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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.

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Multi-Objective Software Project Cost Estimation Using Recent Machine Learning Approaches

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Abstract

The success of software projects for organizations heavily relies on accurate workforce and cost estimates. Initially, effort estimation was based on non-algorithmic methods, but with technological advancements, algorithmic approaches such as regression emerged. In recent years, there has been a growing interest in using Machine Learning and Artificial Intelligence for software cost estimation. In this study, Linear Regression, Multilayer Perceptron, Bagging, SMOreg, IBk, KStar, RandomTree, and RandomForest algorithms were trained with four open-source datasets. Firstly, models were trained with original feature sets, then six different hybrid feature selection methods were proposed to eliminate low-impact features and prevent overfitting. These hybrid feature selection methods, developed using evaluation methods like Relief, Classifier, and Correlation, along with search methods like RandomSearch, PSO, GA, and Ranker. And trained models tested by the 10-fold cross-validation technique. The results showed the ability to quickly obtain adaptable models and the effectiveness of feature selection. KStar, SMOreg, Multilayer Perceptron, and Linear Regression algorithms, along with PSO and GA search methods, yielded satisfactory results even with different feature subsets.

Keywords: Software Cost Estimation, Software Effort Estimation, Artificial Intelligence, Machine Learning, Feature Selection

1. Introduction

Effective project management becomes indispensable for software projects that increase in importance and scope in parallel with the increase in trust in electronic technologies.

Project predictability is a critical factor in software project management, as it makes possible to mitigate potential risks by enabling precise cost and workforce planning. Accurate software effort estimation is a crucial component of software development, providing essential inputs for feasibility analysis, planning, budgeting, bidding. Deviating significantly from the required effort causes losses in terms of cost and quality. Thus, it isparticularly important to estimate development time accurately in the highly competitive software industry, where quality is highly valued.

Currently, the most prevalent methods for effort estimation rely on expert judgment. However, these methodsmay lack reliability as they can be influenced by various factors. Additionally, relying solely on human judgment can be burdensome and time-consuming when dealing with numerous estimation items.

In recent years, the dynamic nature of the market has led to a growing adoption of agile methods in software project management, replacing traditional approaches. Within the agile project management methodology, the most commonly used metric for effort prediction is story scores.

Presently, these estimations are typically made intuitively by relevant individuals for each request, with subsequent review by unit managers. However, this process lacks consistency and continuity, despite consuming significant human resources. On the other hand, machine learning-based models, by quickly analyzing complex relationships between inputs and outputs even in large datasets through iterative cycles of training, increase the chance of producing accurate predictions.

The objective of this study is to propose a machine learning-based approach for effort estimation, aiming to accurately and swiftly predict effort. The study will handle machine learning approach that establish models by learning from past data to predict development efforts. Furthermore, innovative feature selection techniques will be employed to enhance the accuracy and effectiveness of the estimation process. The open-source WEKA platform has been preferred to enable the rapid and efficient training and testing of the selected techniques, aiming to provide a widely applicable approach.

In the study, algorithms from WEKA (Waikato Environment for Knowledge Analysis) were tested and compared for their performance based on data characteristics in the Functions, Lazy Classifiers, Meta, and Tree categories. For this analysis, Functions-based Linear Regression, Multilayer Perceptron, SMOreg, Lazy Classifiers-based IBk, KStar, Meta-based Bagging, and Tree-based RandomTree, Random Forest, M5P algorithms were selected and trained and tested with both the original feature set and after applying feature selection to enhance model performance and prevent overfitting by focusing on unnecessary inputs. Hybrid approaches of evaluation and search methods were used together in different configurations for feature selection. Search methods such as RandomSearch, PSO, GA, Ranker were selected, and their capabilities in searching optimized subsets were utilized.

Knowing the approximate cost of a project at the beginning of the project is important for the reasons for starting the project. The customers of the project or the top management decides whether or not to carry outthe project according to the predictive values. Incorrect estimations make the institutions or organizations inthe position of customers economically and strategically affects. For example, 60% of large projects exceededtheir project budgets. It has been observed that some projects were never completed due to a 15% cost overrun [1].

Software effort estimation is difficult, mainly for two reasons. The first reason is that software is intangible and is outside the definition of conventional physical product. The second reason is that the software development job is an intellectual rather than a physical job. Software startups are easy, but as the software size increases, the workforce estimation process becomes more difficult. It is possible to write a program thatis close to a few thousand lines in a week. But then the speed slows down as the program grows. When this program reaches several tens of thousands of lines, adding a line is worth a few days' effort, maybe even months. Therefore, it has become difficult to follow the side effects of the addition [2]. The dynamically fluctuating technology environment in the software development industry also makes effort estimation confusing [3]. Contributions of this study are:

- High-performance approaches were emphasized by training, testing and comparing 9 differentmachine learning algorithms with 6 different feature selection methods in four different datasets.
- With the WEKA tool, which is easily accessible due to its open source nature, alternatives to lowexecution time, high predictive models have been presented.
- When the estimation error rates obtained were compared with the results in the literature, it wasobserved that successful performances were achieved.

2. Datasets Used in Our Study

In this study, Finnish, Kemerer, Maxwell and China datasets were examined for software cost estimation from the Promise Data repository [4] The primary objective behind utilizing these datasets is their widespread recognition, simplicity, and accessibility to the public. This facilitates easy replication and verification of results, and potentially encourages further exploration and expansion. It is important to note that the approachis not limited to any specific dataset or model but can be applied across various datasets and models. Relateddatasets ‘s information.

Table 1: The related datasets‘s information which includes China, Finnish, Kemerer, Maxwell

Dataset	Project Number	Feature Number	Size (Measure Unit)	Cost (Measure Unit)
China	499	19	Function Point	Man-Hour
Finnish	38	9	Function Point	Man-Hour
Kemerer	15	8	KSLOC	Man--Month
Maxwell	62	27	Function Point	Man-Hour

3. Computation Environment

This study was conducted utilizing the WEKA platform, which is an open-source application written in Java. It was originally developed by a PhD student at the University of Waikato in New Zealand and is governed by the General Public License. WEKA offers a range of algorithms for performing machine learning and data engineering tasks, including classification, clustering, visualization, estimation, correlation analysis, feature selection, and data preprocessing for scientific research. The version utilized in this study was WEKA 3.8.6 (WEKA, 2022).

While WEKA is installed, it presents the weka.jar file, which includes the necessary libraries. WEKA Jar allows for the development of projects by accessing WEKA classes from other platforms such as Java or C#. Within WEKA, datasets are typically in the arff (Attribute Relationship File Format) extension, although it also supports other formats such as textual csv, dat, libsvm, json, and xrff.

4. Feature Selection

Estimating the cost in software projects relies on various factors, including the technology employed, the expertise of developers, the team's past project experiences in a similar domain, and the specific characteristics of the functions being developed. Software workforce estimation is a challenging task due to the multitude of parameters involved, and accurately predicting the relationships between these parameters is not always feasible. To address these ongoing challenges, techniques are continuously evolving to mitigate their impact. Numerous approaches and methods have been suggested to enhance the accuracy and success rate of effort estimation values.

In general, useful features are unpredictable, and features with low correlation and missing data can affect classification performance. Including low-impact variables in model training reduces the model's ability to generalize and may also reduce the overall accuracy of a classifier. Also, adding more variables to a model increases the overall complexity of the model. Therefore, deciding on the optimum features to include in model training is critical in obtaining a generically high-performing model. Various techniques are used in various fields to eliminate unnecessary features.

Various techniques are used in various fields to eliminate unnecessary features. The techniques for feature selection in machine learning can be broadly classified into the following categories:

- ➢ Feature selection based on combining the features for evaluation
- ➢ Feature selection based on the supervised learning algorithm

Feature selection based on combining the features for evaluation: They are classified into feature subset-based and feature ranking-based methods. In the feature subset-based method, the features are combined as possible combinations of feature subsets using any one of the searching strategies. Then, the feature subsets are evaluated using any one of the statistical measures or the supervised learning algorithms to observe the significance of each subset and the most significant subset is selected as the significant feature subset for a given dataset. If the subset is evaluated using the supervised learning algorithm, then this method is known as wrapper method [5] PSO, GA are heuristic searching strategies. One of the widely accepted fundamental benefits of metaheuristic algorithms is that they provide mechanisms to solve large or intractable problems in reasonable execution times while the exact algorithms fail to succeed due to time limitations [6]. Numerous research works on feature selection have utilized the genetic algorithm to create subsets of features for evaluation, with the supervised machine learning algorithm employed to assess these subsets. For instance, Erguzel et al. utilized the genetic algorithm and artificial neural network to classify electroencephalogram signals [7]. Oreski & Oreski proposed an approach for feature selection that combined GA with neural networks for credit risk assessment [8]. Additionally, Wang et al. applied the GA to generate subsets alongside SVM in the process of feature selection for data classification applications [9]. In their research, Yang et al. created a feature selection method for land cover 16 classification using PSO [10]. Feature ranking-based methods involve weighting each feature in a dataset based on statistical or information-theoretic measures and then ranking them according to their weights. The significant features are selected using a predetermined threshold that determines how many features will be chosen from the dataset. Since these methods do not require a supervised learning algorithm to assess feature significance, they follow a filter-based approach. As a result, feature ranking-based methods are more versatile and computationally efficient, regardless of the specific supervised learning algorithm used. Hence, they are a viable choice for selecting important features from datasets with high dimensions. From a taxonomic point of view, these techniques are classified into filter, wrapper, embedded, and hybrid methods. Hybrid methods are a fusion of filter and wrapper-based approaches. Dealing with high-dimensional data can be challenging when using the wrapper method. To address this, Bermejo et al. devised a hybrid feature selection method called the filter wrapper approach. In this method, they initially employ a statistical measure to rank the features based on their relevance. The higher-ranked features are then passed on to the wrapper method, which significantly reduces the number of evaluations required, making it a linear process. As a result, this hybrid approach reduces the computational complexity when applied to medical data classification tasks. The hybrid algorithms are developed by combining the current metaheuristics or classical algorithms. The main purpose of hybrid algorithms is to combine the skills of diverse algorithms to obtain better results. Therefore, hybrid metaheuristic algorithms have significant improvements compared to single metaheuristic algorithms [11]. Ruiz et al developed a feature selection algorithm for selecting the significant genes for the medical diagnosis system. They used a statistical ranking approach to filter the features from high-dimensional space and the filtered features are fed into the wrapper approach. This combination of the filter and wrapper approach was used to distinguish the significant genes causing cancer disease in the diagnosis process [12].

Hybrid methods are a fusion of filter and wrapper-based approaches. Dealing with high-dimensional data can be challenging when using the wrapper method. To address this, Bermejo et al. devised a hybrid feature selection method called the filter-wrapper approach. In this method, they initially employ a statistical measure to rank the features based on their relevance. The higher-ranked features are then passed on to the wrapper method, which significantly reduces the number of evaluations required, making it a linear process. As a result, this hybrid approach reduces the computational complexity when applied to medical data classification tasks. The hybrid algorithms are developed by combining the current metaheuristics or classical algorithms. The main purpose

of hybrid algorithms is to combine the skills of diverse algorithms to obtain better results. Therefore, hybrid metaheuristic algorithms have significant improvements compared to single metaheuristic algorithms [11]. Ruiz et al developed a feature selection algorithm for selecting the significant genes for the medical diagnosis system. They used a statistical ranking approach to filter the features from high-dimensional space and the filtered features are fed into the wrapper approach. This combination of the filter and wrapper approach was used to distinguish the significant genes causing cancer disease in the diagnosis process [12].

