters where there is limited data also not having assumptions like MLR. Besides these methods can deal with the multicollinearity as a general problem in MLR. These methods have been used many areas successfully [23-27]. To the best of our knowledge, penalized regression methods as Ridge Regression, Lasso Regression and Elastic Net Regression have not been employed for estimating the MW generation. The aim of this study is to employ and compare these penalized regression methods estimating the MW generation for Istanbul. First, 18 years for actual data for MW amount with input parameters namely crude birth rate, number of hospitals, number of bed available at the hospital, and Gross Domestic Product (GDP). Next, to predict MW generation these penalized regression methods namely Ridge Regression, Lasso and Elastic Net have been employed and their performances compared with R-squared, RMSE and MSE as a performance measures.

The paper structured as follows: Materials and methods were explained in Section 2. Section 3 discussed the results of the models. Finally, conclusions, limitations of the study and future directions were presented in Section 4.

2. Materials and Methods

2.1 Data collection

The dataset used in this study combined the two tables [28] and [29] the years between 2004-2021 in MS Excel worksheet. The input parameters as number of hospital (NH), number of bed (NB), crude birth rate (CBR), number of health personal (NHP) and gross domestic product (GDP) were selected based on the previous studies and data availability. While MW is a dependent variable, remaining variables are the independent variables. Table 1 provides variables and their types.

Table 1. The variables and their types

Variables	**Type of Variables**
Number of hospitals	Numeric
Number of beds	Numeric
Crude birth rate	Numeric
Number of health personnel	Numeric
GDP	Numeric
Medical Waste	**Numeric**

2.2 Data processing

Data pre-processing is the most key step the modelling process because the real data may contain errors or outliers and missing values [30,31]. The missing values have been filled for NH, NB, GDP, NHP and CBR because they have missing values in this study. The training set is used for training model allocated as 80 % of the samples and the testing set allocated to 20 % of the samples have been used for evaluating samples.

2.3 Penalized Regression Methods

Multiple Linear Regression

Ordinal Least Squares (OLS) aims to estimate β_1,$\beta_2, \dots, \beta_p$ by minimizing the residual sum of squares (RSS).

$$\text{RSS}= \sum_{i=1}^{n}(y_i - \beta_0 - \sum_{j=1}^{p}\beta_j x_{ij})^2 \quad (1)$$

Ridge Regression

Ridge Regression with penalty called L2-norm is a linear regression model was proposed by Hoerl and Kennard proposed in 1970 and designed to handle the multicollinearity. The aim of the ridge regression is to determine the coefficients to minimize the sum of squares by employing the penalty to these coefficients in Eqn. 6.5 where $\lambda \geq 0$ denotes a tuning parameter and $\lambda \sum_{j=1}^{p} \beta_j^2$ denotes a shrinkage penalty.

$$\sum_{i=1}^{n}(y_i - \beta_0 - \sum_{j=1}^{p}\beta_j x_{ij})^2 + \lambda \sum_{j=1}^{p}\beta_j^2 = \text{RSS} + \lambda \sum_{j=1}^{p}\beta_j^2 \quad (2)$$

The selecting the ideal value of λ is important since least squares produce only one set of coefficients while ridge regression generate a different set of coefficient estimates for different values of λ [32].

Lasso Regression

Lasso regression use a penalty term called L1-norm that denotes the sum of absolute coefficients lead coefficient estimates of insignificant parameters equal to zero that means more simpler and more accurate models. The aim of the lasso regression is to find the lasso coefficients by the minimizing the quantity

$$\sum_{i=1}^{n}(y_i - \beta_0 - \sum_{j=1}^{p}\beta_j x_{ij})^2 + \lambda \sum_{j=1}^{p}|\beta_j| = \text{RSS} + \lambda \sum_{j=1}^{p}|\beta_j| \quad (3)$$

The term replaced by the has been changed by in the lasso penalty [32].

Elastic Net Regression

Elastic net combines the ridge regression and lasso regression that to shrink coefficients as ridge regression and to set some coefficients to zero like lasso regression. Also, it has computational advantage over ridge and lasso regression. The aim of the Elastic Net regression is to find the elastic net coefficients by the minimizing the quantity [33].

$$\sum_{i=1}^{n}(y_i - \beta_0 - \sum_{j=1}^{p} \beta_j x_{ij})^2 + \lambda_1 \sum_{j=1}^{p} |\beta_j| + \lambda_2 \sum_{j=1}^{p} \beta_j^2 = \text{RSS} + \lambda_1 \sum_{j=1}^{p} |\beta_j| + \lambda_2 \sum_{j=1}^{p} \beta_j^2 \quad (4)$$

2.4 Performance Measures

Three performance metrics have been used such as MAE, RMSE, and R^2 as shown in Equation (5-7) to compare the penalized regression models [8,15]:

$$\boldsymbol{MAE = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n}} \quad (5)$$

$$\boldsymbol{RMSE = \sqrt{\sum_{i=1}^{n} \frac{(y_i - x_i)^2}{n}}} \quad (6)$$

$$\boldsymbol{R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - x_i)^2}{\sum_{i=1}^{n}(y_i - \bar{x}_i)^2}} \quad (7)$$

2.5 Cross-validation

A resampling procedure is used called Cross-validation (CV) is to produce equal random subsets of samples for training data and testing data when a small data [7]. In this study, the data is divided into five equal size subsamples and one part is denoted as the validation set, the resting four subsamples denoted as the training data as called five-fold CV. Till each sub-sample is used as validation set, the procedure is repeated for instance five times for five-fold CV in this study. Finally, to allege the optimal hyperparameter values, the average accuracy of five validation set is used.

3.Results and Discussion

This section provides the experimental results and discusses the performance of three regression methods such as Ridge, Lasso and Elastic Net Regression considering MAE, RMSE, R-squared as an evaluation metrics.

Table 2. Results of penalized regression models

Penalized Regression Models	**MAE**	**RMSE**	**R^2**
Ridge Regression	427.67	650.37	0.95
Lasso Regression	349.56	596.52	0.96
Elastic Net Regression	2109.32	2310.40	0.42

With regards to the MAE, Lasso Regression achieves the best performance with 349.56, Ridge Regression and Elastic Net Regression second and third with the 427.67 and 2109.32 respectively. The same order of performance is achieved with respect to R^2 and RMSE with values 0.96, 596.52 and 0.42, 2310.40 respectively. The results showed that Ridge Regression and Lasso Regression had good performances that both can be used predicting MW amount. Lasso Regression outperformed other penalized regression models with the minimum RMSE, MAE, also the higher R -squared performance measures with this small dataset. Lasso regression is successful by reaching the good ML performances [2] as well successful than some studies [3,34].

Conclusion

Prediction of MW amount is a vital information for medical waste management systems in the future especially megacities as İstanbul that have profound impact on the environment. Ridge Regression, Lasso and Elastic Net have been employed to predict MW generation for Istanbul. The methods have been compared with the performance measures MAE, RMSE and R-squared. Among the penalized regression models, Lasso Regression outperforms the other algorithms while Ridge Regression and Elastic Net Regression are ranked second and third.
The limitation of this study is small data so SMOTE technique will be used to create artificial data in the future study and the results will be compared.

Conflicts of Interest: The author declares no conflict of interest.

Funding: Funding information is not applicable / No funding was received.

Ethics committee approval (if needed)

This study does not require ethical approval.

References

[1] Ceylan, Z.; Bulkan, S.; Elevli, S. Prediction of medical waste generation using SVR, GM (1,1) and ARIMA models: a case study for megacity Istanbul. *J Environ Health Sci Engineer.* **2020**, *18*:687–697. https://doi.org/10.1007/s40201-020-00495-8.

[2] Jahandideh, S.; Jahandideh, S.; Asadabadi, E.B.; Askarian, M.; Movahedi, M.M.; Hosseini, S.; Jahandideh, M. The use of artificial neural networks and multiple linear regression to predict rate of medical waste generation. *Waste Manag*. **2009, 29***(11)*:2874-9. doi: 10.1016/j.wasman.2009.06.027.

[3] Golbaz, S.; Nabizadeh, R.; Sajadi, H.S. Comparative study of predicting hospital solid waste generation using multiple linear regression and artificial intelligence. *J Environ Health Sci Engineer.* **2019,** *17*:41–51. https://doi.org/10.1007/s40201-018-00324-z.

[4] Shinee, E.; Gombojav, E et al. Healthcare Waste Management in the Capital City of Mongolia. *Waste Manag.* **2008,** *28*: 435-444.

[5] Nie, L.; Qiao, Z.; Wu, H. Medical Waste Management in China: A Case Study of Xinxiang. *J Environ Prot Ecol*. **2014**, *5*: 803-810. http://dx.doi.org/10.4236/jep.2014.510082.

[6] Uysal, F.; Tinmaz, E. Medical waste management in Trachea region of Turkey: suggested remedial action. *Waste Manag Res*. **2004**, Oct;*22(5):*403-7. doi: 10.1177/0734242X04045690.

[7] Birpinar, M.E.; Bilgili, M.S.; Erdoğan, T. Medical waste management in Turkey: A case study of Istanbul. *Waste Manag*. **2009**, *29(1)*:445-8. doi:10.1016/j.wasman.2008.03.015.

[8] Nguyen, X.C.; Nguyen, T.T.H.; La, D.D. et al. Development of machine learning-based models to forecast solid waste generation in residential areas: A case study from Vietnam.*Resour Conserv Recycl.* **2021**,167:105381. https://doi.org/10.1016/j.resconrec.2020.105381.

[9] Bdour, A.; Altrabsheh, B.; Hadadin, N.; Al-Shareif, M. Assessment of medical wastes management practice: a case study of the northern part of Jordan. *Waste Manag*. **2007**, *27*:746–59. https://doi.org/10.1016/J.WASMAN.2006.03.004.

[10] Sabour, M.R.; Mohamedifard, A.; Kamalan, H. A mathematical model to predict the composition and generation of hospital wastes in Iran. *Waste Manag*. **2007**,*27*:584–7. https://doi.org/10.1016/J.