5. Machine Learning Algorithms

In this section, the ML algorithms used in our study and included in the classification area of the WEKA tool are presented.

ML algorithms in WEKA are listed under the following headings and the algorithms used in model training in our study are listed under the relevant headings.

a. Functions
   - o LinearRegression
   - o Multilayer Perceptron
   - o SMOreg (Sequential Minimal Optimization Regression)

b. Lazy Classifiers
   - o IBk (K-nearest neighbors classifier)
   - o KStar (Instance-based classifier)

c. Meta
   - o Bagging

d. Tree
   - o M5P (M5 Model trees)
   - o RandomForest
   - o RandomTree

6. Feature Selection Techniques

Attribute selection in WEKA is performed by the Attribute Evaluator and Search method working together. Attribute Evaluator evaluates the importance of the attributes and tries to find the best set of attributes, guided by the Search method. This approach is used to evaluate the quality of features and to eliminate unimportant features, so that a smaller and more meaningful set of features can be obtained. This can provide the model with a better generalization ability and a faster training time. Feature selection can reduce the dimensionality to enable many data mining algorithms to work effectively on data with large dimensionality [13].

Selecting Attribute Evaluator: The first step is to select the Attribute Evaluator method. The Attribute Evaluator measures the effect of each attribute on classification or regression. Weka has various Attribute Evaluator methods, such as Information Gain, Gain Ratio, ReliefF, Chi-Square, etc. Choosing one of these methods determines the evaluator who will rate the importance of the features.

Search Method Selection: The second step is the selection of the Search method to be used in the feature selection. Search methods try to find the best set of attributes based on the importance rating generated by the Attribute Evaluator. Various Search methods are available in Weka, for example GreedyStepwise, BestFirst, GeneticSearch, etc. Choosing one of these methods determines a search strategy to find the best feature set.

Attribute Selection: Attribute selection is performed using the selected Attribute Evaluator and Search method. In this step, the necessary parameters for feature selection are set and the selection

process is started. Evaluation and selection of features are performed on a specific criterion or threshold value. As a result, the best featureset is determined.

In this section, the Attribute Evaluators and Search Methods used in our study and included in the SelectAttributes area of the WEKA tool are presented.

Attribute Evaluators:

- CfsSubsetEval
- ClassifierAttEval
- Corr. Att.Evaluation
- Relief

Att.Evaluation
Search Methods:

- Random Search
- Particle Swarm Optimization (PSO)
- Genetic Algorithm (GA)
- Ranker

7. Performance Measures

Correlation Coefficient:

The Correlation Coefficient is a statistical value that measures the strength and direction of the relationship between two variables. It is often called the Pearson Correlation Coefficient and takes values between -1 and +1.The formula for the Pearson Correlation Coefficient is expressed as:

$$r = (\Sigma((xi - x) * (yi - \bar{y}))) / \sqrt{((\Sigma(xi - x)\ 2) * (\Sigma(yi - \bar{y})2))} \quad (1)$$

Formula:

- r represents the Correlation Coefficient.
- xi and yi represent the values of the data points.
- x and ȳ represent the mean values of xi and yi.

Mean Absolute Error (MAE):

Mean Absolute Error (MAE) is a method of evaluating the accuracy of a prediction model by calculating the mean of the absolute differences between the measured and predicted values. MAE measures how close a model's predictions are to the true values and represents the mean errors of the predictions.

The formula for MAE is expressed as follows:

$$MAE = (1/n) * \Sigma|yi - xi| \quad (2)$$

Formula:

- MAE stands for Mean Absolute Error.
- n stands for the total number of data points.
- yi represents the true value.
- xi represents the predicted value.

Relative Absolute Error (RAE):

Relative Absolute Error (RAE) calculates the accuracy of a predictive model. RAE can be used in machine learning. Furthermore, RAE is expressed as the ratio; it computes the mean error (residual) of errors producedby a trivial or naive model. The model is considered non-trivial if the result is less than 1. This is the model for a dataset (k):

$$R_k = \frac{\sum_{i=1}^{n} \left| E_{ki} - D_i \right|}{\sum_{i=1}^{n} \left| D_i - \bar{D} \right|} \tag{3}$$

where Ei's is prediction, Di's is actual values, and Rae is the measure of forecast accuracy. D is the mean of Di's; n is the size of the dataset (in data points)

8. Findings

At this stage, considering the Finnish, Kemerer, China, Maxwell datasets implemented and choosing the 10-fold cross-validation technique.

- Firstly, models were created with the original datasets,
- In the second part, by using the hybrid configurations of given below evaluation and search methods among feature selection methods for the the same datasets, optimized and formed most effective features subsets. And these subsets were used to create models.

1. CFS+ RandomSearch
2. CFS+ PSO
3. CFS+ GA
4. ClassifierAttEval + Ranker
5. Corr. Att.Evaluation + Ranker
6. Relief Att.Evaluation + Ranker

Therefore, each discussed algorithm was initially tested with the original data, and then the most effective feature subsets obtained from the same datasets were evaluated with nine algorithms using six different hybrid methods for each subset. In the first stage, the results obtained with the original dataset will be examined, and in the second stage, the findings obtained as a result of the feature selection applied dataset will be presented. Finally, by examining the performance criteria reached with the results of methods obtained without feature selection and with different feature selection methods:

▪ The highest performances achievable with the original datasets,

▪ Dataset-specific and holistic analysis of algorithms that demonstrate the highest performance in the model formed with the original data,

▪ Highest achievements after attribute selection,

▪ Analysis of which feature selection is superior compared to the others,

Ultimately, specific to the dataset and holistically, the aim is to obtain a generic approach that is not reliant on the specific dataset by considering the overall evaluation of these results.Specific to the dataset and holistically, Ultimately, the goal is to obtain a generic approach that is not reliant on the specific dataset by considering the overall evaluation of these results.The performance evaluation of the models was carried out by considering the Correlation Coefficient as well as several error metrics, including MAE and RAE.

In order not to be affected by small deviations while examining the results, the values close to the best and the worst results with a small percentage difference were added to the table. In addition, due to its higher resistance to overfitting, models with less number of feature subsets and close to the best results are also included. Table 1 presents Finnish model performance measurements.

Table 2. Finnish Model Performance Measurements

Finnish Dataset						
	Machine Learning Algortihm	**Number Of Selected Features**	**Feature Selection Technique**	**Correlation Coefficient**	**MAE**	**RAE (%)**
The Highest Result Without Feature Selection	Kstar	9	Original Feature Set	0.9889	0.1344	13.1344
The Lowest Result Without Feature Selection	IBk	9	Original Feature Set	0.7697	0.539	52.6711
The Hightest Results	Kstar	6	ClassifierAttEval+ Ranker	0.9948	0.0873	8.5274
	RandomForest	5	CFS + PSO	0.9942	0.0976	9.5354
	RandomForest	5	CFS+ GA	0.9942	0.0976	9.5354
The Lowest Results	Ibk	6	ClassifierAttEval+ Ranker	0.7421	0.5756	56.2528

Table 2 presents Finnish model performance measurements.

Table 3. China Model Performance Measurements

China Dataset						
	Machine Learning Algortihm	**Number Of Selected Features**	**Feature Selection Technique**	**Correlation Coefficient**	**MAE**	**RAE (%)**
The Highest Result Without Feature Selection	Linear Regression	19	Original Feature Set	0.9889	362.939	9.809
The Lowest Result Without Feature Selection	IBk	19	Original Feature Set	0.8918	1571.1824	42.4638
The Hightest Results	MultilayerPerceptron	16	Relief. Att.Evaluation + Ranker	0.9914	370.1846	10.0048
	MultilayerPerceptron	16	Corr. Att.Evaluation + Ranker	0.9912	406.1195	10.976
	SMOreg	16	Relief. Att.Evaluation + Ranker	0.9898	269.3637	7.28
	SMOreg	7	Random Search	0.9866	351.7668	9.5071
	LinearRegression	9	CFS + PSO	0.986	395.7794	10.6966
	LinearRegression	10	CFS+ GA	0.9859	411.7442	11.1281
The Lowest Results	IBk	16	Corr. Att.Evaluation + Ranker	0.8396	1418.9499	38.3495
	Random Tree	16	Relief. Att.Evaluation + Ranker	0.8098	1263.9482	34.1603

Table 3 shows China model performance measurements.

Table 4. Maxwell Model Performance Measurements

Maxwell Dataset						
	Machine Learning Algortihm	**Number Of Selected Features**	**Feature Selection Technique**	**Correlation Coefficient**	**MAE**	**RAE (%)**
The Highest Result Without Feature Selection	SMOreg	27	Original Feature Set	0.8191	3812.9653	60.6894
The Lowest Result Without Feature Selection	Ibk	27	Original Feature Set	0.463	5517.129	87.8139
The Hightest Results	Kstar	20	CFS+ GA	0.8596	4078.3244	64.913
	LinearRegression	20	CFS+ GA	0.8544	3395.0666	54.0379
	Kstar	9	CFS + PSO	0.85	4040.6726	64.3137
The Lowest Results	Ibk	24	Corr. Att.Evaluation + Ranker	0.4487	5720.7419	91.0547
	Random Tree	20	CFS+ GA	0.4398	5223.2222	83.1359

Table 4 presents Maxwell model performance measurements.

Table 5. Kemerer Model Performance Measurements

Kemerer Dataset						
	Machine Learning Algortihm	**Number Of Selected Features**	**Feature Selection Technique**	**Correlation Coefficient**	**MAE**	**RAE (%)**
The Highest Result Without Feature Selection	SMOreg	8	Original Feature Set	0.5737	114.3301	71.0419
The Lowest Result Without Feature Selection	Random Tree	8	Original Feature Set	-0.0271	250.9131	155.9111
The Hightest Results	SMOreg	5	Corr. Att.Evaluation + Ranker	0.7171	103.4371	64.2732
	SMOreg	5	CFS + PSO	0.6946	96.4073	59.9051
	SMOreg	5	CFS+ GA	0.6946	96.4073	59.9051
The Lowest Results	Bagging	5	CFS+ RandomSearch	0.1168	182.9247	113.6648
	Random Tree	5	CFS+ RandomSearch	0.1189	194.63	120.94

Table 5 presents Kemerer model performance measurements.