[11] Idowu, I.; Alo, B.; Atherton, W.; Al, K.R. Profile of medical waste management in two healthcare facilities in Lagos, Nigeria: a case study. *Waste Manag Res.* **2013**, *31*:494–501. https://doi.org/10.1177/0734242X13479429.
[12] Al-Khatib, I.A.; Abu, Fkhidah. I.; Khatib, J.I.; Kontogianni, S. Implementation of a multi-variable regression analysis in the assessment of the generation rate and composition of hospital solid waste for the design of a sustainable management system in developing countries. Waste Manag Res. **2016**, 34:225–34. https://doi.org/10.1177/0734242X15622813.
[13] Çetinkaya, A.Y.; Kuzu, S.L.; Demir,A. Medical waste management in a mid-populated Turkish city and development of medical waste prediction model. *Environ Dev Sustain.* **2020**, *22*:6233–6244. https://doi.org/10.1007/s10668-019-00474-6.
[14] Chauhan, A.; Singh, A. An ARIMA model for the forecasting of healthcare waste generation in the Garhwal region of Uttarakhand. *India Int J Serv Oper Informatics*. **2017**, *8*:352. https://doi.org/10.1504/ijsoi.2017.086587
[15] Karpušenkaitė, A.; Ruzgas, T.; Denafas, G. Forecasting medical waste generation using short and extra short datasets: Case study of Lithuania. *Waste Manag Res*. **2016,** *34(4)*:378-87. doi: 10.1177/0734242X16628977
[16] Thakur, V.; Ramesh, A. Analyzing composition and generation rates of biomedical waste in selected hospitals of Uttarakhand, India. *J Mater Cycles Waste Manag*. **2018**,*20*:877–90. https://doi.org/10.1007/s10163-017-0648-7.
[17] Dissanayaka, D.M.S.H.; Vasanthapriyan, S. Forecast municipal solid waste generation in Sri Lanka. In 2019 International Conference on Advancements in Computing, Sri Lanka ,5-7 December 2019 ;210-215. doi: 10.1109/ICAC49085.2019.9103421.
[18] Meleko, A.; Adane, A. Assessment of Health Care Waste Generation Rate and Evaluation of its Management System in Mizan Tepi University Teaching Hospital (MTUTH), Bench Maji Zone, South West Ethiopia. *Ann Rev Resear*.**2018**, *1*: 555566. http://dx.doi.org/10.19080/ARR.2018.01.555566.
[19] Karpušenkaitė, A.; Ruzgas, T.; Denafas, G. Time-series-based hybrid mathematical modelling method adapted to forecast automotive and medical waste generation: Case study of Lithuania. *Waste Manag Res.* **2018**, *36*: 454 - 462.
[20] Papacharalampous, G.; Tyralis, H.; Koutsoyiannis, D. Univariate time series forecasting of temperature and precipitation with a focus on machine learning algorithms: A multiple-case study from Greece. *Water Resour Manag*. **2018**, *32*:5207–5239. http://dx.doi.org/10.1007/s11269-018-2155-6.
[21] Pavlyshenko, B. M.Machine-Learning Models for Sales Time Series Forecasting. *Data*. **2019**,*4(1)*:1–11. https://doi.org/10.3390/data4010015.
[22] Birpinar, M.E.; Bilgili, M.S.; Erdoğan, T. Medical waste management in Turkey: A case study of Istanbul. *Waste Manag*. **2009**, *29(1)*:445-8. doi:10.1016/j.wasman.2008.03.015.
[23] Musarrat Ijaz, Zahid Asghar & Asma Gul (2021) Ensemble of penalized logistic models for classification of high-dimensional data, Communications in Statistics- Simulation and Computation, 50:7, 2072-2088, DOI: 10.1080/03610918.2019.1595647
[24] Buyrukoğlu, S. & Yılmaz, Y. (2021). An Approach for Airfare Prices Analysis with Penalized Regression Methods . Veri Bilimi , 4 (2) , 57-61 .
[25] Greenwood CJ, Youssef GJ, Letcher P, Macdonald JA, Hagg LJ, Sanson A, et al. (2020) A comparison of penalised regression methods for informing the selection of predictive markers. PLoS ONE 15(11): e0242730. https://doi.org/10.1371/journal.pone.024273
[26] Rendall R, Pereira AC, Reis MS. Advanced predictive methods for wine age prediction: Part I - A comparison study of single-block regression approaches based on variable selection, penalized regression, latent variables and tree-based ensemble methods. Talanta. 2017 Aug 15;171:341-350. doi: 10.1016/j.talanta.2016.10.062. Epub 2016 Nov 9. PMID: 28551149.
[27] Tütmez, B. (2020). Air Quality Assessment by Statistical Learning-Based Regularization . Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi , 35 (2) , 271-278 . DOI: 10.21605/cukurovaummfd.792412
[28] İstanbul Metropolitan Municipality Department Open Data Portal. Available online:https://data.ibb.gov.tr/en/dataset/31d85b21-32a9-4270-95d9-1712a6567ea/resource/50036dfd-aea5-4f06-832f-f7020fdaaa5a/download/ilce-yl-ve-atk-turu-baznda-atk-miktar-2021.xlsx (Accessed 10 July 2022)
[29] The official website of Turkish Statistics Institute. Available online: https://biruni.tuik.gov.tr/medas/ (accessed 10 July 2022)
[30] Ramírez-Gallego, S.; Krawczyk, B.; García, S.; Woźniak, M.; Herrera, F. A survey on data preprocessing for data stream mining: Current status and future directions. *Neurocomputing.* **2017**,*239*:39-57. https://doi.org/10.1016/j.neucom.2017.01.078.
[31] Kwak, S.K.; Kim, J.H. Statistical data preparation: management of missing values and outliers. *Korean J of anesthesiology.* **2017,** *70(4)*:407. doi: 10.4097/kjae.2017.70.4.407.
[32] James, G., Witten, D., Hastie, T., & Tibshirani, R. "An introduction to statistical learning", Vol. 112, p. 18,. New York: springer, 2013.
[33] Zhang, Z., Lai, Z., Xu, Y., Shao, L., Wu, J., & Xie, G. S. "Discriminative elastic-net regularized linear regression". IEEE Transactions on Image Processing, 26(3), 1466-1481, 2017
[34] Tesfahun, E.; Kumie, A.; Beyene, A. Developing models for the prediction of hospital healthcare waste generation rate. *Waste Manag Res.* **2016**, Jan;*34(1)*:75-80. doi: 10.1177/0734242X15607422.

ANKARA SCIENCE UNIVERSITY, RESEARCHER
Vol. 3, No. 1 July 2023
e-ISSN: 2717-9494
Research Article/Araştırma Makalesi
Doi: https://doi.org/10.55185/researcher.1210472

Selection of Business Intelligence System Software as Decision Support: A Case Study

Emir Hüseyin ÖZDER[1*], Turan Erman ERKAN[2]
[1]Ankara Science University, Faculty of Engineering and Architecture, Industrial Engineering Department, Ankara, Türkiye; ORCID: 0000-0002-1895-8060
[2]Atılım University, Faculty of Engineering, Industrial Engineering Department, Ankara, Türkiye; erman.erkan@atilim.edu.tr
ORCID: 0000-0002-0078-711X
* Corresponding Author: emir.ozder@ankarabilim.edu.tr

Received: 26 November 2022; Accepted: 27 July 2023

Reference/Atıf: E. H. Özder, T. E. Erkan, "Selection of Business Intelligence System Software as Decision Support: A Case Study", Researcher, vol.3, no.1, pp.19-28, July 2023, doi: 10.55185/researcher.1210472

Abstract

This study focuses on Business Intelligence (BI) systems and investigates their benefits in the matter of better decision making for corporations. BI systems are computer-based decision support tools that analyse business data and generate meaningful information in order to incorporate decision making. BI systems work in parallel with existing information systems of the companies. As a matter of fact, BI systems are the next steps to be established on existing operational information systems. In this context, the purpose of this study is to examine the yield of BI systems for the companies tended to implement decision support systems aligned with their operational information systems. To investigate this phenomenon, an empirical study will be conducted among some companies in production sector in Turkey. The companies' actual implementations will be highlighted by the help of the questionnaire to be applied to those companies. Moreover, in the case study, BI system alternatives will be compared as per specifically defined criteria. In this manner, Multi criteria decision making approach will be used and Analytic Hierarchy Process (AHP) and Fuzzy AHP (FAHP) methods will be applied for the selection of the best alternative. Lastly, expected benefits and outcomes of proposed BI system will be estimated by taking into consideration of the facts and findings of the study.

Keywords: business intelligence; AHP; fuzzy AHP; decision support systems

Özet

Bu çalışma, İş Zekası (İZ) sistemlerine odaklanmakta ve şirketler için daha iyi karar verme konusunda faydalarını araştırmaktadır. İZ sistemleri, iş verilerini analiz eden ve karar vermeyi dahil etmek için anlamlı bilgiler üreten bilgisayar tabanlı karar destek araçlarıdır. İZ sistemleri, şirketlerin mevcut bilgi sistemleri ile paralel çalışır. Nitekim İZ sistemleri, mevcut operasyonel bilgi sistemleri üzerine kurulacak sonraki adımlardır. Bu bağlamda bu çalışmanın amacı, operasyonel bilgi sistemleri ile uyumlu karar destek sistemlerini uygulama eğiliminde olan şirketler için İZ sistemlerinin getirisini incelemektir. Bu olguyu araştırmak için Türkiye'de üretim sektöründe faaliyet gösteren bazı şirketler arasında ampirik bir çalışma yapılmıştır. Firmalara uygulanacak çalışma ile firmaların fiili uygulamaları ortaya konulacaktır. Ayrıca vaka çalışmasında İZ sistem alternatifleri, özel olarak tanımlanmış kriterlere göre karşılaştırılacaktır. Bu doğrultuda Çok kriterli karar verme yaklaşımı kullanılacak ve en iyi alternatifin seçimi için Analitik Hiyerarşi Prosesi (AHP) ve Bulanık AHP (BAHP) yöntemleri uygulanacaktır. Son olarak, önerilen İZ sisteminin beklenen faydaları ve sonuçları, çalışmanın gerçekleri ve bulguları dikkate alınarak tahmin edilecektir.

Anahtar Kelimeler: iş zekası; AHP; bulanık AHP; karar destek sistemleri

1. Introduction

Decision Support Systems (DSS) are computer-based information systems that provide inter-active information support to managers and business professionals during the decision-making processes. In this context, BI systems are the most well-known type of DSS systems. BI systems use analytical models, specialized databases, decision makers' own insights and judgments, and interactive computer-based modelling process to support business decisions [1]. BI systems attempt to incorporate the knowledge of experts in various fields and suggest possible alternatives and embrace various disciplines that make up supply chain management. Accordingly, BI systems are used to address various problems, from strategic problems such as network planni ng, to tactical problems such as assignment of products to warehouses, as well as operational problems such as production scheduling and delivery mode selection. The inherent size and complexity of many of these systems make BI systems essential for effective decision making [2].

Recently, BI systems have considerable impact on corporations to consider the establishment and the use of BI tools due to the opportunities they provide. BI systems attract companies' attention since BI tools are capable to perform data mining, statistical analysis, and analytical processing of data in order to come up with better decision-making mechanism and enhanced representation of knowledge. As a matter of fact, most of the innovative companies consider making investments on BI systems. The companies are also making investigations at the outset of each BI design and implementation project to determine whether the benefits of a BI system will compensate its costs. On the other hand, success factors and performance indicators of BI systems have also been evaluated in the companies that already use BI systems. Besides, evaluations on the costs, benefits and the necessity of BI systems are always major considerations for corporations.

In this context, the main area of concern of this study is to investigate the necessity and perceived values of BI systems at the companies in production sector. In this scope, an empirical study and a survey were conducted with questionnaires applied to the companies in Ankara production sector in order to highlight the companies' perspectives on this issue and to examine their current BI system implementations. Moreover, this paper also evaluates the BI system software with a case study and selects the most applicable BI software by AHP and Fuzzy AHP Analysis for the companies in Turkey production sector. The plan of the study is as follows: After the introduction, the literature review is mentioned in the second part. The third part consists of a general discussion of the study outline and the methods used. In the fourth part, the results are analyzed. In the last part, conclusion and evaluation were made.

2. Literature Review

It is important to note that the use of information in the supply chain has also increasingly been enabled by enterprise software such as Enterprise Resource Planning (ERP) systems [3]. In addition to ERP systems, the considerable increase in the complexity of decision making and in the amount of accessible information to be concerned by managers has accelerated the development and use of decision support systems by teams of business professionals. This dramatic expansion has opened the door to use of Business Intelligence tools for decision support [4]. In this manner, BI systems can be accepted as enhancements to ERP systems. Accordingly, ERP systems and BI operations are mutually supportive. Both can exist without the other, but both can be much more profitable if used together [5].

The deluge of data has affected all organizations, and today's technology executives are feeling the pressure to help their organizations use information to work smarter. Operational systems such as ERP and front - office Customer Relationship Management (CRM) systems have been seen universally as "must haves," but for companies seeking to secure a sustainable competitive advantage in today's unforgiving marketplace, business intelligence now falls into the "must have" category as well [6].