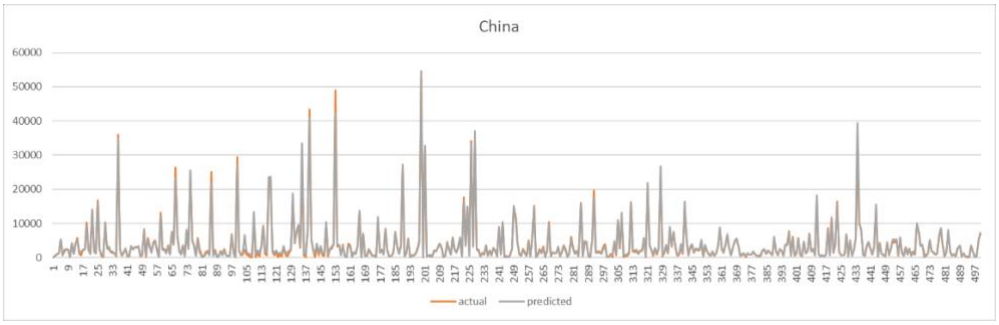

Figure 1. China Dataset Actual And Predicted Values

Figure 1 shows the efforts comparison for the actual and predicted by the model for in China dataset. Multilayer Perceptron algorithm was found to be the most successful to achieve best estimation. The Relief Att. Evaluation and Ranker methods were utilized during the analysis.

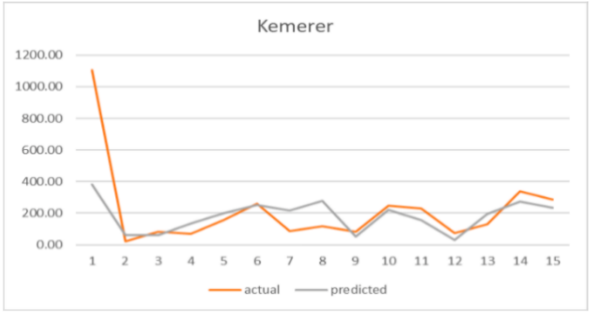

Figure 2. Kemerer Dataset Actual And Predicted Values

Figure 2 shows Kemerer dataset actual and predicted values. The KStar algorithm was found to be the most successful to achieve best estimation. The CFS and Genetic Algorithm methods were utilized during the analysis. The efforts comparison for the actual and predicted by the model are depicted.

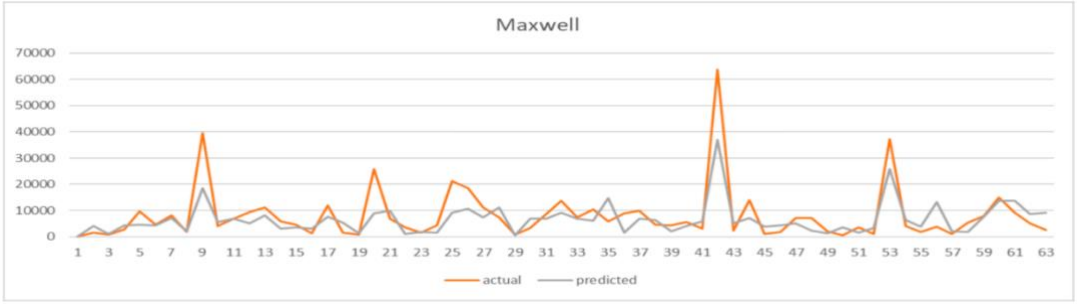

Figure 3. Maxwell Dataset Actual And Predicted Values

Figure 3 shows Maxwell dataset actual and predicted values. it was determined that the highest performance measurements as algorithms were obtained when KStar, SMOreg, MultilayerPerceptron and LinearRegression were used. It has been noted that models created using IBk, RandomTree and Bagging algorithms tend to give low results.

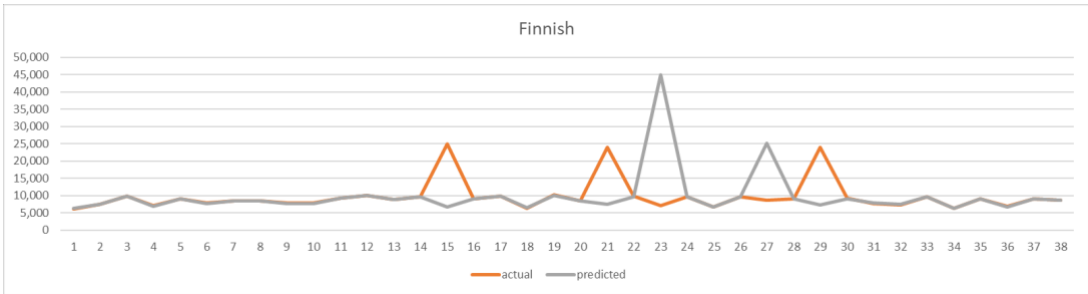

Figure 4. Finnish Dataset Actual And Predicted Values

Figure 4 shows Finnish dataset actual and predicted values. KStar algorithm was found to be the most successful to achieve best estimation. The ClassifierAttEval and Ranker methods were utilized during the analysis.

Table 6. Model Performance Results with Feature Selection

Dataset	Orginal Feature Set	Model	FeatureSelection	Selected Feature Set	Correlation Coefficient
Finnish	9	KStar	CFS+ RandomSearch	5	0.9916
Finnish	9	RandomForest	CFS+ PSO	5	0.9942
Finnish	9	RandomForest	CFS+ GA	5	0.9942
Finnish	**9**	**KStar**	**ClassifierAttEval+ Ranker**	**6**	**0.9948**
Finnish	9	KStar	Corr. Att.Evaluation + Ranker	6	0.9912
Finnish	9	KStar	Relief. Att.Evaluation + Ranker	6	0.9916
China	19	SMOreg	CFS+ RandomSearch	7	0.9866
China	19	SMOreg	CFS+ PSO	9	0.9853
China	19	LinearRegression	CFS+ GA	10	0.9859
China	19	SMOreg	ClassifierAttEval+ Ranker	16	0.9887
China	19	MultilayerPerceptron	Corr. Att.Evaluation + Ranker	16	0.9912
China	**19**	**MultilayerPerceptron**	**Relief. Att.Evaluation + Ranker**	**16**	**0.9914**
Maxwell	27	LinearRegression	CFS+ RandomSearch	16	0.8354
Maxwell	27	K Star	CFS+ PSO	9	0.85
Maxwell	**27**	**K Star**	**CFS+ GA**	**20**	**0.8596**
Maxwell	27	M5p	ClassifierAttEval+ Ranker	24	0.8515
Maxwell	27	SMOreg	Corr. Att.Evaluation + Ranker	24	0.8336
Maxwell	27	M5p	Relief. Att.Evaluation + Ranker	24	0.8472
Maxwell	27	SMOreg	Relief. Att.Evaluation + Ranker	14	0.838
Kemerer	8	SMOreg	CFS+ RandomSearch	5	0.6795
Kemerer	**8**	**SMOreg**	**CFS+ PSO**	**5**	**0.6946**
Kemerer	**8**	**SMOreg**	**CFS+ GA**	**5**	**0.6946**
Kemerer	8	SMOreg	ClassifierAttEval+ Ranker	5	0.5405
Kemerer	8	RnndomTree	Corr. Att.Evaluation + Ranker	5	0.6658
Kemerer	8	MultilayerPerceptron	Relief. Att.Evaluation + Ranker	5	0.6295

Table 6 shows that even if the best result is obtained with a large number of feature sets, close to the best results can also be obtained with a less numbered feature set.

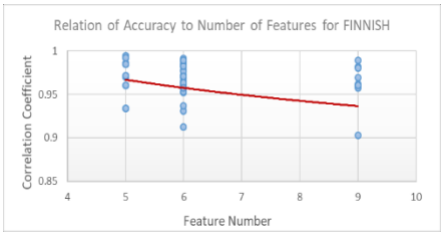

Figure 5. Relation of Accuracy To Number of Features For Finnish

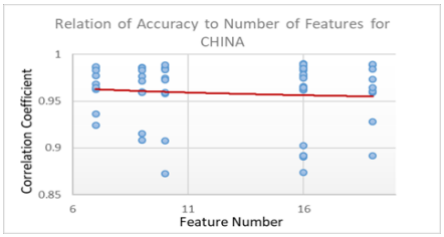

Figure 6. Relation of Accuracy To Number of Features For China

Figure 5 shows the relation of accuracy to number of features for Finnish and Figure 6 shows the relation of accuracy to number of features for China.

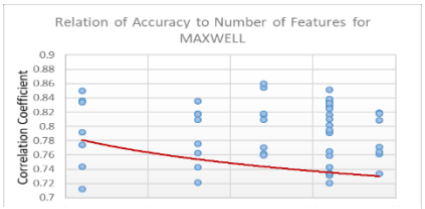

Figure 7.Relation of Accuracy To Number of Features For Maxwell

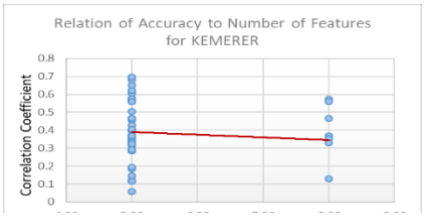

Figure 8. Relation of Accuracy To Number of Features For Kemerer

Figure 7 shows the relation of accuracy to number of features for Maxwell and Figure 8 shows the relation of accuracy to number of features for Kemerer.

Table 7. Comparative Analysis of Gained Results with Literature

Dataset	Author(s)	Intelligent method	MMRE	PRED	Correlation Coefficient	MAE	RAE
China	(Rehal & Sharma, 2021)	SMOReg			0.9897	270.4561	7.3095
	(Kumar, Behera, Kumari, Nayak & Nail, 2020)	Spiking Neural Network	0.23				
		fuzzy c-means clustering-Functional Link Artificial Neural Networks	0.45				
		intuitionistic fuzzy c-means clustering-Functional Link Artificial Neural Networks	0.33				
		Long short-term memory	0.41				
		Output layer self-connection recurrent neural networks	0.32				
	Proposed Model	MLP & Relief Att.Eval. + Ranker	0.2655	0.0847	0.9914	370.1846	10.005
Finnish	(Benala & Bandarupalli, 2016)	AnalogyBased Estimation - Least Squares Support Vector Machin	1.7974	0.52			
		AnalogyBased Estimation - Extreme Learning Machines	2.3929	0.15			
		AnalogyBased Estimation - Artificial Neural Networks	2.124	0.32			
	Proposed Model	Kstar & ClassifierAttEval + Ranker	0.2521	0.0104	0.9948	0.0873	8.5274
Maxwell	(Benala & Bandarupalli, 2016)	AnalogyBased Estimation - Least Squares Support Vector Machin	1.1529	0.42			
		AnalogyBased Estimation - Extreme Learning Machines	4.2891	0.16			
		AnalogyBased Estimation - Artificial Neural Networks	4.4466	0.12			
	(Kumar, Behera, Kumari, Nayak & Nail, 2020)	Artificial Neural Network	1.32				
		Functional Link Artificial Neural Networks	0.42				
		Elman neural network	1.3748				
		Long short-term memory	0.37				
		Output layer self-connection recurrent neural networks	0.31				
	Proposed Model	Kstar & CFS + GA	0.7644	0.1274	0.8596	4078.324	64.913
Kemerer	(Benala & Bandarupalli, 2016)	AnalogyBased Estimation - Least Squares Support Vector Machin	0.66412	0.4			
		AnalogyBased Estimation - Extreme Learning Machines	1.8071	0.13			
		AnalogyBased Estimation - Artificial Neural Networks	2.0333	0.08			
	Proposed Model	SMOReg & Corr. Att.Evaluation + Ranker	0.5940	0.1289	0.7171	103.4371	64.273

Table 7 shows the best results obtained and the literature studies found with Artificial Neural Network methods applied to the same datasets and Machine Learning methods without feature selection are given. It is clear that high performance can be achieved with machine learning models by applying the low-cost and sustainable model feature selection targeted in the study. In the model outputs created with the relevant datasets, it was determined that the highest performance measurements as algorithms were obtained when KStar, SMOreg, MultilayerPerceptron and LinearRegression were used. It has been noted that models created using IBk, RandomTree and Bagging algorithms tend to give low results.