BI helps managers by downloading information from a variety of sources for better basic leadership, traditional usage, traditional data frames, and at the same time hierarchical and functional planning, both at the traditional and strategic level; New tools are needed for job analysis [14]. There is another problem with many definitions; They tend to change in the light of the shape of what they change after a change. This is the case with BI, for example. Initially, the software business, which was busy with BI, BI, was understood as special insight, rather than state or open knowledge. Even years later, BI is still used by engineers and programmers [15]. BI is a framework that transforms knowledge into knowledge, then transforms it into learning and thus develops the company's core decision-making process [16]. BI is defined as a framework that collects, modifies, and displays information gathered from a variety of sources. BI is a system and a response that helps decision-makers understand the economic situation of the firm [17]. BI is defined as frameworks that shorten the time needed to achieve significant business data and capture, modify, and present organizational information from a variety of sources, making it possible to use efficiency in the management decision-making process [18], allowing dynamic corporate information to be viewed, examination and clarification [17].

Business intelligence systems may be viewed as information systems with special focus on providing accessible business data, i.e., they can be viewed as type of decision support system with the capability of (easily and quickly) providing reliable and up-to-date information or key figures about the organization. Recent years have witnessed a remarkable increase of companies investing in BI systems, [19]. This makes it interesting to study the use and knowledge of the effects on the businesses of the companies utilizing, or having the ability to utilize, such systems [7]. However, the installation of such an Enterprise system is always very complex, expensive and has a massive impact on the entire organization. Due to these reasons, the installation should be evaluated carefully in order to avoid unsuccessful results in its implementation. Usually, considerations for the selection of BI systems are based on qualitative judgments and multi-criteria decisions. Therefore, the use of multi-criteria decision-making tools such as AHP and FAHP will facilitate successful results in the selection of BI systems.

3. Study Outline and Method

The study encompasses two different stages. The first stage is the survey on business intelligence applications conducted among 82 Turkish companies in Ankara production sector so as to depict the business values from BI systems, effectiveness of BI systems on decision making support, and to demonstrate the necessity for the use of BI systems. In the latter section of the paper, a case study is performed for the selection of the most suitable BI software for the companies in Ankara production sector. In the selection methodology, an analytic modelling approach such as AHP and FAHP methods have been put forward for evaluating BI software alternatives.

3.1 Survey on Business Intelligence Applications

The survey was conducted with the application of questionnaires to 82 Turkish companies from different business segments in production sector that implement BI tools for decision support. The study was carried out and the questionnaires were applied to relatively large companies that have more than 30 employees. After the application of questionnaires, the aggregated results will be presented on bar charts and the importance and value of BI systems is to be asserted.

The questions in the questionnaire consist of 6 categories. Accordingly, these categories are,

1: Visions, objectives, and strategies

2: Business values from BI systems

3: Requirements analysis and needs

4: Change Management

5: Technical Solutions

6: Decision making support

In the first category, the aim is to measure how well the currently implemented BI application suits to the company’s strategic scope and the level of contribution that BI systems make for organizational objectives and visions of the company.

The second category refers to Business values acquired from BI systems. It investigates the level of effectiveness of BI systems in supporting the company’s core business processes and meeting organizational needs.

The fourth Category reflects the effectiveness on establishing the route for organizational change and settlement of the new technology and procedures.

The Fifth Category indicates the compliance between proposed technical solutions and stipulated business objectives.

The last category, which is related to decision making support, examines the utilization of BI system in decision making and the performance of the system in supporting majority of business decisions.

Each category includes 6 questions and respondents were asked to assess these questions as per their agreement on each statement. The grades in the questionnaire were arranged on the basis of 1-to-7 Likert scale, that is, 1 refers to strongly disagreeing and 7 refers to strongly agreeing, and intermediate values refers to moderate ratings. Accordingly, the Score 4 is assumed as neutral score where it means neither agreement nor disagreement. As per the results gained from the questionnaires, the bar charts are constructed with respect to each question and the number of companies below an above the neutral score (4 out of 7) is represented. Also, average scores of the companies having assessed above 4 points and below 4 points to questions were represented in the spider diagrams to illustrate the difference between the companies that well-utilizes BI systems and the others that poorly utilizes and unaware of the outcomes of BI systems. The questionnaires were applied to companies in various industries as it is represented on the Table 1.

Table 1: The Respondent's business segments

Business Segments	**Count**
Machinery and Metal Forming	14
Electronics	13
Real Estate and Construction	12
Defence	8
Home Appliances	8
Pharmaceutical and Healthcare	7
Food and Catering	6
Energy	5
Textile	5
Others	4
TOTAL	**82**

3.2 Analytic Hierarchy Process (AHP)

The AHP enables the decision-makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria environment in confliction [20]. With AHP, the decision maker selects the alternative that best meets his decision criteria developing a numerical score to rank each decision alternative based on how well each alternative meets them. AHP approach is most useful where teams of people are working on the problems, especially those involving human perceptions and judgments [8].

In AHP, preferences between alternatives are determined by making pair-wise comparisons. In a pair-wise comparison, the decision maker examines two alternatives by considering one criterion and indicates a preference. These comparisons are made using a preference scale, which assigns numerical values to different levels of preference [21]. For instance, the scale can be 1-7 scale which lies between "equal importances" to "extreme importance". In the pair-wise comparison matrix, the value 7 indicates that one factor is extremely more important than the other, and the value 1/7 indicates that one factor is extremely less important than the other, and the value 1 indicates equal importance [22]. Therefore, if the importance of one factor with respect to a second is given, then the importance of the second factor with respect to the first will be the reciprocal [9].

- Obtaining Weights for Each Decision Criteria

Step 1: Ranking each criteria in the Pair-wise Comparison Matrix

Step 2: Normalize each column to get a new judgment matrix A' by dividing Each Value to The Column Total.

Step 3: Take average of each row of normalized matrix A' to assign the importance levels (weights of criteria) by dividing the sum of rows by the number of criteria.

- Scoring Alternatives as per Each Decision Criteria

After determination of decision criteria weights, the next step is to determine how well each alternative satisfies on the decision criteria. To make this evaluation, pair-wise comparison matrix should be constructed for each decision criteria in which rows and columns are representing the alternatives. Then, the matrix will be normalized as per each column, and next, row averages will determine the score of each alternative relative to particular decision criteria.

- Obtaining Overall Score of Each Alternative

Matrix multiplication will be performed between the ranking matrix that represents the relative scores of each alternative with respect to decision criteria and decision criteria weights matrix that indicates importance level of each criterion. Eventually, the overall scores will be obtained, and the best alternative is now ready to be selected by considering the highest overall score.

- Consistency Test of the Comparison Matrix

The additional step in AHP analysis is checking for the consistency of the decision maker's comparisons. The comparison matrix will be considered to be consistent if $CR=CI/RI<0.10$

3.3 Fuzzy Analytic Hierarchy Process (FAHP)

In most of the real-world problems, some of the decision data can be precisely assessed while others cannot. Humans are unsuccessful in making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting [23]. Essentially, the uncertainty in the preference judgments give rise to uncertainty in the ranking of alternatives as well as difficulty in determining consistency of preferences [9, 24].

In complex systems, the experiences and judgments of humans are represented by linguistic and vague patterns. Therefore, a much better representation of this linguistics can be developed as quantitative data; this type of data set is then refined by the evaluation methods of fuzzy set theory. The fuzzy AHP technique can be viewed as an advanced analytical method developed from the traditional AHP. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision-making problems based on decision maker's judgments; fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgments of decision makers in conventional AHP approaches [25]. So, many researchers [26 - 32] who have studied the fuzzy AHP which is the extension of Saaty's theory, have provided evidence that fuzzy AHP shows relatively more sufficient description of these kind of decision-making processes compared to the traditional AHP methods.

Fuzzy AHP also has pair wise comparison matrix like classical AHP approach. However, triangle fuzzy numbers instead of constant numbers are used to judge criteria in the comparison matrix. Accordingly, assignment of Triangular Fuzzy sets Scale are represented as follows [10],

Table 2: Triangular Fuzzy Sets Scale

Linguistic scale	Explanation	TFN	Inverse TFN
Equal Importance	Two activities contribute equally to the objective	(1, 1, 1)	(1, 1, 1)
Moderate Importance	Experience and judgment slightly favor one activity over another	(1, 3, 5)	(1/5, 1/3, 1)
Strong Importance	Experience and judgment strongly favor one activity over another	(3, 5, 7)	(1/7, 1/5, 1/3)
Very Strong Importance	An activity is favored very strongly over another, its dominance	(5, 7, 9)	(1/9, 1/7, 1/5)

According to the responses on the question form, the corresponding triangular fuzzy values for the linguistic variables are placed and for a particular level on the hierarchy the pair wise comparison matrix is constructed. Sub totals are calculated for each row of the matrix and new *(l, m, u)* set is obtained, then in order to find the overall triangular fuzzy values for each criterion, *li/Σli, mi/Σmi, ui/Σui,(i=1,2,..., n)* values are found and used as the latest $Mi(l_i, m_i, u_i)$ set for criterion *Mi* in the rest of the process. In the next step, membership functions are constructed for each criterion and intersections are determined by comparing each couple.

In fuzzy logic approach, for each comparison the intersection point is found, and then the membership values of the point correspond to the weight of that point. This membership value can also be defined as the degree of possibility of the value. For a particular criterion, the minimum degree of possibility of the situations, where the value is greater than the others, is also the weight of this criterion before normalization. After obtaining the weights for each criterion, they are normalized and called the final importance degrees or weights for the hierarchy level.

To apply the process depending on this hierarchy, according to the method of Chang's [33] extent analysis, each criterion is taken and extent analysis for each criterion, *gi*; is performed on, respectively. Therefore, *m extent* analysis values for each criterion can be obtained [34]. Where *gi* is the goal set (*i = 1, 2, 3, 4, 5, ...n)* and all the M_{gi}^{j} (*j = 1, 2, 3, 4, 5, ..., m)* are Triangular Fuzzy Numbers *(TFNs)*.

The basic operations to be applied throughout FAHP method. The steps of Chang's analysis can be given as follows:

Step 1: The value of fuzzy synthetic extent with respect to the i th object is defined. To obtain $\sum_{j=1}^{m} M_{gi}^{j}$ perform the fuzzy addition operation of m extent analysis values for a particular matrix and to obtain perform the fuzzy addition operation of M^{j}_{gi} (j = 1, 2..., m) values such that. Then, compute the inverse of the vector above,

Step 2: As $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ can be equivalently.

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy Mi (i = 1, 2, k) numbers can be defined by

$V (M \geq M_1 ,M_2 ,.....M_k)$ $V[(M \geq M_1)$ and $(M \geq M_2)$ and....and $(M \geq M_k)] = \text{Min } V(M \geq M_i)$, i=1,2,3,…k

Assume that $d(A_i) = \min V (S_i \geq S_k)$ for k = 1, 2...., n; k ≠ i. Then the weight vector is given by where A_i= (i=1, 2...n) are n elements.

Step 4: Via normalization, the normalized weight vectors are where W is a non-fuzzy number. In Fuzzy AHP, the above procedure that consists of 4 steps should be applied for both the comparison of decision criteria and comparison of alternatives with respect to each decision criteria. Therefore, the decision maker is supposed to obtain a weight vector for decision criteria and the same number of weight vectors as the number of decision criteria indicating alternatives' scores.

Lastly, the overall scores are obtained as non-fuzzy numbers in the same way like classical AHP method by performing matrix multiplication between the ranking matrix that represents the relative scores of each alternative with respect to decision criteria and decision criteria weights matrix that indicates importance level of each criterion. Eventually, the overall scores will be obtained and the best alternative to be selected by considering the highest overall score.

In the methodology, one cannot find a consistency process for fuzzy inputs and the consistency index method is not appropriate for FAHP method because of the fuzziness. Accordingly, fuzziness concept has some bias including decision maker's inconsistency. Because of that the publications applying Chang's fuzzy AHP did not require any consistency mechanism as seen in many applications in the literature

4. Analysis And Results

The analysis and results are presented initially by considering the survey on Business Intelligence Applications over Turkish companies that make use of BI systems. In the light of the facts and findings acquired from the survey, the study is performed by using AHP and FAHP methods in order to select the most favourable BI system software.

4.1 Analysis on the Survey on Business Intelligence Applications

The questionnaires were applied to respondents from 82 Turkish companies; the data was compiled for aggregation and graphical representation of the results.

As mentioned before, the questions were divided into 6 categories as follows,

1: Visions, objectives and strategies

2: Business values from BI systems

3: Requirements analysis and needs

4: Change Management

5: Technical Solutions

6: Decision making support

In the light of the survey, the results are presented in two formats. The first format indicates, for each category and question, the number of respondents who assessed a score of below 4 (the neutral score) and the number of respondents who assessed a score of above 4. The other format is in the form of spider diagrams showing the average score of the assessments that are below and above the neutral score for each question, i.e., the most common assessment for each question for the companies having assessed the below and above neutral scores. In this context, the difference will be observed between the companies having a good understanding and utilization of BI systems over the poor ones with respect to each category.

In the light of the evaluation constituted by 82 Turkish companies that use BI tools, Category based average scores are approximately 4.14, 4.26, 4.42, 4.38, 4.25, and 4,62 out of 7, which corresponds to the approximate overall grade of 60%, proves the agreement on BI systems' contributions to companies' Strategy, Business value and Decision-making support. Eventually, Innovative companies utilizing BI systems well; receive crucial benefits from this software in Turkey. However, it is inferred that there is no adequate awareness and vision for BI systems in small and middle-sized companies in Turkey. Therefore, they should begin to get insight about BI systems and had better use BI systems to incorporate decision making.

5. Selection of Business Intelligence Vendor

Selection of Business intelligence vendor is a critical progress. It requires comprehensive considerations and high amounts of money to design and implement the system. This paper brings a multi criteria decision making approach to select the BI vendor among possible alternatives with respect to specific criteria.

First of all, decision criteria have been determined by the discussions of companies implementing BI systems and by concerning expert judgement made by a specialist. Accordingly, the specified decision criteria with their description are given below:

- ✓ Analytical Modelling & Processing (C1): The capability of software to compile analytical processes such as analytical models, data mining and online analytical processing.
- ✓ Data Visualization & Graphical Support (C2): The ability of the software to represent information and enterprise knowledge with inter-active reporting and graphical presentations.
- ✓ User Interface (C3): The ability of the system in terms of providing a user-friendly interface and facilitating ease of use.
- ✓ Technical Guidance & Support (C4): The performance of the vendor in providing an effective consultation, trouble shooting, technical guidance and support throughout design, testing and implementation phases.

- ✓ Cost (C5): The amount of total cost of ownership which refers to investment costs in design and implementation with the addition of operational and maintenance costs throughout the lifetime of the BI system.

Secondly, the possible alternatives are to be elected for the evaluation. The 14 alternatives are determined as A, B, C, D, E, F, G, H, I, J, K, L, M and N since they are most well-known Business intelligence vendors, and it is relatively easier to compare them as there are too many experts experienced on these vendors. Besides, all software have satisfactory capabilities in terms of the decision criteria that were defined for our scope. Therefore, there will be a challenge in comparing these alternatives. As a matter of fact, the ranking and performing the pair-wise comparisons for both alternatives and for decision criteria were carried out with the expert judgment applied by specialist through considering the discussions made with Turkish companies having expertise on BI systems.

5.1 AHP Analysis

The hierarchical structure was created as a result of the data obtained. After the hierarchical structure is created, the scale is determined to compare the criteria. The binary comparison matrix is created and solved. The binary comparison matrix that created in the previous step is normalized. In the matrix obtained, relative significance weights are obtained by taking the average of each row. The consistency of the subsequent transactions is tested. In the last step, weights are determined. According to the results, software I is the alternative with the highest weight. So, software I is selected as the best BI system alternative by considering the AHP results for BI system integration to the companies operating in production sector.

Table 3. Final weights of each alternative according to AHP

Name	Criteria Weights
A	0,095432
B	0,085701
C	0,046253
D	0,051043
E	0,0959
F	0,033123
G	0,016741
H	0,102232
I	0,13209
J	0,04436
K	0,064611
L	0,096928
M	0,119611
N	0,013975

5.2 FAHP Analysis

The same procedures were made for the FAHP method. According to the results, software I is selected as the best BI system alternative by considering the FAHP results for BI system integration to the companies operating in production sector in Ankara.

Table 4. Final weights of each alternative according to FAHP

Name	Criteria Weights
A	0,18223
B	0,1623
C	0,22544
D	0,12821
E	0,15198
F	0,34646
G	0,2977
H	0,16981
I	0,66873
J	0,17561
K	0,08384
L	0,19018
M	0,3048
N	0,10738

6. Conclusion

By taking into consideration of the facts and findings of the report, this study puts an emphasis on Business intelligence systems and demonstrates real business values and the level of decision-making support acquired from BI systems. Accordingly, BI awareness and perceived values were measured by the application of questionnaires to 82 companies operating in production sector in Ankara. Consequently, it is highlighted that BI systems are beneficial tools to support decision making against business cases that enforces decision making. However, survey results indicated that BI systems are not effectively used in Ankara Production Sector in terms of enhancing company vision, business values, understanding requirements and supporting business decisions. Furthermore, a case study was conducted to evaluate BI software alternatives and to select the best alternative for the integration of BI systems to the companies attempting to insert BI systems in their decision-making mechanism. The important point is that this project brings an analytical and multi criteria decision making approach to BI system selection. Therefore, AHP and Fuzzy AHP methods were used to select the best BI software alternative. Accordingly, all software were assessed with respect to relevant criteria. Then, software I was selected as the best alternative in both methods. Hence, software I will be the most preferable option for the companies tended to implement BI systems. More to the point, the finding of the survey indicated that BI systems are effective to incorporate decision making although the use and awareness of BI systems is not satisfactory in Ankara production sector. On the other hand, managers had better perform BI system selection by means of analytical and multi criteria decision making methods such as AHP or Fuzzy AHP since BI system selection is critical for companies and involves multi criteria and conflicting objectives.

Acknowledgments: This study was developed as a result of the project course of undergraduate students.

Competing interests

The authors declare that they have no competing interests.

Funding: Funding information is not applicable / No funding was received.

Ethics approval and consent to participate

This study does not require ethical approval.

References

[1] O'Brien,J. and Marakas,G., Management Information Systems, (2009). p.384.
[2] Simpchi-Levi,D., Kaminsky, P. And Simpchy-Levi, E.: Designing and Managing the Supply Chain, (2008).p.421.
[3] Chopra, S., Meindl, P., Supply Chain Management, (2010). p.470-471.

[4] O'Brien,J. and Marakas,G., Management Information Systems, (2009). p.383.
[5] Ohson, D., Managerial Issues of Enterprise Resource Planning Systems, (2010). p.144.
[6] SAS Institute., How to Select a Business Intelligence Vendor. p.2.
[7] Riabacke, A., Larsson, A. and Danielson, M.: Business Intelligence as Decision Support in Business Processes: An Emprical Investigation. (2011). p. 384-386.
[8] Zhang, L., Comparison Of Classical Analytic Hierarchy Process (AHP) Approach and Fuzzy AHP Approach In Multiple-Criteria Decision Making For Commercial Vehicle Information Systems And Networks (Cvisn) Project, (2010). p.5.
[9] Ozdagoglu, A. and Ozdagoglu, G. Comparison Of Ahp And Fuzzy Ahp For The Multicriteria Decision Making Processes With Linguistic Evaluations. (2007). p. 65-75.
[10] Ballı, S. and Korukoğlu, S.: Operating System Selection Using Fuzzy Ahp And Topsis Methods. Mathematical and Computational Applications, Vol. 14, No. 2. (2009). p. 119-130.
[11] Cebeci, U.: Fuzzy AHP-based decision support system for selecting ERP systems in textile industry by using balanced scorecard. Expert Systems with Applications, No. 36 (2009). p. 8900-8909.
[12] Kong, F. and LIU, H.: Applying Fuzzy Analytic Hierarchy Process To Evaluate Success Factors Of E-Commerce. International Journal of Information and Systems Sciences, Vol 1.(2005). p. 406-412.
[13] Riabacke, A., Larsson, A. and Danielson, M.: Business Intelligence as Decision Support in Business Processes: An Emprical Investigation. (2011). p. 384-391.
[14] Rasoul, D. G., and Mohammad, H. (2016). A model of measuring the direct and impact of business intelligence on organizational agility with partial Mediatory role of Empowerment: Tehran construction Engineering Organization (TCEO) and EKTA organization industries.co. Social and Behavioral Sciences, Vol. 230, pp. 413-421.
[15] Solberg Søilen, K. (2015). A place for Intelligence studies as a Scientific Discipline, Halmstad, Sweden. Journal of Intelligence Studies in Business, Vol. 5(3), pp. 35-46.
[16] Singh, H., & Samalia, H. (2014). A Business Intelligence Perspective for Churn Management. Procedia – Social and Behavioral Sciences, 109, 51-56.
[17] Nofal, M., & Yusof, Z. (2013). Integration of Business Intelligence and Enterprise Resource Planning within Organizations. Technology, Vol. 11, pp. 658-665.
[18] Den Hamer, P. (2005). The organization of Business Intelligence. The Hague: SDU Publishers.
[19] Hannula, M. and Pirttimäki, V. (2003) 'Business intelligence: empirical study on the top 50 Finnish companies', Journal of American Academy of Business, Vol. 2, No. 2, pp.593–599.
[20] Cheng, C. H., Yang, K. L., and Hwang, C. L., (1999), "Evaluating Attack Helicopters by AHP Based on Linguistic Variable Weight", European Journal of Operational Research, 116, 423-435.
[21] Taha, H.A. (2003) Operations Research. Pearson Education, Inc., Fayetteville.
[22] Sarkis, J., and Talluri, S., (2004), "Evaluating and Selecting e-Commerce Software and Communication Systems for a Supply Chain", European Journal of Operational Research, 159, 318-329.
[23] Kulak, O., and Kahraman, C., (2005), "Fuzzy Multi-Criterion Selection Among Transportation Companies Using Axiomatic Design and Analytic Hierarchy Process", Information Sciences, 170, 191-210.
[24] Leung, L. C., and Chao, D., (2000), "On Consistency and Ranking of Alternatives in Fuzzy AHP", European Journal of Operational Research, 124, 102-113.
[25] Bouyssou, D., Marchant, T., Pirlot, M., Perny, P., Tsoukias, A., and Vincke, P., (2000), Evaluation Models: A Critical Perspective, Kluwer, Boston.
[26] Boender, C. G. E., De Graan, J. G., and Lootsma, F. A., (1989), "Multicriteria Decision Analysis with Fuzzy Pairwise Comparisons", Fuzzy Sets and Systems, 29, 133-143.
[27] Buckley, J. J., (1985/a), "Ranking Alternatives Using Fuzzy Members", Fuzzy Sets and Systems, 15, 21-31.
[28] Buckley, J. J., (1985/b), "Fuzzy Hierarchical Analysis", Fuzzy Sets and Systems, 17, 233-247.
[29] Chang, D. Y., (1996), "Applications of The Extent Analysis Method on Fuzzy- AHP", European Journal of Operational Research, 95, 649-655.
[30] Laarhoven, P. J. M., and Pedrycz, W., (1983), "A Fuzzy Extension of Saaty's Priority Theory", Fuzzy Sets and Systems, 11, 229-241.
[31] Lootsma, F., (1997), Fuzzy Logic for Planning and Decision-Making, Kluwer, Dordrecht.
[32] Ribeiro, R. A., (1996), "Fuzzy Multiple Criterion Decision Making: A Review and New Preference Elicitation Techniques", Fuzzy Sets and Systems, 78, 155-181.
[33] Chang, D. Y., (1992), "Extent Analysis and Synthetic Decision", Optimization Techniques and Applications, World Scientific, Singapore, 1, 352.
[34] Kahraman, C., Cebeci, U., and Da, R., (2004), "Multi-Criterion Comparison of Catering Service Companies Using Fuzzy AHP: The Case of Turkey", International Journal of Production Economics, 87, 171-184.