As a result, it seems that Machine Learning Based Approaches can be used as a high-performance method for software cost estimation and it is an open area for improvement.

9. Conclusion

The main goal of a successful software project is to produce software that will meet the expectations of the customer with a predetermined budget at a predetermined time. The failure of many software projects is due to the fact that the estimates made at the initial planning stage were not correct. For this reason, it can be said that the most basic and first project management activity in the success of a software project is the appropriate and effective allocation of necessary resources. In other words, it is critical to determine the resources that will be needed in the realization of the relevant project by making the planning on the right basis. Cost is the crux of these resources and is highly dependent on the effort within the project. In this case, estimating the effort needed is important in determining the cost.

For the software cost estimation process, which is a very important step in software project management, traditionally and predominantly manual input and expert opinion are still used today. However, these techniques cannot handle to estimate the cost of large and complex software. Therefore, to improve the software cost estimation process has aimed in this thesis. For this purpose, a machine learning- based approach has been adopted to make the software cost estimation process faster, more consistent and repeatable accurately. By leveraging machine learning techniques, the goal is to automate and optimize the software cost estimation process, reducing the reliance on manual and subjective judgements.

During the development of a machine learning-driven approach, the Finnish, Kemerer, China, and Maxwell datasets provided were utilized for software cost estimation. Models were constructed using the algorithms outlined and the validation technique employed was 10-fold cross-validation.

The study generally showed that machine learning-based models are applicable in software development effort estimation by quickly adapting to different data types, unlike traditional methods. Additionally, it is clear that better results can be obtained by applying feature selection to the data. It has been observed that the proposed hybrid feature selection methods can achieve better results compared to studies in the literature. In addition to all these, it has been observed that there are algorithms and feature selection methods that give the best results in different data sets, and it has been observed that the Kstar, SMOReg, LineaeRefression and MulitilayerPerceptron methods, which have achieved the best results with more data, are open to testing in order to reach a general conclusion.

As a result, it seems that Machine Learning Based Approaches can be used as a high-performance method for software cost estimation, and it is an open area for improvement. In future studies, similar methods can be studied with more and different datasets in order to generalize the obtained inferences and improve performance with different parameter values.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] LIU Qin and MINTRAM Robert C. (2005), "Preliminary Data Analysis", Software Quality Journal, Volume 13,pp. 91-115.

[2] SONER Taner (2014), Parametrik Tahmin Modellerinin Yazılım Projelerine Uygulanmasına Yönelik Bir Yazı-lım Paketinin Geliştirilmesi (Master's Thesis), Ankara University Institute of Science, Ankara.

[3] RIJWANI Poonam and JAIN Sonal (2016), "Enhanced Software Effort Estimation using Multi Layered FeedForward Artificial Neural Network Technique", Procedia Computer Science, Volume 89, pp. 307-312.

[4] SAYYAD Shirabad and MENZIES Tim (2005), The PROMISE Repository of Software Engineering Databases, School of Information Technology and Engineering University of Ottawa, Canada, http://promise.site.uot-tawa.ca/SERepository, DoA. 05.03.2023.

[5] DANASINGH Asir Antony, BALAMURUGAN Suganya and EPIPHANY Jebamalar Leavline (2016), "Lite-rature Review on Feature Selection Methods for High-Dimensional Data", International Journal of Com-puter Applications, Volume 136, No 10, pp. 9-17.

[6] DOKEROGLU Tansel, SEVINC Ender, KUCUKYILMAZ Tayfun and COSAR Ahmet (2019), "A survey onnew generation metaheuristic algorithms", Computers & Industrial Engineering, Volume 137, pp. 106040, DOI: 10.1016/j.cie.2019.106040. DoA. 08.07.2023.

[7] ERGUZEL Turker, OZEKES Serhat, TAN Oguz and GULTEKIN Selahattin (2015), "Feature Selection and Classification of Electroencephalographic Signals an Artificial Neural Network and Genetic AlgorithmBased Approach", Clinical EEG and Neuroscience, Volume 46, No 4, pp. 321-326.

[8] ORESKI Stjepan and ORESKI Goran (2014),"Genetic algorithm-based heuristic for feature selection in creditrisk assessment", Expert systems with applications, Volume 41, No 4, pp. 2052-2064.

[9] WANG Yanqiu, CHEN Xiaowen, JIANG Wei, LI Li, LI Wei, YANG Lei, LIAO Mingzhi, LIAN Baofeng, LV Yingli, WANG Shiyuan, WANG Shuyuan and LI Xia (2011), "Predicting human microRNA precursorsbased on an optimized feature subset generated by GA–SVM", Genomics, Volume 98, No 2, pp. 73-78.

[10] YANG He, DU Qian and CHEN Genshe (2012), "Particle swarm optimization-based hyperspectral dimensio-nality reduction for urban land cover classification", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Volume 5, No 2, pp. 544-554.

[11] DOKEROGLU Tansel, DENIZ Ayca and KIZILOZ Hakan Ezgi (2022), "A comprehensive survey on recent metaheuristics for feature selection", Neurocomputing, Volume 494, No 14, pp. 269-296.

[12] RUIZ Roberto, RIQUELME Jose C. and AGUILAR-RUIZ Jesus S. (2006), "Incremental wrapper-based geneselection from microarray data for cancer classification", Pattern Recognition, Volume 39, No 12, pp. 2383-2392.

[13] LIU Huan and YU Lei (2005), "Toward integrating feature selection algorithms for classification and cluste-ring", IEEE Transactions on Knowledge and Data Engineering, Volume 17, No 4, pp. 491-502.

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Identification of Green Retrofitting Procurement and Permitting Processes in High-rise Office Buildings in Jakarta Based on PerMen PUPR No.21 Year 2021 and GBC Indonesia that Affects Project Time Performance

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Abstract

The concept of green buildings or green buildings is highly needed in the present era, considering the drastic decline in global climate conditions. However, its development is greatly hindered because the implementation of green building concepts is primarily focused on new constructions, while almost two-thirds of the world's buildings are already built. Therefore, the objective of this research is to enhance the Performance of Green Retrofitting Implementation Time, which is expected to accelerate the growth of existing green buildings in Indonesia by identifying the Procurement and Permitting Processes of Green Retrofitting in High-Rise Office Buildings in Jakarta based on PERMEN PU NO 21 TAHUN 2021 (Regulation of the Minister of Public Works and Housing Number 21 of 2021) and Green Building Council Indonesia (GBCI) through work breakdown structure (WBS) along with their high-risk activities and improvement strategies using a preventive approach that Influences the Performance of Green Retrofitting implementation time. This research analysis involves 15 respondents' data on risks in the procurement and permitting processes, which will be processed using a qualitative risk approach. Based on the results of literature studies, expert validation, and respondent questionnaires, a total of 83 activities in the procurement and permitting processes of green retrofitting were identified, 214 risk indicators that affect the performance of green retrofitting schedule, along with 56 prevention strategies for the high-risk situation, aiming to accelerate the growth of existing green buildings in Indonesia.

Keywords: Green Retrofitting, High Rise Office Building, WBS, Procurement, Permitting, Schedule Performance

1. Introduction

Several studies in recent years have estimated the impacts of global and regional climate change across various sectors. These changes pose challenges for all countries worldwide [1]. Based on the literature review, current climate change has reached a range of 0.5-0.8°C over the past century [2]. Scientists are striving to keep the global average temperature increase below 2°C from pre-industrial levels and aiming to limit the temperature rise to 1.5°C above pre-industrial levels. This is expected to significantly reduce the risks and impacts of climate change [3].

Countries worldwide are making efforts to address the impacts of climate change, including through agreements such as the Paris Climate Agreement. One key point in this agreement is the achievement of net zero emissions. The Paris Agreement was initiated during the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris on December 12, 2015. The event was attended by 195 countries, including Indonesia [4].

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Gases such as CO2, methane, nitrous oxide, CFCs, and other elements are the main contributors to climate change and the greenhouse effect. Among these gases, CO2 is the largest contributor, accounting for approximately 50% of the global greenhouse effect, with billions of tons being emitted into the Earth's atmosphere each year. Other gases, such as CFCs, CH4 (methane), O3, and NOx, contribute in smaller proportions, approximately 20%, 15%, 8%, and 7% respectively [5]. In 2018, CO2 emissions reached a record high of around 33.1 billion tons, further exacerbating global warming [6].

The construction/building industry has a significant contribution to CO2 emissions, which play a role in global warming. It is estimated that around 33% of CO2 gas emissions worldwide come from buildings [7]. According to the Global Share of Buildings and Construction Final Energy and Emissions 2019 data, carbon emissions generated by the building industry reached 38% of the total global carbon emissions. The construction sector itself contributes to emissions in several categories, with 27% coming from the operational phase of existing buildings, 6% from the construction of new buildings, and 7% from other sectors within the construction industry [8]. This indicates that the construction/building industry plays a crucial role in environmental degradation and contributes significantly to CO2 emissions.

In response to that, it is necessary to implement the concept of green building. Green building is a concept for 'sustainable buildings' and has specific requirements, including location, planning and design systems, renovation, and operation, which adhere to energy-saving principles and must have a positive impact on the environment, economy, and society [32]. Green building refers to structures and processes that are responsible for the environment and efficient resource use throughout the building's life cycle: from site selection to design, construction, operation, maintenance, renovation, and demolition. This practice extends and complements classic building design concerns about economics, utility durability, and comfort [32]. According to Regulation of the Minister of Public Works and Housing No. 21 of 2021, a green building is a building that meets the Technical Standards for Building Construction and has a significant measurable performance in energy, water, and other resource savings through the application of Green Building principles (BGH) in accordance with its function and classification at each stage of its implementation.

However, looking at the projected number of buildings already constructed by 2040, existing buildings are estimated to make up two-thirds of the buildings in that year [8]. The demolition of non-green buildings not only involves a significant waste of resources and energy but also leads to secondary pollution and ecological damage. On the other hand, if non-green buildings continue to be used, their negative impact on the environment will persist. Therefore, retrofitting existing buildings with green solutions (Green Retrofitting) is a more resource-efficient and sustainable approach compared to developing new green buildings.

To achieve success and ensure proper implementation in green retrofitting activities, it is important to have adequate procurement and permitting processes. In this regard, a comprehensive reference is needed that covers all stages of the building lifecycle, including procurement and permitting stages. The development of a Work Breakdown Structure (WBS) and risk management are also crucial in this context. WBS helps identify and organize the work activities involved in the project, while risk management helps identify high-risk stages of work and offers appropriate solutions and responses to mitigate those risks.