ANKARA SCIENCE UNIVERSITY, RESEARCHER
Vol. 3, No. 1 July 2023
e-ISSN: 2717-9494
Research Article/Araştırma Makalesi
Doi: https://doi.org/10.55185/researcher.1281521

On Solutions of a Parabolic Partial Differential Equation of Neutral Type Including Piecewise Continuous Time Delay

Zekeriya ÖZKAN[1,*], Duygu ARUĞASLAN ÇİNÇİN[2], Marat AKHMET[3]
[1]Aksaray University, Ortaköy Vocational School, Aksaray, Türkiye; ORCID: 0000-0002-6543-8527
[2]Süleyman Demirel University, Department of Mathematics, Isparta, Türkiye; ORCID: 0000-0003-1867-0996
[3]Middle East Technical University, Department of Mathematics, Ankara, Türkiye; ORCID: 0000-0002-2985-286X
* Corresponding Author: zekeriyaozkan@gmail.com

Received: 12 April 2023; Accepted: 28 July 2023

Reference/Atıf: Z. Özkan, D. Aruğaslan Çinçin, Marat Akhmet, "On Solutions of a Parabolic Partial Differential Equation of Neutral Type Including Piecewise Continuous Time Delay", Researcher, vol.3, no.1, pp.29-35, July 2023, doi:10.55185/researcher.1281521

Abstract

Check for updates

There have been very few studies on partial differential equations including piecewise constant arguments and generalized piecewise constant arguments. However, as far as we know, there is no study conducted on neutral type partial differential equations including piecewise constant argument of generalized type. With this motivation, we discuss the solution and analysis of a parabolic partial differential equation of neutral type including generalized piecewise constant delay. The aim of this study is to investigate detailed and well-defined qualitative properties of this equation. The formal solution of the handled equation is obtained by using the separation of variables method. Since there exist the piecewise constant arguments, we get an ordinary differential equation with respect to the time variable on each consecutive intervals and then apply the Laplace transform method using the unit step function and method of steps. With the help of the qualitative properties of the solutions of the obtained differential equation, unboundedness and oscillations of the solutions of the issue problem can be investigated.

Keywords: partial differential equation, neutral type, piecewise constant argument, laplace transformation, oscillation, unboundedness.

1. Introduction and Preliminaries

There are several mathematical models in the literature that use differential equations to investigate real-world situations. Most of these models include simply the present states of the processes, but in some circumstances, genuine issues cannot be portrayed realistically by these models since current and future states are heavily impacted by past states. From this point of view, functional differential equations enable to consider more practical mathematical models and meet the challenges encountered in many fields such as physics, medicine, economics, engineering. A careful examination of mathematical models including piecewise constant arguments is demonstrated in ([1]). Because difference and differential equations are so closely connected, differential equations including piecewise constant arguments are hybrid dynamical systems ([2]). Differential equations including piecewise constant arguments have attracted the interest of scientists in domains such as mathematics, physics, biology, engineering, economics, health, and others since the early 1980s ([3-5]). Some qualitative properties such as stability, oscillation, periodicity, boundedness/unboundedness and convergence of solutions to ordinary differential equations including piecewise constant arguments have been investigated in the literature ([6-23]). However, research on partial differential equations including piecewise constant arguments is scarce ([24-38]) when compared to ordinary differential equations with deviating arguments. In the studies ([24-38]), some qualitative properties were examined and problems were handled by the method of steps and transforming to difference equations. In 1991, the first fundamental work ([24]) was published for partial differential equations including piecewise constant arguments. It has been demonstrated that partial differential equations including piecewise constant time naturally exist when partial differential equations are approximated using piecewise constant arguments. For example, if the lateral heat change at discrete times is measured, in the equation

$$u_t(x,t) = a^2 u_{xx}(x,t) - bu(x,t) \tag{1a}$$

which describes heat flow in a rod with both diffusion $a^2u_{xx}(x,t)$ along the rod and heat loss (or gain) across the lateral sides of the rod, then the following differential equation including piecewise constant argument

$$u_t(x,t) = a^2u_{xx}(x,t) - bu(x,t/h) \tag{1b}$$

where $h > 0$ is a constant, is obtained for $t \in [nh,(n+1)h]$, $n = 0,1,2, \ldots$, ([24]).

Wiener's book [34] is a good resource for both ordinary and partial differential equations including piecewise constant arguments. However, as far as we are aware, no research has been conducted on a neutral type equation including piecewise constant arguments of generalized type using the Laplace transform. With this reason, we address the initial boundary value problem

$$u_t(x,t) = a^2u_{xx}(x,t) + bu_t\big(x,\beta(t)\big), 0 \le x \le 1, \quad \theta_0 \le t < \infty \tag{2}$$

under boundary conditions

$$u(0,t) = 0, \; u(1,t) = 0, \quad \theta_0 \le t < \infty \tag{3}$$

and initial condition

$$u(x,\theta_0) = u_0(x), \quad 0 \le x \le 1. \tag{4}$$

in the present research.

In this problem, a and b are nonzero real parameters, and $u: G \times [0,1] \to (-\infty,\infty)$, $\beta(t)$ is the generalized type piecewise constant function such that for $\theta_i \le t \le \theta_{i+1}$, $i = 0,1,2,\cdots$, $\beta(t) = \theta_i$, $|\theta_i| \to \infty$ as $i \to \infty$ and $u_0(x)$ is a continuous function on $[0,1]$. This equation is an example of neutral type since it contains the derivative u_t at different values of t.

From this point on, without losing generality, we will suppose that $\theta_0 = 0$ and there are two positive numbers $\underline{\theta}$ and $\overline{\theta}$ to satisfy $\underline{\theta} \le \theta_{i+1} - \theta_i \le \overline{\theta}$, $i = 0,1,2,\cdots$.

2. Existence of Solution

Before starting to solve the initial boundary value problem (2)-(4), let us define the properties of the solution $u(x,t)$ in G.

Definition 1 A function $u(x, t)$ is called a solution of the initial boundary value problem (2)-(4) in G if it satisfies the following three conditions:

(i) $u(x, t)$ is continuous in G,

(ii) u_t and u_{xx} exist and are continuous in G, there may be exceptional points (x, θ_i), $i = 0,1,2,\cdots$, where one-sided derivatives exist with respect to the second argument,

(iii) $u(x, t)$ satisfies Eq. (2) in G, with the possible exception of the points (x, θ_i), $i = 0,1,2,\cdots$, and conditions (3) and (4).

We can write $x(\beta(t))$ as a piecewise-defined function as follows

$$x\big(\beta(t)\big) = \begin{cases} x(0) & \text{if} \quad \theta_0 = 0 \le t \le \theta_1, \\ x(1) & \text{if} \quad \theta_1 \le t \le \theta_2, \\ \quad\vdots & \\ x(n) & \text{if} \quad \theta_n \le t \le \theta_{n+1}, \\ \quad\vdots & \end{cases}$$

Using this piecewise-defined function, we can write the following equality

$$x\big(\beta(t)\big) = x_0 u_0(t) + (x(\theta_1) - x_0)u_{\theta_1}(t) + (x(\theta_2) - x(\theta_1))u_{\theta_2}(t) + \cdots + \big(x(\theta_{n+1}) - x(\theta_n)\big)u_{\theta_{n+1}}(t) + \cdots.$$

We can rewrite $x\big(\beta(t)\big)$, using series, as follows

$$x\big(\beta(t)\big) = x(0) + \sum_{i=0}^{\infty}\big(x(\theta_{n+1}) - x(\theta_n)\big)u_{\theta_{n+1}}(t) \tag{5}$$

where $u_{\theta_{n+1}}(t)$ is the Heaviside step function defined as

$$u_n(t) = \begin{cases} 0 & \text{if} \quad t < n, \\ 1 & \text{if} \quad t \geq n. \end{cases}$$

Let us seek a solution in the form $u(x,t) = X(x)T(t)$. Then, taking partial derivatives of $u(x,t)$ and introducing partial derivatives of $u(x,t)$ into Equation 2, we have

$$\frac{T'(t) - bT'\big(\beta(t)\big)}{a^2 T(t)} = \frac{X''(x)}{X(x)} = -\mu^2,$$

where μ is a real constant. From boundary conditions, we get $X(0) = 0, X(1) = 0$.

Then separation of variables gives a boundary value problem

$$\begin{aligned} X''(x) + \mu^2 X(x) = 0, \\ X(0) = 0, X(1) = 0, \end{aligned} \tag{6}$$

whose orthonormal set of solutions is given by

$$X_j(x) = 2\sin(\pi j x), j = 1, 2, 3, \cdots, \tag{7}$$

on [0, 1], and the following ordinary differential equation including piecewise constant argument of generalized type

$$T_j'(t) + a^2\pi^2 j^2 T_j(t) = bT_j'\big(\beta(t)\big). \tag{8}$$

In Equation 8, taking $t = \beta(t)$ with the condition $b \neq 1$, we obtain

$$T_j'\big(\beta(t)\big) + a^2\pi^2 j^2 T_j\big(\beta(t)\big) = bT_j'\big(\beta(t)\big).$$

If we solve for $T_j'\big(\beta(t)\big)$ from the last equality and introduce $T_j'\big(\beta(t)\big)$ into Equation 8, we get

$$T_j'(t) + a^2\pi^2 j^2 T_j(t) = \frac{ba^2\pi^2 j^2}{b-1} T_j\big(\beta(t)\big). \tag{9}$$

Now, using equality 5 we can write Equation 9 in an explicit way as

$$T_j'(t) + a^2\pi^2 j^2 T_j(t) = \frac{ba^2\pi^2 j^2}{b-1}\left(T_j(0) + \sum_{n=0}^{\infty}\Big(T_j(\theta_{n+1}) - T_j(\theta_n)\Big)u_{\theta_{n+1}}(t)\right).$$

Then, if we take Laplace transform of the last equality and solve for $\mathcal{L}\{T_j(t)\}$, we obtain

$$\mathcal{L}\{T_j(t)\} = \frac{1 + \dfrac{b}{(b-1)s}}{s + a^2\pi^2 j^2} T_j(0) + \frac{ba^2\pi^2 j^2}{b-1}\sum_{n=0}^{\infty}\Big(T_j(\theta_{n+1}) - T_j(\theta_n)\Big)\frac{e^{-\theta_{n+1}s}}{s(s + a^2\pi^2 j^2)}.$$

After applying inverse Laplace transform to last equality, we get the solution of Equation 9, and moreover Equation 8, as follows

$$T_j(t) = \left(\frac{b - e^{-a^2\pi^2 j^2 t}}{b-1}\right)T_j(0) + \frac{b}{b-1}\sum_{n=0}^{\infty}\Big(T_j(\theta_{n+1}) - T_j(\theta_n)\Big)\big(1 - e^{-a^2\pi^2 j^2 (t-\theta_{n+1})}\big)u_{\theta_{n+1}}(t). \tag{10}$$

Then, we have a proposition to obtain the solution given by the solution 10 through a nonrecursive relation.

Proposition 1 *The solution of Equation 9, and moreover Equation 8, on the interval* $[0,\infty)$ *is given by*

$$T_j(t)=\left(\frac{b-e^{-a^2\pi^2 j^2(t-\beta(t))}}{b-1}\right)\prod_{i=1}^{\sigma(t)}\left(\frac{b-e^{-a^2\pi^2 j^2(\theta_i-\theta_{i-1})}}{b-1}\right)T_j(0) \tag{11}$$

where $\sigma(t)$ *denotes the number of discontinuity moments* θ_i *on the interval* $(0,t]$, *the numbers* $T_j(0)$ *and it is assumed that* $\prod_{i=1}^{0}(\cdot)=1$.

Proof: Let $T_{nj}(t)$ be the solution of Equation 9, and moreover Equation 8, on an arbitrary interval $[\theta_n,\theta_{n+1})$. Then $T_{nj}(t)$ satisfies the following differential equation

$$T_{nj}^{'}(t)+a^2\pi^2 j^2 T_{nj}(t)=\frac{ba^2\pi^2 j^2}{b-1}T_{nj}(\theta_n).$$

If we solve this equation, we obtain the general solution of the last equation as follows

$$T_{nj}(t)=\frac{b-e^{-a^2\pi^2 j^2(t-\theta_n)}}{b-1}T_{nj}(\theta_n).$$

Since solution $T_j(t)$ is continuous on the interval $[\theta_0,\infty)$, we have

$$T_{nj}(\theta_{n+1})=T_{n+1,j}(\theta_{n+1}).$$

Then, with the help of this equality, we obtain

$$T_{nj}(t)=\frac{b-e^{-a^2\pi^2 j^2(t-\theta_n)}}{b-1}\prod_{i=1}^{n}\left(\frac{b-e^{-a^2\pi^2 j^2(\theta_i-\theta_{i-1})}}{b-1}\right)T_{0j}(0).$$

Since $T_{nj}(t)$ represents the solution on an arbitrary interval $\theta_n\le t<\theta_{n+1}$ and $T_j(t)$ is continuous on the interval $[0,\infty)$, the solution on the interval $t\in[0,\infty)$ can be expressed in the following way

$$T_j(t)=\frac{b-e^{-a^2\pi^2 j^2(t-\beta(t))}}{b-1}\prod_{i=1}^{\delta(t)}\left(\frac{b-e^{-a^2\pi^2 j^2(\theta_i-\theta_{i-1})}}{b-1}\right)T_j(0). \tag{12}$$

Hence, proposition is proved.

Then, we will obtain a nonrecursive relation in Equation 10 by writing $t=\theta_{n+1}$ and $t=\theta_n$ in the solution 11, respectively, and subtracting $T_j(\theta_n)$ from $T_j(\theta_{n+1})$ we will get the following equality

$$T_j(\theta_{n+1})-T_j(\theta_n)=\left(\frac{1-e^{-a^2\pi^2 j^2(\theta_{n+1}-\theta_n)}}{b-1}\right)\prod_{i=1}^{n}\left(\frac{b-e^{-a^2\pi^2 j^2(\theta_i-\theta_{i-1})}}{b-1}\right)T_j(0). \tag{13}$$

After introducing Equality 13 into the solution 10, we can rewrite the solution of Equation 9, and moreover Equation 8, and consequently, the solution of Equation 9, and moreover Equation 8, as follows

$$T_j(t) = \left(\left(\frac{b - e^{-a^2\pi^2 j^2 t}}{b-1} \right) + \frac{b}{b-1} \sum_{n=0}^{\infty} \left(\frac{1 - e^{-a^2\pi^2 j^2(\theta_{n+1}-\theta_n)}}{b-1} \right) \prod_{i=1}^{n} \left(\frac{b - e^{-a^2\pi^2 j^2(\theta_i - \theta_{i-1})}}{b-1} \right) \times \left(1 - e^{-a^2\pi^2 j^2(t-\theta_{n+1})}\right) u_{\theta_{n+1}}(t) \right) T_j(0). \tag{14}$$

So, the solutions of the equation of neutral type (2) satisfying the boundary conditions (3) are obtained as $u_j(x,t) = X_j(x)T_j(t),\ j = 1,2,\cdots$.

Since the Equation 2 is linear, with the superposition principle the solution of boundary value problem (2)-(3) on the region $[0,1] \times [0,\infty)$ is given by

$$\begin{aligned} u(x,t) &= \sum_{j=1}^{\infty} T_j(t) X_j(x) \\ &= \sum_{j=1}^{\infty} \left(\left(\frac{b - e^{-a^2\pi^2 j^2 t}}{b-1} \right) + \frac{b}{b-1} \sum_{n=0}^{\infty} \left(\frac{1 - e^{-a^2\pi^2 j^2(\theta_{n+1}-\theta_n)}}{b-1} \right) \prod_{i=1}^{n} \left(\frac{b - e^{-a^2\pi^2 j^2(\theta_i - \theta_{i-1})}}{b-1} \right) \times \left(1 - e^{-a^2\pi^2 j^2(t-\theta_{n+1})}\right) u_{\theta_{n+1}}(t) \right) T_j(0)\sqrt{2}\sin(\pi j x). \end{aligned} \tag{15}$$

Now, only the initial condition must be checked. To do this, putting $t = 0$ in the solution 15 gives

$$u(x,0) = u_0(x) = \sum_{j=1}^{\infty} T_j(0)\sqrt{2}\sin(\pi j x) \tag{16}$$

where

$$T_j(0) = \sqrt{2} \int_0^1 u_0(x) \sin(\pi j x)\, \mathrm{d}x. \tag{17}$$

Hence, Equality 15 with Equality 17 gives the solution of problem (2), (3), (4) in $[0,1] \times [0,\infty)$.

Theorem 1 *Assume that* $b > 1$. *Then each solution* $T_j(t)$ *of Equation 9, and moreover Equation 8), is monotone unbounded as* $t \to +\infty$.

Proof: For $b > 1$, we have

$$\frac{b - e^{-a^2\pi^2 j^2 t}}{b-1} > 1,$$

for all t. So,

$$\prod_{k=1}^{\delta(t)} \left(\frac{b - e^{-a^2\pi^2 j^2(\theta_i - \theta_{i-1})}}{b-1} \right)$$

grows fastly as $t \to +\infty$, and proof can be obtained from the solution 12.

Theorem 2 *Assume that* $e^{-a^2\pi^2 j^2 \underline{\theta}} < b < \frac{1}{2}$. *Every function* $T_j(t)$ *tends to zero and has oscillation as* $t \to +\infty$.

Proof: From the inequality $e^{-a^2\pi^2 j^2 \underline{\theta}} < b < \frac{1}{2}$, we get the following inequalities

$$-1 < \frac{b - e^{-a^2\pi^2 j^2(\theta_i - \theta_{i-1})}}{b-1} < 0.$$

These inequalities give oscillation property and tending to zero property of the solution 12.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] S. Busenberg and K. L. Cooke, "Models of vertically transmitted diseases with sequential-continuous dynamics," *in Nonlinear Phenomena in Mathematical Sciences,* Lakshmikantham, V. (editor), Academic Press, New York, 179-187, 1982.

[2] K. L. Cooke and J. Wiener, "Retarded differential equations with piecewise constant delays," *J. Math. Anal. and Appl.,* 99(1), 265-297, 1984.

[3] Y. Muroya, "New contractivity condition in a population model with piecewise constant arguments," *J. Math. Anal. Appl.,* 346(1), 65-81, 2008.

[4] M. U. Akhmet, D. Aruğaslan, and E. Yılmaz, "Stability in cellular neural networks with a piecewise constant argument," *Journal of Computational and Applied Mathematics,* 233, 2365-2373, 2010.

[5] M. U. Akhmet and E. Yılmaz, *Neural Networks with Discontinuous/Impact Activations,* Springer: New York, 2013.

[6] M. U. Akhmet, "Integral manifolds of differential equations with piecewise constant argument of generalized type," *Nonlinear Anal,* 66, 367-383, 2007.

[7] M. U. Akhmet, *Nonlinear Hybrid Continuous Discrete-Time Models,* Atlantis Press: Amsterdam-Paris, 2011.

[8] M. U. Akhmet, "Functional Differential Equations with Piecewise Constant Argument*," In: Regularity and Stochasticity of Nonlinear Dynamical Systems,* Springer, 79-109, 2018.

[9] M. Akhmet, M. Dauylbayev, and A. Mirzakulova, "A singularly perturbed differential equation with piecewise constant argument of generalized type," *Turkish Journal of Mathematics,* 42(1), 1680-1685 (IF 0.614), 2018.

[10] M. U. Akhmet, "Almost periodic solutions of the linear differential equation with piecewise constant argument," *Discrete and Impulsive Systems, Series A, Mathematical Analysis,* 16, 743-753, 2009.

[11] M. U. Akhmet and C. Büyükadalı, "Differential equations with state-dependent piecewise constant argument," *Nonlinear Analysis: Theory, methods and applications,* 72 (11), 4200-4211 (IF 2.012), 2010.

[12] M. U. Akhmet, "Stability of differential equations with piecewise constant arguments of generalized type," *Nonlinear Anal.,* 68, 794-803, 2008.

[13] D. Aruğaslan and N. Cengiz, "Green's Function and Periodic Solutions of a Spring-Mass System in which the Forces are Functionally Dependent on Piecewise Constant Argument," *Süleyman Demirel University Journal of Natural and Applied Sciences,* 21 (1), 266-278, 2017.

[14] D. Aruğaslan, and N. Cengiz, "Existence of periodic solutions for a mechanical system with piecewise constant forces," *Doi: 10.15672/HJMS.2017.469 Hacet. J. Math. Stat.,* 47, (no. 3), 521-538, 2018.

[15] D. D. Bainov and P. S. Simeonov, *Impulsive Differential Equations: Asymptotic Properties of the Solutions,* World Scientific: Singapore, New Jersey, London, 1995.

[16] A. M. Samoilenko and N. A. Perestyuk, *Impulsive Differential Equations,* World Scientific: Singapore, New Jersey, London, Hong Kong, 1995.

[17] I. Győri, "On approximation of the solutions of delay differential equations by using piecewise constant arguments," *Internat. J. Math. Math. Sci.,* 14(1), 111-126, 1991.

[18] A. R. Aftabizadeh and J. Wiener, "Oscillatory and periodic solutions for systems of two first order linear differential equations with piecewise constant argument," *Appl. Anal.,* 26(4), 327-333, 1988.

[19] I. Győri, and G. Ladas, "Linearized oscillations for equations with piecewise constant arguments," *Differential and Integral Equations,* 2(2), 123-131, 1989.

[20] A. R. Aftabizadeh, J. Wiener and J. Ming Xu, "Oscillatory and periodic solutions of delay differential equations with piecewise constant argument," *Proc. Amer. Math. Soc.,* 99(4), 673-679, 1987.