The Work Breakdown Structure (WBS) is a crucial component in project planning. It starts with a hierarchical arrangement of tasks and levels that help identify the flow of the project within the designated and established timeline [9]. With a well-defined WBS and effective risk management, the implementation of green retrofitting activities can be carried out in a focused and efficient manner, ensuring the successful achievement of project goals.

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2. Literature Review

2.1 Concept of Green Retrofitting for High-rise Office Buildings

The definition of green retrofitting according to Regulation of the Minister number 21 of 2021 is the effort to adjust the performance of a utilized building to meet the requirements of Green Building Criteria (Bangunan Gedung Hijau- BGH) [10]. Meanwhile, according to the U.S. Green Building Council (USGBC), green retrofitting is any type of improvement to an existing building, either fully or partially occupied, aimed at enhancing energy and environmental performance, reducing water usage, and improving comfort and indoor environmental quality in terms of natural light, air quality, and noise, all done in a financially beneficial manner for the owner [11].

The aspects considered in the implementation of green retrofitting are categorized into 6 criteria: Appropriate Site Development (ASD), Energy Efficiency & Refrigerant (EER), Water Conservation (WAC), Material Resources & Cycle (MRC), Indoor Air Health & Comfort (IHC), and Building & Environment Management, as outlined by the Green Building Council Indonesia [12].

Regulations related to the assessment of green building performance/certifications currently include assessments conducted by the government through Regulation of the Minister of Public Works and Housing No. 21 of 2021, and non-government assessments by GBCI through Greenship, as well as EDGE, developed by the International Finance Corporation (IFC).

GREENSHIP Existing Building (EB) is a building certification system designed for buildings that have been constructed and operational for at least one year. The implementation of green building practices in GREENSHIP Existing Building focuses on operational and building maintenance management [12]. GREENSHIP itself is a rating system product issued by the Green Building Council Indonesia, taking into consideration the local conditions, natural characteristics, and regulations and standards applicable in Indonesia. The certifications provided include New Building (NB), Existing Building (EB), Interior Space (IS), Homes, Neighborhood (NH), and Net Zero Healthy (NZH).

Regulation of the Minister of Public Works and Housing (Peraturan Menteri PUPR) No. 21 of 2021 is a regulation concerning the Assessment of Green Building Performance issued by the government and enacted on March 31, 2021. The green building performance assessed in this regulation is divided into two categories: new buildings and existing buildings (retrofitting). For existing buildings, the stages are divided into two phases: utilization and disposal phases [10].

2.2 Procurement Process for Green Retrofitting in Indonesia

According to Presidential Regulation, Number 12 of 2021 concerning Government Procurement of Goods/Services, procurement of goods/services through Providers is a way to obtain goods/services provided by Business Entities. Business Entities refer to companies or individuals engaged in specific fields of business or activities. The Government Goods/Services Providers, hereinafter referred to as Providers, are Business Entities that provide goods/services based on contracts [13].

The only government institution responsible for developing and formulating policies for government procurement of goods/services is the Government Goods/Services Procurement Policy Institution

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(LKPP), while the implementation of government goods and services is carried out by the Electronic Procurement Services (LPSE) [13].

E-procurement is an auction system for government procurement of goods/services that utilizes internet-based technology, information, and communication to ensure effectiveness, efficiency, transparency, and accountability [14]. According to Andrianto [15], e-procurement is defined as the digitalization process of government procurement tender/auction assisted by the Internet. The features of e-procurement include E-auction, E-Tender, and E-catalogue. E-auction is an online auction system between goods/services providers and users. E-Tender is the procedure for selecting goods/services providers, open to all registered providers in LPSE. E-catalog is an electronic list developed by LKPP.

The procurement process for green retrofitting activities only applies during the retrofitting phase for private buildings, and the planning is carried out by the building management. On the other hand, for government building renovation procurement, it applies to both the planning and implementation phases.

2.3 Permitting Process for Green Retrofitting in Indonesia

Permitting is a process where the government unilaterally grants approval to individuals or communities to legally perform certain acts or activities. In essence, this process serves as a regulatory instrument by the state to control the conduct of its citizens in activities that should not violate the law or harm others [16]. Based on Ministerial Regulation Number 21 of 2021, the licensing process applicable to green retrofitting activities involves PBG (Building Use Approval) and SLF (Certificate of Functionality) during the utilization phase of green retrofitting work. Meanwhile, for the disposal phase, the required permit is RTB (Technical Demolition Plan). According to GREENSHIP Existing Building (EB) by GBCI, the necessary permits for green retrofitting are PBG, SLF, and UKL/UPL documents issued by BAPPEDAL (Environmental Impact Control Agency) [12].

Building Use Approval (PBG) is a permit granted to the owner of a building to construct, modify, expand, reduce, and/or maintain the building in accordance with the technical standards for building construction [17]. The related regulations are governed by Government Regulation Number 16 of 2021. PBG is a reporting permit that can be processed during the construction process [18].

Certificate of Functionality (SLF) is proof that a building has been tested for its safety and functionality. By possessing an SLF, a building is officially recognized and is expected to provide a sense of safety and comfort to its occupants. The regulations related to SLF are governed by the Minister of Public Works and Housing Regulation Number 19/PRT/M/2018 on the Implementation of Building Construction Permits (IMB) and Certificate of Functionality, and Minister of Public Works and Housing Regulation Number 27/PRT/M/2018 on the Certificate of Functionality for Buildings [19].

Environmental Impact Analysis (AMDAL), Environmental Management Efforts, and Environmental Monitoring Efforts (UKL-UPL) are Environmental Documents that must be prepared by businesses whose activities have a significant impact on the environment. These documents will outline the process of developing business infrastructure (such as buildings, factory installations, etc.), soil conditions or geological aspects, types of potential environmental impacts (including liquid waste, solid waste, gas, and noise), as well as how the business entity intends to manage and monitor its activities to minimize potential environmental damage risks [20]. The regulations concerning UKL-UPL documents are outlined in the Minister of Environment Regulation Number 16 of 2012 on Guidelines for the Preparation of Environmental Documents [20]

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The Technical Demolition Plan, abbreviated as RTB, is a planning document issued by the owner of a building to the government as a declaration that the said building will be demolished, and there is a plan for the demolition of the building [18]. The plan for the demolition of the building must comply with technical standards as stipulated by laws and regulations. To determine whether the demolition plan meets these technical standards or not, a consultation process involving experts with the relevant expertise and skills related to building construction is necessary.

2.4 Work Breakdown Structure of Procurement and Permitting for Green Retrofitting

Work Breakdown Structure (WBS) is an extremely effective tool used in project management. It serves as the foundation for effective project planning, execution, control, status tracking, and reporting. All the work contained within the WBS must be identified, estimated, scheduled, and budgeted. The WBS is a structure and code that integrates and links all project work along with the required resources (scope, schedule, and cost) [21].

A project WBS involves grouping project work elements oriented towards products that organize and define the total project scope. It is a multi-level framework that graphically represents elements indicating the work that needs to be accomplished in logical relationships. Each lower level represents a more detailed definition/division of project components. It is a structure and code that integrates and links all project work and is used throughout the project life cycle to identify, establish, and track specific work scope. The WBS is created with enough detail so that each control account has a unique WBS element [21].

According to the PMBOK 6th Edition, the main benefit of creating a Work Breakdown Structure (WBS) is to provide a framework for what needs to be delivered in the project. The process of creating a WBS is only done once or at designated points in the project. Additionally, the WBS represents a hierarchical decomposition of the total work scope to be performed by the project team to achieve project objectives and deliver the required outcomes. The WBS organizes and defines the total project scope and represents the work specified in the currently approved project scope statement [23].

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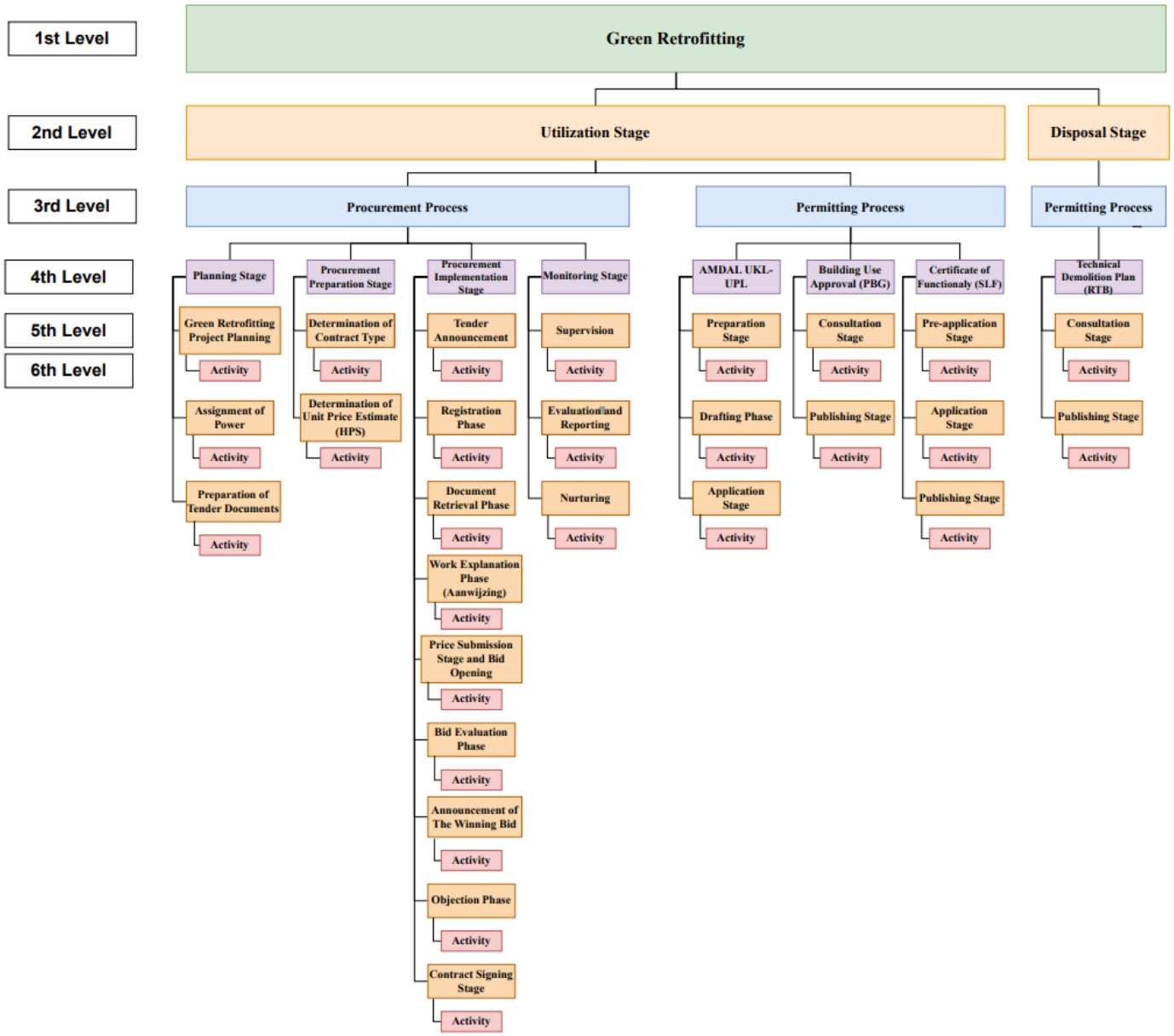

Figure 1: Work Breakdown Structure of Procurement and Permitting for Green Retrofitting

Source: Self Administered

In this research, the Work Breakdown Structure (WBS) for the Procurement and Permitting Process of Green Retrofitting Activity aims to define activities within a project related to the procurement process and permitting process at the utilization and demolition stages. The development of the WBS structure for the Procurement and Permitting Process of Green Retrofitting Activity is based on the requirements of GREENSHIP Existing Building (EB) and on Peraturan Menteri PUPR No. 21 Year 2021 (Regulation of the Minister of Public Works and Housing Number 21 of 2021). The following details the levels in the WBS for the Procurement and Permitting Process of Green Retrofitting Activity:
Level 1: Green Retrofitting
Level 2: Work Phases
Level 3: Work Phase Processes
Level 4: Process Methods
Level 5: Process Support
Level 6: Work Activities

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2.5 Risk Assessment

According to the PMBOK 6th Edition, a risk event is something that has been identified beforehand that may or may not occur. If it happens, it can have either a positive or negative impact on the project. Uncertainty is the lack of knowledge about an event that reduces confidence in the conclusions drawn from data. Risk management is the process of identifying, evaluating, and planning responses to events, both positive and negative, that may occur during the project [22].