[21] Y. K. Huang, "Oscillations and asymptotic stability of solutions of first order neutral differential equations with piecewise constant argument," *J. Math. Anal. Appl.,* 149(1), 70-85, 1990.
[22] H. Liang and G. Wang, "Existence and uniqueness of periodic solutions for a delay differential equation with piecewise constant arguments," *Port. Math.,* 66(1), 1-12, 2009.
[23] R. Yuan, "The existence of almost periodic solutions of retarded differential equations with piecewise constant argument," *Nonlinear Anal., 48(7), Ser. A: Theory Methods,* 1013-1032, 2002.
[24] J. Wiener, "Boundary value problems for partial differential equations with piecewise constant delay," *Internat. J. Math. Math. Sci.,* 14(2), 363-379, 1991.
[25] J. Wiener and L. Debnath, "A wave equation with discontinuous time delay," *Internat. J. Math. Math. Sci.,* 15(4), 781-788, 1992.
[26] J. Wiener and L. Debnath, "Boundary value problems for the diffusion equation with piecewise continuous time delay," *Internat. J. Math. Math. Sci.,* 20(1), 187-195, 1997.
[27] J. Wiener and W. Heller, "Oscillatory and periodic solutions to a diffusion equation of neutral type," *Internat. J. Math. Math. Sci.,* 22(2), 313-348, 1999.
[28] J. Wiener and V. Lakshmikantham, "Complicated dynamics in a delay Klein-Gordon equation," *Nonlinear Anal.,* 38(1), Ser. B: Real World Appl., 75-85, 1999.
[29] Q. Wang and J. Wen, "Analytical and numerical stability of partial differential equations with piecewise constant arguments," *Numer. Methods Partial Differential Equations,* 30(1), 1-16, 2014.
[30] T. Veloz and M. Pinto, "Existence, computability and stability for solutions of the diffusion equation with general piecewise constant argument," *J. Math. Anal. Appl.,* 426(1), 330-339, 2015.
[31] H. Bereketoğlu and M. Lafci, "Behavior of the solutions of a partial differential equation with a piecewise constant argument," *Filomat*, 31.19, 5931-5943, 2017.
[32] Q. Wang, "Stability of numerical solution for partial differential equations with piecewise constant arguments," *Advances in Difference Equations,* 2018(1), 1–13, 2018.
[33] M. L. Büyükkahraman and H. Bereketoğlu, "On a partial differential equation with piecewise constant mixed arguments," *Iranian Journal of Science and Technology, Transactions A: Science,* 44.6, 1791-1801, 2010.
[34] J. Wiener, *Generalized solutions of functional differential equations,* World Scientific. Publishing Co., Inc, River Edge, NJ. xiv+410 pp. ISBN:981-02-1207-0, 1993.
[35] S. M. Shah, H. Poorkarimi and J. Wiener, Bounded solutions of retarded nonlinear hyperbolic equations, *Bull. Allahabad. Math. Soc.,* 1, 1-14, 1986.
[36] H. Chi *et al.*, "On the exponential growth of solutions to nonlinear hyperbolic equations," *Internat. J. Math. Math. Sci.,* 12(3), 539-545, 1989.
[37] J. Wiener and L. Debnath, "A survey of partial differential equations with piecewise continuous arguments," *Internat. J. Math. Math. Sci.,* 18(2), 209-228, 1995.
[38] H. Poorkarimi and J. Wiener, "Bounded solutions of nonlinear parabolic equations with time delay," *Proceedings of the 15th Annual Conference of Applied Mathematics (Edman, OK, 1999), 87-91 (electronic), Electron. J. Differ. Equ. Conf.,* 2, Southwest Texas State Univ., San Marcos, TX, 1999.

ANKARA SCIENCE UNIVERSITY, RESEARCHER
Vol. 3, No. 1 July 2023
e-ISSN: 2717-9494
Research Article/Araştırma Makalesi
Doi: https://doi.org/10.55185/researcher.1286182

Developing and Implementation of Leading and Lagging Indicators in Process Safety Management

Siamak CHERAGHİ[1*], Mazdak KHODADADI-KARIMVAND [2]
[1] Department of Health, Safety, and Environment HSE, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran; ORCID: 0000-0002-0973-8840
[2]Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran ORCID: 0000-0003-2765-3784
* Corresponding Author: siamak_cheraghi@aut.ac.ir

Received: 20 April 2023; Accepted: 27 July 2023

Reference/Atıf: S. Cheraghi, M. Khodadadi-Karimvand, "Developing and Implementation of Leading and Lagging Indicators in Process Safety Management", Researcher, vol.3, no.1, pp.36-45, July 2023, doi:10.55185/researcher.1286182

Abstract

Check for updates

Implementing process safety management alone does not guarantee the effective implementation of the safety system. Instead, the process safety management system's continuous review, modification, and improvement improve individual and process safety. Therefore, determining and deploying various performance indicators is particularly important. This article discusses the difficulties of determining and deploying leading and lagging performance indicators and their effectiveness in process safety management. Finally, in the form of a case study, the transfer of chemical products (crude oil) from producers to storage tanks and the transfer of feed to units have been discussed. In this research, Leading and Lagging indicators have been used to test the performance of process safety management to ensure the correctness of the management system, and protective layers have been selected. The final result is the addition of some indicators and the proposal to remove several Leading and Lagging indicators. According to the conclusions, some indicators should be replaced with new safety indicators, and the rest should be retained due to their efficiency in achieving progressive safety goals.

Keywords: Process Safety Management (PSM), Leading and Lagging Indicators, Key Performance Indicators

1. Introduction

In process safety management, researchers have conducted valuable investigations and research so far. Therefore, Process safety management is being implemented and reviewed worldwide with various methods. With this in mind, Safety indicators are used in multiple industries to monitor the safety efficiency related to economic activities and their consequences to help us prevent accidents [1]. The purpose of safety indicators is to show possible safety risks during or before operations, which can be done with the help of various methods using experimental facts, knowledge, simulation, and other approaches [2]. Accordingly, The Lagging indicators consistently record the safety information of the process or person after the occurrence of an event or illness, or injury. Still, unlike Lagging indicators, Leading indicators act preventive based on predicting accidents and events [3].

Moreover, Safety indicators play an essential role in predicting and preventing accidents. Consequently, using these indicators will not only help us advance the safety goals, but it is also a suitable measure to recognize the performance of the existing safety system. Hence, Safety performance indicators include various categories, so Leading and Lagging indicators are the frameworks for this research. Moreover, Leading indicators complete and improve Lagging indicators too. Due to that reason, these indicators became broad topics for researchers [4],[5]. In addition, to examine Leading indicators more effectively, it is recommended to collect and review the required information right from the target plant [6]. In addition, Leading indicators focus on identifying the weak points and strengths of the safety system to predict possible accidents [7]. Therefore, optimal deployment of these indicators needs checking them by a safety management method. So, the process safety management model of the Center of Chemical Process Safety creates a broader perspective to identify indicators.

2. Safety Model of Center of Chemical Process Safety

About fifteen years after the first release of the process safety management model of the United States Industrial Safety and Health Organization in early 2007, the Occupational Safety & Health Association (OSHA) also published an up-to-date and complementary model. Therefore, this system was experienced in various industries during its trial implementation in the United States. Moreover, OSHA's model focuses on the category of risk. Due to that reason, experts recall this model by the name of risk-based process safety management [8],[9].

Another essential element of this model is its emphasis on researching the root causes of accidents and applying lessons learned from accidents and near-misses because CCPS attaches great importance to the results obtained after accidents. Moreover, preventing the root causes of previous accidents can avoid the same accident's recurrence and many of the initial factors of other possible mishaps. The model presented by the Center of Chemical Process Safety (CCPS) includes twenty elements [8],[9]:

1. Process Safety Culture
2. Compliance with Standards
3. Process Safety Competency
4. Workforce Involvement
5. Stakeholders Outreach
6. Process Knowledge Management
7. Hazard Identification and Risk Analysis
8. Operating Procedures
9. Safe Work Practices
10. Asset Integrity and Reliability
11. Contractor Management
12. Training and Performance Assurance
13. Management of Change
14. Operational Readiness
15. Conduct of Operations
16. Emergency Management
17. Incident Investigation
18. Measurements and Metrics
19. Auditing
20. Management Review and Continuous Improvement

The CCPS model is much richer in content than other models presented in process safety management. In addition, its authors use the experiences of industries and their incidents to achieve and improve this model, which makes this model more applicable in the oil and gas and petrochemical industries [9].

2.1 Determining key performance indicators in Facilities

Four-tier approach: Major accidents rarely happen in oil and gas industries, and determining and identifying key performance indicators in this industry based on a few numbers of casualties with a low probability of occurrence would be a complex task. So, this causes inadequate and limited information sources to avoid catastrophic events [10],[11].

Therefore, developing safety indicators can lead to the preparation of accurate information and statistics to prepare and establish protective safety layers. For this purpose, CCPS has provided a four-tier approach called the process safety indicators pyramid (see Figure 1).

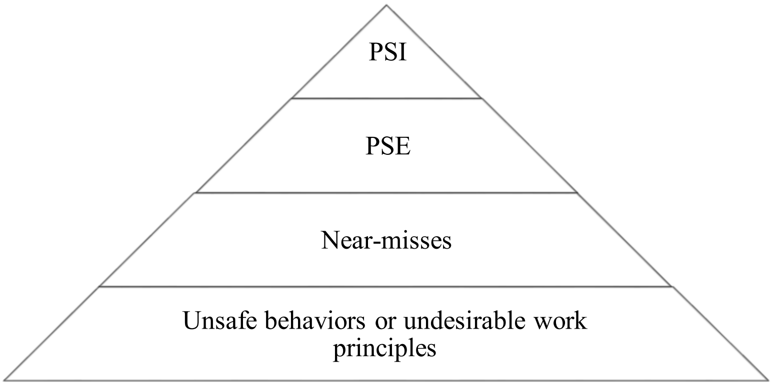


Figure 1: Process Safety Indicators Pyramid [10].

- P.S.I. Events with high intensity and consequences are known as Lagging indicators [10].
- PSE or process safety incidents are at a more limited level than PSI, which can lead to a process safety incident in the future [10].
- Near misses are on the third level of the process safety index pyramid; these events have insignificant consequences [10].
- Level 4 occurrence of an unsafe behavior or condition is considered a proactive indicator of the safety management system [10].

Determination of critical protection layers and selection of key performance indicators: Since the selection of effective indicators replicates challenges in front of the process safety management system, therefore, the selection of leading indicators that are placed in the 3rd and 4th levels of the pyramid of process safety management indicators will provide the most significant impact on protective layers of risk control [10].

In addition, based on the instructions provided by the government organization of Health, safety, and Environment of the United Kingdom, it is suggested to apply a six-step approach to select key indicators (see Figure 2).

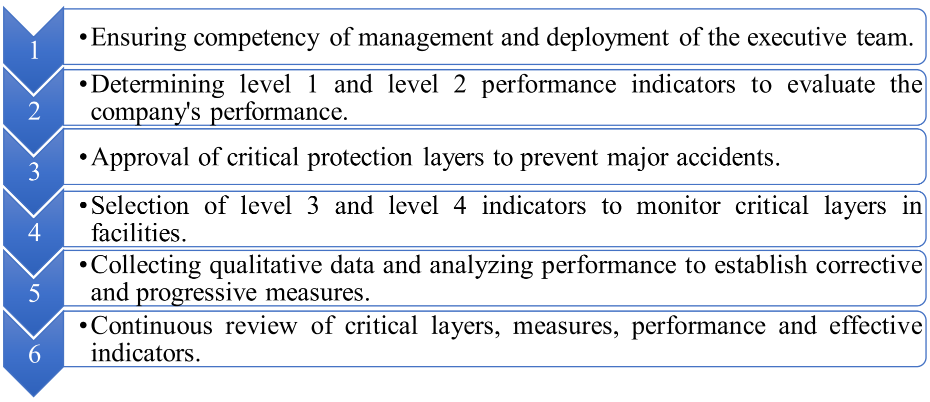


Figure 2: A six-step approach to select and review key performance indicators [10].

- Ensuring competency of management and deployment of the executive team:

It should be ensured that the output information and data are reviewed and modified at an adequate level for the organization's management to agree and implement necessary measures for the continuous development of the organization, including investing in the weak points of protective measures, prioritizing actions and recruiting human resources to advance and improve the performance of the process safety management system [10],[11].