Risk management is an approach taken toward the risks of a project, which, involves understanding, identifying, and evaluating the project's risks. Subsequently, it considers what actions to take in response to the potential impacts and the possibility of transferring or reducing the risks. Risk management encompasses a series of activities related to risk, including planning, assessment, handling, and monitoring of risks [23]

The purpose of risk management is to recognize risks within a project and develop strategies to reduce or even avoid them, while also seeking ways to maximize existing opportunities [24]. According to the PMBOK 6th Edition, risk management processes are divided into 7 processes, namely: Risk Management Planning, Risk Identification, Qualitative Risk Analysis, Quantitative Risk Analysis, Risk Response Planning, Risk Response Implementation, and Risk Monitoring. The PMBOK 6th Edition is widely used as a reference for risk management planning, especially in construction projects [22].

The risk assessment in the green retrofit project was ranked for 19 risks using the risk criticality index (RC), which is the result of the likelihood of occurrence and effect indexes (MI). Revealing that the top 5 risk rankings are as follows: "post-retrofit tenants' cooperation risk," "regulatory risk," "market risk," "financial risk," and "pre-retrofit tenants' cooperation risk." [25]. The highest risk in the rating was the "post-retrofit renters' cooperation risk," which indicated that tenants were likely to be uncooperative once the green retrofit was finished. Achieving the most effective use of energy-saving equipment and maximizing all potential benefits would not be possible without the tenants' involvement. Bon-Gang Hwang et al emphasized that the top 5 risks in LO (Likelihood of occurrence) and MI (magnitude of impact) values are "Complex procedures to obtain approvals", "Overlooked high initial cost", "Unclear requirements of owners", "Employment constraint", and "Lack of availability of green materials and equipment". The top position risk (Complex procedures to obtain approvals) was because green residential building projects always involve some particular green features, which would result in lengthier planning approval and permit procedures [26].

2.6 Project Time Performance

Time performance is the comparison of the actual project implementation period to the estimated project implementation period. Time performance can be used as a measure of slippage in a construction schedule. The project implementation begins on the agreed-upon date specified in the contract agreement and ends when all the work is completed. This ratio or comparison serves as the standard measure of project performance, allowing the estimation of project performance through statistics [27].

Time performance is crucial in construction implementation and is one of the primary factors for the success of a construction project. Both design-build and traditional systems of construction projects generally have specific implementation plans and schedules, determining when the project should start, when it should be completed, how it will be executed, and how resources will be allocated [28].

Good time performance seems to be one of the indicators of project success. Poor time performance can lead to various undesirable issues. Time performance is considered good when a project is completed according to the agreed-upon schedule by all parties [29]. In the procurement process, time performance control is crucial and requires leadership, strategy, and management systems. The time needed for procurement and permits significantly impacts the project's implementation and completion time [30]. Project owners must have accurate

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scheduling, recording of work completion status, and contractual authority to accelerate project completion (project time efficiency) [31].

3. Research Methodology

To answer the objectives of this research, the researcher used a qualitative research method. Data validation was carried out using a structured questionnaire and interviews with 5 experts who are proficient in the procurement and permitting of buildings for the green retrofitting activity. Data collection was conducted using a standardized questionnaire administered to 15 experienced respondents who have experience in implementing procurement and permitting. The following figure shows how this research was conducted in order:

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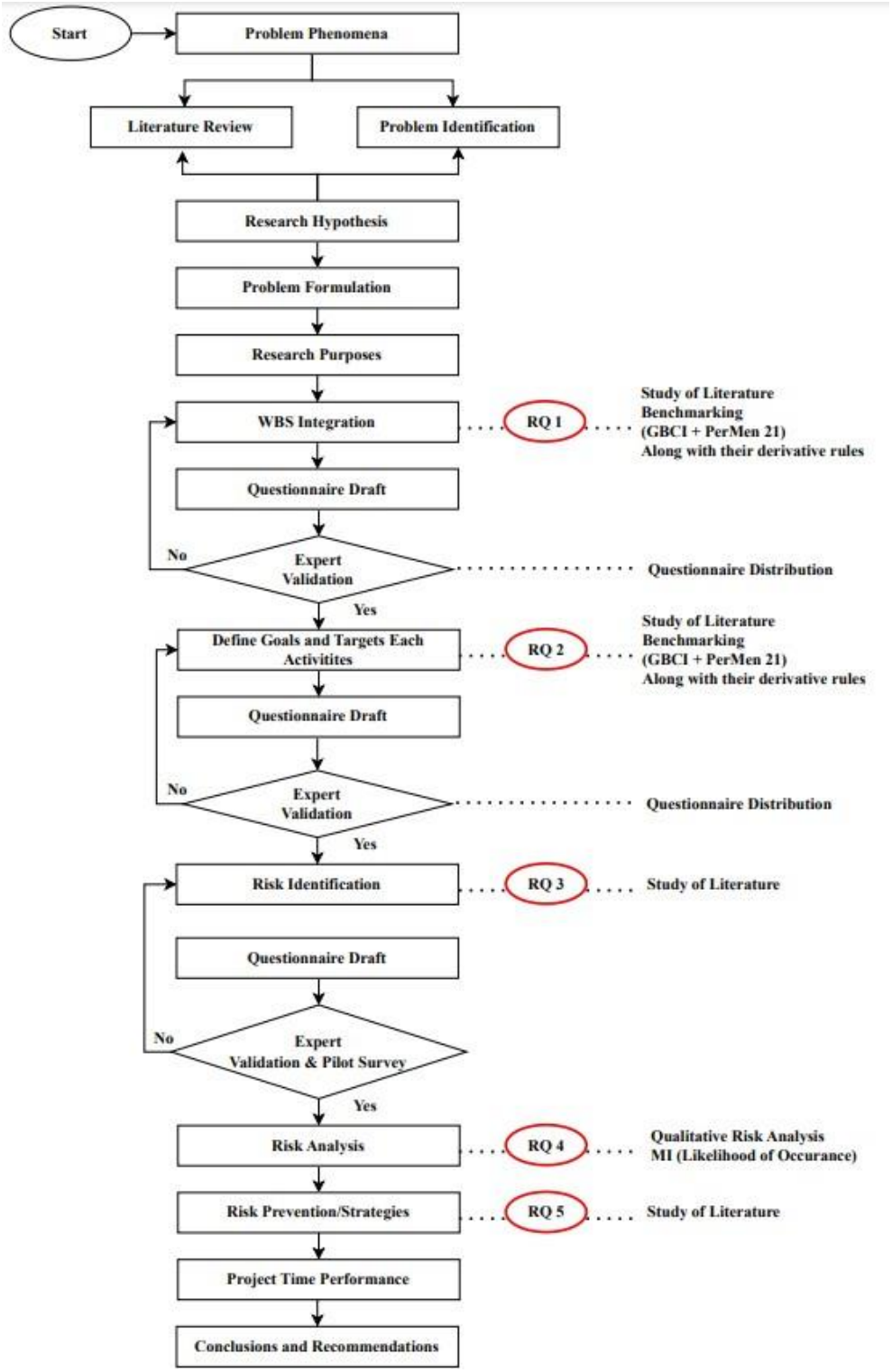

Figure 2: Research Flowchart

Source: Self-Administered

4. Conceptual Framework

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Conceptual framework this research represents the Relationships Model between Variables in the Relationship between Green Retrofitting WBS, Procurement Activity, Permitting Activity, Risk, and Risk Strategies, and Project Time Efficiency of High-rise Office Buildings with The Accuracy Level based can show likes:

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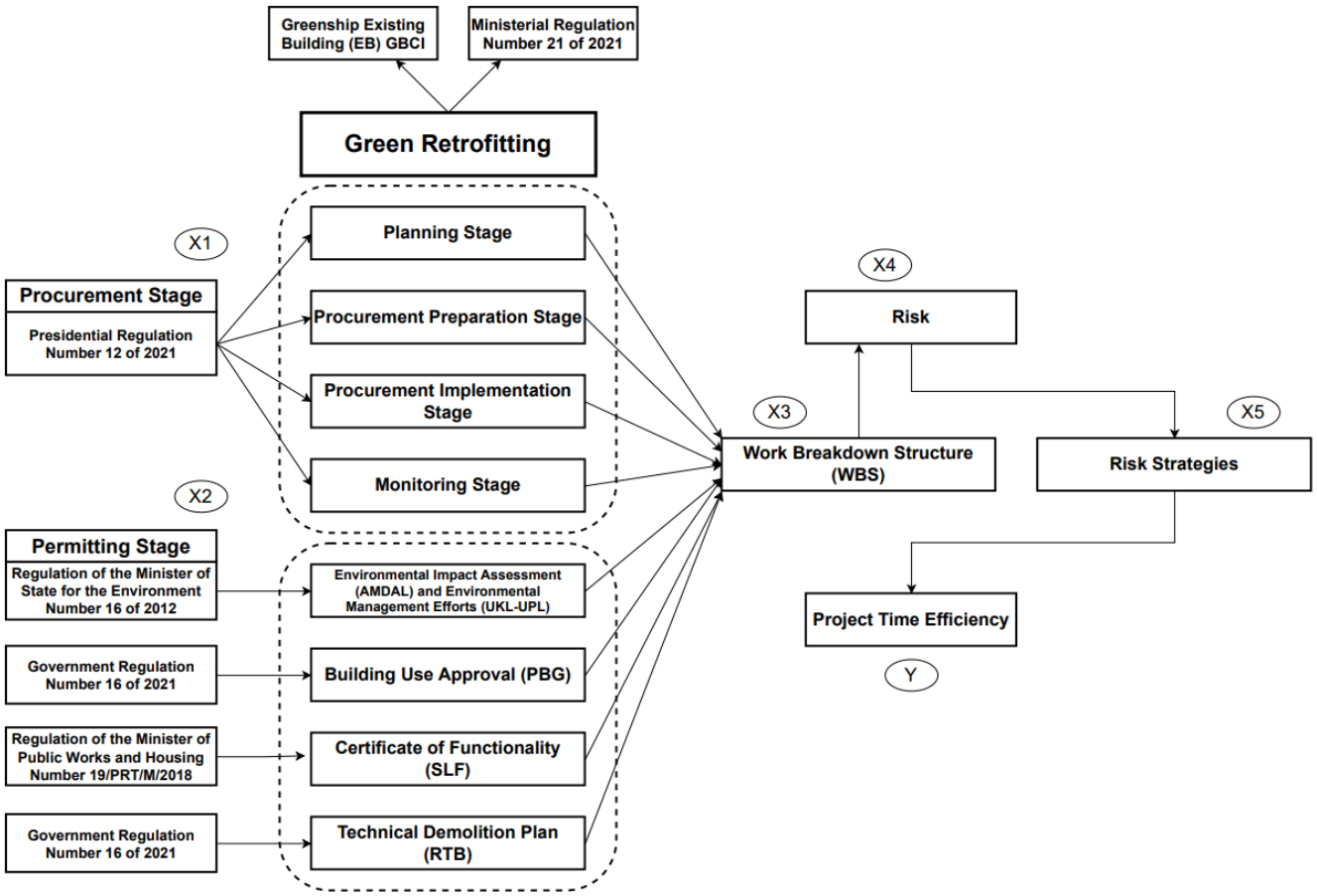