Then, the first step to determine the key performance indicators is to select and establish a group consisting of operational people, safety experts, and managers of the organization at different levels [10],[11].

- Determining level 1 and level 2 performance indicators to evaluate the company's performance:

Lagging critical indicators of the performance of an organization or facility and the provider of the main line of the company's performance data play a facilitating role in analyzing these output data. Since level 1 and level 2, incidents and events of the organization provide basic information about the organization's performance. Still, due to the low frequency of incidents, they cannot be considered good statistical information. Also, level 1 and 2 key indicators are used based on the organizational definition and existing policies; these two indicators should be reviewed annually to evaluate the organization's performance [10],[11].

- Approval of critical protection layers to prevent significant accidents:

Leading portal

The Leading portal will recognize the dangers and risks that lead to a significant accident. The Leading portal determines and approves the appropriate protective layers with the correct placement to improve these protective layers to defeat most of the safety risks [1],[12].

External portal

The external portal includes experiences and the most efficient principles of risk control that have been made available through the publication of other production units of the oil and gas industries or other industries [12].

Lagging portal

The Lagging portal of the safety management system is based on the studies of root cause analysis of incidents or root cause analysis of high potential events [1],[11].

- Selection of level 3 and level 4 indicators to monitor critical layers in facilities:

Since selecting key performance indicators should reflect operational activities and activities of different management systems, it is possible to apply these indicators in different industries. Deduction and matching this level of indicators leads companies to determine or strengthen a part of the protective layers or identify existing weaknesses [10],[11].

- Collecting qualitative data and analyzing performance to establish corrective and progressive measures:

The effort to collect information to analyze the performance of indicators must not lead to the acquisition of fake statistics and points. Also, to gain trust in the studies, quality assurance processes should be useful to confirm the collected information's accuracy, compatibility, and completeness. Correlation and other statistical analysis should be applied to these indicators too. Functional data and frequent, meaningful changes should be presented transparently for management to review corrective and proactive measures [10],[11].

- Continuous review of critical layers, measures, performance, and effective indicators:

The key performance indicators should be ensured to focus on the most critical safety barriers to prevent major accidents. The key performance indicators of level 3 and level 4 could provide information with a reported near miss or deviation in the lake of accidents. Therefore, the key performance indicators of levels 3 and 4 should be revised annually [10],[11].

3. Study of Leading and Lagging indicators in crude oil transportation

3.1 Inspection and Maintenance

- Process controls

Inspection and maintenance of systems.

- Desired safety outcomes

No unexpected leaks will occur due to the failure of flexible hoses and other equipment.

- Leading indicators

The percentage of safety devices or equipment with particular usage that works correctly in the inspection.

The number of maintenances carried out during the predicted time scale.

- Lagging indicators

The number of unexpected leaks due to the failure of flexible hoses and the rest of the equipment.

- Removed Lagging indicators

Clogging of the tanker outlet: This event can be registered with the tank defect detector.

Static electricity spark: It will be challenging to ensure that static electricity is the cause of fire and explosion, and such an event will be infrequent.

Several fires or explosions occur due to sparks from damaged electrical equipment: this event is infrequent and often preventable.

- Removed Leading indicators

Inspection program progress: Indicates the safe operation of critical equipment.

3.2 Workers competency

- Process controls

Competency of operators: selection, information, training, and evaluation.

- Desired safety outcomes

Operators and contractors have the knowledge and skills to effectively and efficiently transfer the product from the ship to the storage tank or road transit.

- Leading indicators

The percentage of employees who participate in transferring products that benefit from the level of knowledge necessary for successful transfer and accumulation of products.

- Lagging indicators

The number of times that the transfer does not go according to plan due to errors caused by employees who need to meet the knowledge required to do the job correctly.

- Removed Lagging indicators

Excess pressure or lack of pressure in the tanker: ensuring the competence of the tanker cleaning staff due to the possibility of error in complex tasks; complexity increases the probability of error due to insufficient qualifications.

3.3 Critical tasks that take place under dangerous conditions

- Process controls

Functional procedures: written structures and work exercises.

- Desired safety outcomes

Correct the tank's selection and the equipment's operation during the product transfer by ship to the storage tank and road transport.

- Leading indicators

The percentage of procedures and guidelines reviewed and revised over time.

- Lagging indicators

The number of times the product was not transferred due to wrong or unclear procedure.

- Removed Lagging indicators

Tanker over-pressurization or depressurization: It is better to focus on a more extensive set of actions because this will show a more comprehensive picture of the procedure's reliability.

- Removed Leading indicators

Before removing the procedures, it must be ensured that they are not common in primary activities (methods may be used in several activities).

3.4 Process or industrial unit out of safe condition

- Process controls

Process procedures: equipment and warning systems.

- Desired safety outcomes

Critical safety equipment and alarms detect conditions that exceed the minimum safety requirement.

- Leading indicators

The percentage of performance tests that equipment and safety alarms complete during the test program.

The percentage of repairs that are carried out to determine safety system errors according to the plan.

- Lagging indicators

The number of equipment and safety alarms that fail to function according to their design purpose during usage or testing.

- Removed Lagging indicators

The number of times the storage tank or tanker trailer has overfilled or experienced a pressure drop due to the malfunction of the level gauge.

The number of times the product has been moved at the wrong flow rate or pressure due to flow meter or pressure meter failure.

- Removed Leading indicators

The percentage of safety equipment that correctly detects the transfer conditions.

The percentage of safety equipment and alarms that are activated in predetermined conditions.

3.5 Unit changes

- Process controls

Industrial unit change system.

- Leading indicators

Percentage of potential risks and process risks that unit changes have eliminated.

The percentage of unit changes that have been reviewed before deployment.

- Lagging indicators

The number of times the equipment or industrial unit exceeds its safety standards during changes.

- Removed Lagging indicators

The number of incidents of leakage of hazardous materials or fire and explosion due to failure of a flexible hose and other equipment.

- Removed Leading indicators

Documenting changes and post-change reviews.

3.6 Industrial unit design

- Process controls

Industrial unit design system.

- Desired safety outcomes

The process units are optimal with equipment that works properly, and reliability is not affected by failure due to improper operation and design flaws.

- Leading indicators

The percentage of critical safety items of the industrial unit or equipment is consistent with the current standards and codes.

- Lagging indicators

The number of incidents from the unit associated with failure, leakage of hazardous material contents, or failure of safety equipment.

- Removed Leading indicators

In a specific period: the percentage of the unit or equipment critical items in harmony with the current standard.

3.7 Communication

- Desired safety outcomes

Effective management of movement and storage of products and effective warning notification for problems that need to be fixed.

- Leading indicators

The percentage of check times ensures that the pump is turned off and the valves are closed after pumping.

- Lagging indicators

The number of repetitions of times that the transfer command was ignored in the communication system.

- Removed Lagging indicators

Events based on the failure of defects are infrequent. It should be considered in the emergency order section.

- Removed Leading indicators

The percentage of moving products whose completion has been checked by communication.

The percentage of completed transfers approved to start in which the transfer rate was confirmed before the process began.

3.8 Work permits

- Process controls

Work permit system.

- Desired safety outcomes

High-risk repair tasks in a way that does not result in damage or injury.

- Leading indicators

Percent of work permits that face problems contrary to the planned arrangements.

Percentage of work done under work permit conditions.

- Lagging indicators

The number of events in which the equipment or industrial unit fails due to the failure of high-risk maintenance measures.

- Removed Leading indicators

The specific goals and basis of the work permit system: It is one activity that worsens over time.

Specific period of time: Although important, it is not considered a critical factor before the start.

3.9 Emergency arrangement and order

- Process controls

Emergency arrangement and order.

- Desired safety outcomes

The pressure of a massive event during product movement or stock reduction.

- Leading indicators

The percentage of interrupting the process or isolating the systems and achieving the standard performance during the test.

- Lagging indicators

The number of emergency elements of the procedure failed to achieve their intended performance in the design.

- Removed Leading indicators

The percentage of times that the fire pumps are activated automatically and detect fire during the test is a small result of what one of the sensors has received.

The percentage of employees or contractors trained to comply with the order in emergency conditions: this indicator does not provide information on how the system works and its results.

The percentage of emergency response experiences completed according to the plan: This indicator also does not provide information about how the system works or its future consequences.

4. Conclusion

Various methods are used to establish process safety management to make process industries as safe as possible, but more than simply establishing process safety management is needed. The safety management system's continuous improvement should be reviewed and revised frequently to ensure the effectiveness of the selected protection layers. For this reason, adequate protective layers are stabilized or strengthened, and inactive layers that do not play a role in preventing accidents are replaced with newer layers based on the needs of the organization. Moreover, the new protection layers will be selected by determining the leading and lagging key performance indicators.

Based on research, developing leading and lagging performance indicators is inevitable in all industries, and various industries can establish process indicators to achieve their goals in the safety field. Considering the need for organizations to implement a systematic and integrated method to develop leading and lagging performance indicators, it is necessary to have a way of developing leading and lagging safety indicators. The method presented in this article satisfies the needs of many organizations active in oil, gas, and petrochemicals, which are also used in the oil industries of the world's leading countries.

This research investigated transferring chemical products (crude oil) from producers to storage tanks and then sending the feed to the units. Leading and Lagging indicators were used to test the efficiency of process safety management to ensure the system works properly. So, nine layers of protection were selected for inspection and maintenance, workers' competency, critical tasks under dangerous conditions, process or industrial units out of safe condition, unit changes, industrial unit design, communications, work permits, and emergency arrangement and order. Then, the result is the addition of some indicators, the proposal to remove several leading and lagging indicators, and the retention of practical indicators.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Pęciłło, Małgorzata. "Identification of gaps in safety management systems from the resilience engineering perspective in upper and lower-tier enterprises." Safety Science 130 (2020): 104851.

[2] Van Derlyke, Peter, Luz S. Marín, and Majed Zreiqat. "Discrepancies Between Implementation and Perceived Effectiveness of Leading Safety Indicators in the US Dairy Product Manufacturing Industry." *Safety and Health at Work* (2022).

[3] Chen, Fu-Li, et al. "Development and Validation of an Integrated Healthy Workplace Management Model in Taiwan." Safety and Health at Work (2022) Vision zero.

[4] Zwetsloot, Gerard, et al. "Vision zero: Developing proactive leading indicators for safety, health and wellbeing at work." *Safety Science* 130 (2020): 104890.

[5] Payne, Stephanie C., et al. "Safety climate: Leading or lagging indicator of safety outcomes?." *Journal of Loss Prevention in the Process Industries* 22.6 (2009): 735-739.

[6] Versteeg, Katelyn, et al. "Utilizing construction safety leading and lagging indicators to measure project safety performance: A case study." *Safety Science* 120 (2019): 411-421.

[7] Xu, Jing, et al. "Implementing safety leading indicators in construction: Toward a proactive approach to safety management." *Safety Science* 157 (2023): 105929.

[8] OSHA, Process Safety Management. U.S. Department of Labor, Occupational Safety and Health Administration, No.3132, 2000.

[9] CCPS (Center for Chemical Process Safety),Guideline for Process Safety Metrics, American Institution of Chemical engineers, 2008.

[10] UK HSE, Step-By-Step Guide to developing Process Safety Performance Indicators, United Kingdom HSE Dept., 2006.

[11] OGP, Asset Integrity- the Key to Managing Major Incident Risks, International Association of Oil & Gas Producers Report 415, 2008.

[12] OGP, Process Safety- Recommended Practice on key Performance Indicators, International Association of Oil & Gas Producers Report 456, 2011.