Figure 3: Conceptual Framework of the relationship between green retrofitting and project time

Source: Self-Administered

When doing categorical analysis, factor variables must be transformed into a collection of indicator variables. Finding the risks that have an impact on the scheduled time performance of green retrofitting office high-rise buildings based on procurement and permitting activity is the next stage after achieving the WBS standard. Below is an explanation of the risk variables used in this study:

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Table 1: Research Indicator Variables
Source: Self-Administered

VARIABLE		INDICATOR		Reference
ZX1 X1	PROCUREMENT STAGE	X1. 1	Planning Stage	[13]
		X1. 2	Procurement Preparation Stage	[13]
		X1. 3	Procurement Implementation Stage	[13]
		X1. 4	Monitoring Stage	[13]
X2	PERMITTING STAGE	X2. 1	Environmental Impact Assessment and Environmental	[20]
		X2. 2	Building Use Approval (PBG)	[18]
		X2. 3	Certificate of Functionality (SLF)	[19]
		X2. 4	Technical Demolition Plan (RTB)	[18]
X3	WBS	X3. 1	Input	[22]
		X3. 2	Techniques and Equipment	[22]
		X3. 3	Output	[22]
X4	RISK	X4. 1	Risk Identification	[22]
		X4. 2	Risk Analysis	[22]
		X4. 3	Risk Strategies	[22]
Y	PROJECT TIME EFFICIENCY	Y	Schedule Performance	[22][31]

5. Discussion & Conclusion:

The activities in the procurement and permitting process of green retrofitting have been organized using the Work Breakdown Structure (WBS) tools based on GREENSHIP Existing Building Ver 1.1 by GBCI, which includes regulations and guidelines related to environmental permits, such as: Environmental Impact Assessment (AMDAL) Permit: Based on Regulation No. 16 of 2012 on Environmental Impact Assessment Document Preparation for AMDAL UKL-UPL. Building Permit (PBG) Requirements: Based on PP No. 16 of 2021 for building permit requirements. Technical Demolition Plan (RTB): Based on the Technical Regulation of the Minister of Public Works and Housing No. 21 of 2021. Certificate of Occupancy Permit: Reference is made to Regulation of the Minister of Public Works and Housing No. 19/PRT/M/2018 regarding the Implementation of Building Permit (IMB) and Certificate of Occupancy for the execution of green retrofitting activities. Regarding procurement, it is based on Regulation of the Ministry of Public Works No. 21 of 2021, which pertains to the implementation of procurement for green retrofitting activities. There are a total of 27 work packages in the procurement phase, with 17 of them related to procurement activities and the remaining 10 being associated with the permitting phase.

From the 27 work packages related to procurement and permitting activities for green retrofitting, it has been determined that there are a total of 83 activities. These activities are based on GREENSHIP Existing Building Ver 1.1 by GBCI for permitting in the implementation of green retrofitting activities and Regulation of the Ministry of Public Works No. 21 of 2021 for procurement. Each of these activities can be used to identify their objectives and targets, which are useful for identifying potential risks or risk factors that may occur due to the non-fulfillment of activity goals. This risk identification is crucial for the successful execution of green retrofitting projects, as it allows for proactive risk management and mitigation strategies.

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From the 27 work packages related to procurement and permitting, based on the findings from the previous sections and in alignment with the research objectives, a total of 214 risks/factors have been identified in the procurement and permitting phases of green retrofitting activities. Out of these, 84 are associated with the procurement phase, and the remaining 130 risks/factors are related to the permitting phase of green retrofitting activities, mitting activities for green retrofitting, it has been determined that there are a total of 83 activities. These activities are based on GREENSHIP Existing Building Ver 1.1 by GBCI for permitting in the implementation of green retrofitting activities and Regulation of the Ministry of Public Works No. 21 of 2021 for procurement. Each of these activities can be used to identify their objectives and targets, which are useful for identifying potential risks or risk factors that may occur due to the non-fulfillment of activity goals. This risk identification is crucial for the successful execution of green retrofitting projects, as it allows for proactive risk management and mitigation strategies.

Based on the risks/risk factors identified in the stages of procurement and permitting for green retrofitting activities, it was found that out of the total risks, 56 were categorized as high risks, 72 were categorized as medium risks, and 86 were categorized as low risks. The total of 83 activities in the procurement and permitting processes of green retrofitting were identified, 158 risk and 56 high-risk indicators that affect the performance of green retrofitting schedule from each of the procurement and permitting activities, along with 56 prevention strategies for the high-risk situation.

The results of research by developing WBS on the procurement and permitting stage of Retrofitting are guided by GBC Indonesia and PUPR Ministerial Regulation Number 21 of 2021 (Regulation of the Minister of Public Works and Housing Number 21 of 2021) along with their derivative regulations and developing the risk strategies for the high-risk activity expected to significantly increase the project time efficiency of green retrofitting in Indonesia.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Arnell, N. W., Lowe, J. A., Challinor, A. J., & Osborn, T. J. (2019). Global and regional impacts of climate change at different levels of global temperature increase. *Climatic Change*, *155*(3), 377–391. https://doi.org/10.1007/s10584-019-02464-z

[2] Lubis, R. F., Delinom, R., & Geoteknologi, P. (n.d.). *PERUBAHAN IKLIM DAN PEMANASAN GLOBAL DI INDONESIA; DAMPAKNYA TERHADAP KONDISI BAWAH PERMUKAAN STUDI KASUS : DKI JAKARTA*.

[3] Skytt, T., Nielsen, S. N., & Jonsson, B. G. (2020). Global warming potential and absolute global temperature change potential from carbon dioxide and methane fluxes as indicators of regional sustainability – A case study of Jämtland, Sweden. *Ecological Indicators*, *110*. https://doi.org/10.1016/j.ecolind.2019.105831

[4] BPHN. (n.d.). na_ruu_ratifikasi_paris_agreement (2). *Na_ruu_ratifikasi_paris_agreement*. Retrieved July 23, 2023, from https://bphn.go.id/data/documents/na_ruu_ratifikasi_paris_agreement.pdf

[5] Eko, W., Peneliti Bidang, C., Ozon, P., & Udara, P. (n.d.). *PENGARUH PEMANASAN GLOBAL TERHADAP LINGKUNGAN BUMI*.

[6] Izumi, F. (2020). Climate Emergency Declaration. *Climate Emergency Declaration*.

[7] UGM (n.d) The building industry contributes to the process of environmental degradation

[8] Architecture 2030. (n.d.). Actions For Zero Carbon Buildings Existing Buildings.

[9] Devi, Tr., & Reddy, Vs. (n.d.). Work Breakdown Structure of the Project. In *International Journal of Engineering Research and Applications (IJERA)* (Vol. 2). www.ijera.com

ANKARA SCIENCE UNIVERSITY, RESEARCHER
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Research Article/Araştırma Makalesi
Doi: https://doi.org/10.55185/researcher.1405184

[10] Regulation of the Minister of State for the Environment Number 16 of 2012 concerning Performance Evaluation Green Building
[11] The U.S. Green Building Council. (n.d.). Building Retrofits.
[12] Green Building Council Indonesia. (n.d.). GREENSHIP Rating Tools Existing Building.
[13] Presidential Regulation Number 12 of 2021 concerning Government Procurement of Goods/Services
[14] Sutedi, Adrian., (2012) Legal aspects of the procurement of goods and services and their various issues
[15] Andrianto, Nico., (2007) Transparency and public accountability through e-government
[16] Priyanta, M. (2019). *Regulasi Perizinan Mendirikan Bangunan dalam Mendukung Kemudahan Berusaha Menuju Bangsa yang Adil dan Makmur*. https://doi.org/10.24843/JMHU.2019.v08.i03
[17] Simbawa, Anggreini Anglia., (2022) Procedure for obtaining building construction approval
[18] Government Regulation Number 16 of 2021 concerning building
[19] Minister of Public Works and Housing Regulation Number 27/PRT/M/2018 on the Certificate of Functionality for Buildings
[20] Minister of Environment Regulation Number 16 of 2012 on Guidelines for the Preparation of Environmental Documents
[21] Burghate, M. (2018). Work Breakdown Structure: Simplifying Project Management. In *International Journal of Commerce and Management Studies (IJCAMS)* (Vol. 3, Issue 2). www.ijcams.com
[22] A Guide to the Project Management Body of Knowledge (PMBOK 6 ® Guide)
[23] Kerzner, Project Management: A Systems Approach to Planning, Scheduling, and Controlling, 2017; Kerzner,
[24] Strategic Planning for Project Management Using a Project Management Maturity Model, 2001 24. Wideman, Risk Management. A guide to managing risk opportunities, 1992
[25] Zhao, X., Hwang, B.G., and See, Y.L. (2015). Green Retrofit Projects: Risk Assessment and Mitigation. E (Eds) Procs 31st Annual ARCOM Conference, 7-9 September 2015, Lincoln, UK, Association of Researchers in Construction Management, 125-134.
[26] Hwang, B. G., Shan, M., Phua, H., & Chi, S. (2017). An exploratory analysis of risks in green residential building construction projects: The case of Singapore. *Sustainability (Switzerland)*, *9*(7). https://doi.org/10.3390/su9071116
[27] Bacon, R. W., & Besant-Jones, J. E. (1998). Estimating construction costs and schedules Experience with power generation projects in developing countries. In *Energy Policy* (Vol. 26, Issue 4).
[28] (Kerzner, Project Management: A Systems Approach to Planning, Scheduling, and Controlling, 2017)
[29] Yean, F., Ling, Y., Swee, ;, Chan, L., Chong, ; Edwin, & Ee, L. P. (n.d.). *Predicting Performance of Design-Build and Design-Bid-Build Projects*. https://doi.org/10.1061/ASCE0733-93642004130:175
[30] Lusi indah, Wijayanti., Development of quality management system procurement consultant services to improve procurement performance in Ministry of Transportation (2017)
[31] Huston, Charles L. Management of Project Procurement. (1996)
[32] Sudarwani, M. M. (2021). The implementation of green architecture and green building is an effort to achieve sustainable architecture.

ANKARA SCIENCE UNIVERSITY, RESEARCHER
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Optimization of Controller Parameter Multilevel Converter Based STATCOM for Reactive Power Compensation

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Abstract

Static Synchronous Compensator (STATCOM) is a self-tuning proportional-integral (PI) controller that has been developed to handle the voltage and reactive power of Cascaded H-Bridges (CHB-STATCOM) in order to improve the power system. The purpose of optimizing controller parameters for a Multilevel Converter-based STATCOM (Static Synchronous Compensator) in the context of reactive power compensation is to enhance the performance and efficiency of the STATCOM system in regulating the power factor and voltage of an electrical system. This controller was introduced in this article. This research presented that the STATCOM should have the capability to operate both in inductive and capacitive mode of operation and absorb or injects the desired amount of reactive power into the grid. The reactionary power that is received or supplied contributes to the improvement of the power system. The benefits of the self-tuning PI controller have been optimized to their full potential through the use of Accelerated Particle Swarm Optimization (APSO) strategies. The STATCOM is implemented into the electrical system, and its reaction to varying reactive and voltage levels is analyzed as part of the process of determining whether or not the optimization techniques are successful. Two controllers are now in operation at the STATCOM. The first controller is in charge of managing the DC voltage, and the second controller is in charge of controlling the reactive power. Both controllers are in use at the same time. The output of the controller is then transferred to the phase change carrier, which is followed by pulse width modulation in a sinusoidal pattern. Because of this, the power converter switch may now function properly.

Keywords: APSO, Reactive power compensation, STATCOM, PI control, Phase shift pulse width modulation, APSO

1. Introduction

Brought on by non-linear loads have a deleterious effect on both power quality and grid dependability over time. Because total system power is determined by adding together the system's active and reactive powers, an increase in reactive power is inextricably related to a similar increase in total power. In [1, 2], several strategies for increasing the grid's response power are described. Because of how successfully they control the overall system's reactive power, shunt Flexible AC Transmission System (FACTS) devices are widely used. A coordinated power source consisting completely of solid-state components is used to power STATCOM and other FACTS systems. Connected in series with the power supply, it is an excellent replacement for the cumbersome reactive components of conventional static VAR compensators (SVC). It also beats SVC in terms of the dependability of the nation's electrical grid. [3]. STATCOM's primary role is to control voltage at the point of common coupling (PCC) during a power system changeover. The STATCOM obtains these reactive currents from the power infrastructure in a controlled fashion. Intricate design challenges for these layered STATCOM [4] stem from the need for a large number of instruments to track DC voltage and uneven voltage across the DC-link capacitor [5] A conventional two-loop management system was proposed. The PCC voltage is controlled by the outer

loop, and the inverter current is controlled by the interior loop with a steady-state inaccuracy of zero. Capacitor banks were among the first components of electrical apparatus to be installed in an effort to regulate power supply. However, with the help of modern technology, system managers have access to more flexible and effective tools that can manage huge quantities of power. Flexible AC transmission systems are a specific type of these tools. (FACTS). These devices are carefully installed on selected electric buses, and they are used to quickly alter various system settings in order to boost system efficiency, control power flow, and enhance system reliability [6]. They are large-scale regulators that modify system-wide parameters like reactive power, voltage, and phase angle. [1].

Numerous researches have determined PI benefits through trial and error to reach an optimal working point, power system under STATCOM control exhibits significantly non-linear behavior. Linear controllers are simple to implement but difficult to fine-tune in this architecture. Transient performance requirements must be addressed by fine tweaking of controller settings. In this research, we use the non-linear and non-gradient Simplex algorithm to optimize the control system parameters of a STATCOM built from two converters based on six-pulse voltage sources. The performance index serves as the basis for the objective function of the system, which is written in terms of the actual and ideal values of the system's variables. Several simulation tests examining step-response performance have validated the optimized performance of the STATCOM control system, which consists of two PI controllers and two compensators. With the right settings in place, the system responds quickly and precisely [2–7]. This is not a good option in practice due to the radical changes in system features brought about by the inclusion of STATCOM devices or the improvement of the transmission architecture. [8].

In the realm of heuristics for parameter optimization, accelerated particle swarm optimization (APSO) [9] is a well-known method. It has been used to modify controller gains [10-11]. It is possible for the gains of an APSO-based PI scheduler to auto-tune in response to variations in the system and demand. This will result in a significantly more adaptable PI system. The consensus time of APSO is low (A Moreover, it outperforms SVC in terms of power system reliability [3]) because it does not necessitate offline training like an artificial neural network. During a transition in the electricity system, STATCOM's main function is to regulate the voltage at the point of common coupling (PCC). The most important development challenges for these layered STATCOM [7] involve extracting controlled reactive currents from the electrical infrastructure. are the many instruments used to track DC voltage and imbalanced voltage at the DC link capacitor. It also ignores the reasoning principles of the approximate control, which points to PSO's superior performance [12] -[25].

Optimizing the controller parameters for a Multilevel Converter-Based Static Synchronous Compensator for reactive power compensation can be a challenging task, and there are several potential problems and issues that may arise during the optimization process, Multilevel converters are inherently complex due to the multiple voltage levels they can generate. Optimizing the controller parameters for such converters requires a deep understanding of their operation and the interaction between different voltage levels. There may be trade-offs between different control objectives, such as voltage regulation, harmonic mitigation, and response time. Finding the right balance among these objectives can be challenging. Power systems are subject to variability due to changes in load, generation, and network conditions. The optimized parameters that work well under one set of conditions may not perform optimally under different conditions. The accuracy of the system model used for optimization is crucial. Inaccurate models can lead to suboptimal parameter values or instability in the real system. Over-optimization, where parameters are tuned too precisely for specific operating conditions, can lead to instability or poor performance when conditions deviate from the optimized scenario. Changes to controller parameters can impact the safety and reliability of the power system. Safety measures and risk assessments must be considered during the optimization process.

A Multilevel Converter-Based STATCOM presents various technical and practical challenges. It requires a combination of expertise in control theory, power systems, and optimization techniques, along with careful consideration of system complexity and constraints. Successful optimization should aim to strike a balance between different control objectives while accounting for the dynamic and variable nature of power systems.

In this investigation, we use Accelerated Particle Swarm Optimization to design a self-tuning PI controller for CHB-STATCOM [13]. (APSO). By tweaking the original PSO algorithm, we get accelerated PSO. The primary goal of this research is to develop a robust CHB-STATCOM scheduler that can effectively account for disturbances within a few cycle time windows of their occurrence.

2. STATCOM

To sum up, STATCOM is an apparatus that counteracts the reactive power of an electrical grid. It may behave as both a generator and a sink of reactive energy. To complement the tiny synchronous condenser compensator (STATCOM) that controls the PCC's power factor (PF), the proposed inverter does double duty by transforming DC power from the DC link into AC power for the mains supply and syphoning off enough reactive power from the grid to increase the PCC's PF [14]. The major power line and the primary power line servicing the PCC are both illustrated in Figure1 as part of the basic STATCOM arrangement. Transformer, capacitor, coupling reactor, and regulated power supply make up the voltage source converter (VSC) in the centre of a STATCOM.

In addition to its more common name, "voltage source converter," or "VSC," can also refer to a device that converts direct current (DC) to alternating current (AC). It can produce asymmetrical AC power with user-defined phase and angle of rotation. A VSC can be charged while the DC battery stores energy. By using coupling reactance to link the sources to the system and regulate the current, the converter output can be joined to the power system. The coupling transformer regulates the input voltage of the STATCOM converter and the output voltage of the PCC.

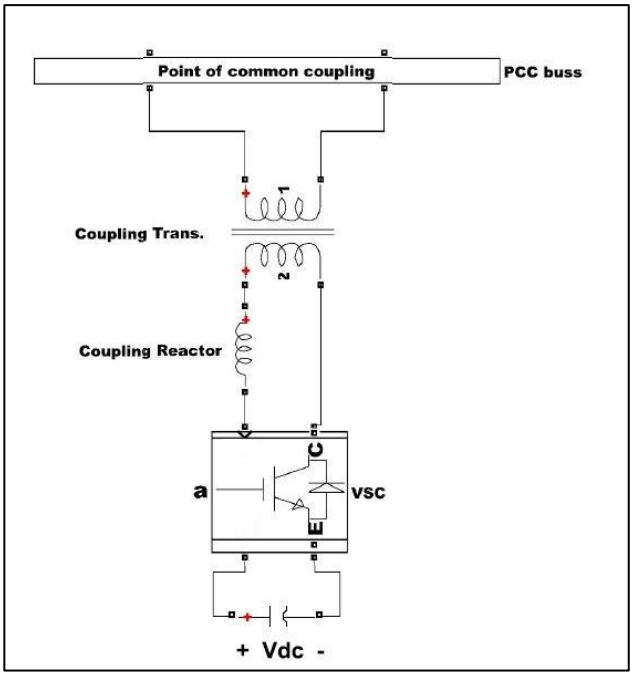

Figure 1: The grid connection of STATCOM

System software A STATCOM can be used either in VAR mode or with voltage control turned on. The STATCOM aids the PCC in keeping the voltage stable during dynamic disruptions, allowing the PCC to provide superior transient properties. By switching into this state, a STATCOM will either:

- When the system voltage is high, the STATCOM will absorb reactive power.
- When the system voltage is low, the STATCOM will generate and inject reactive power.

The STATCOM reactive power production is either held steady or adjusted based on VAR mode monitoring of the reactive power and comparison to a standard number.

Multi-level simulation of a single-phase cascaded H-bridge converter. Multilayer cascaded H-bridge inverters have a basic layout shown in Figure2. This N-level converter offers the possibility of 2N+1 different values for the phase voltage at the output. Because of the power requirements of each H-bridge, the previously noted voltage discrepancy problem may be avoided. However, to prevent voltage fluctuations of the DC-bus capacitor, it is necessary to adjust the active power provided to each bridge. [4]. There are a number of methods outlined in [5] for dampening DC-link voltage variations.

Many applications also take reactive power into account, which is where the cascaded H-bridge architecture shines. Since high-power electrical switches have their limits, we have to settle with a low-frequency modulation strategy. [6]- [8]. When compared to a regular power supply, a multilayer converter offers several advantages. Since the output pattern has fewer spurious harmonics, cheaper, smaller output filters may be employed. Since there are more voltage steps between the highest and lowest values in the staircase pattern, the voltage burden on semiconductor components is lessened. Switching losses may be minimized in multi-level inverters due to their lower switching frequency [1]. Multiple converters often use SPWM as the primary management technique. By contrasting a triangle waveform with a sine wave, PSPWM generates control signals for converter switches.

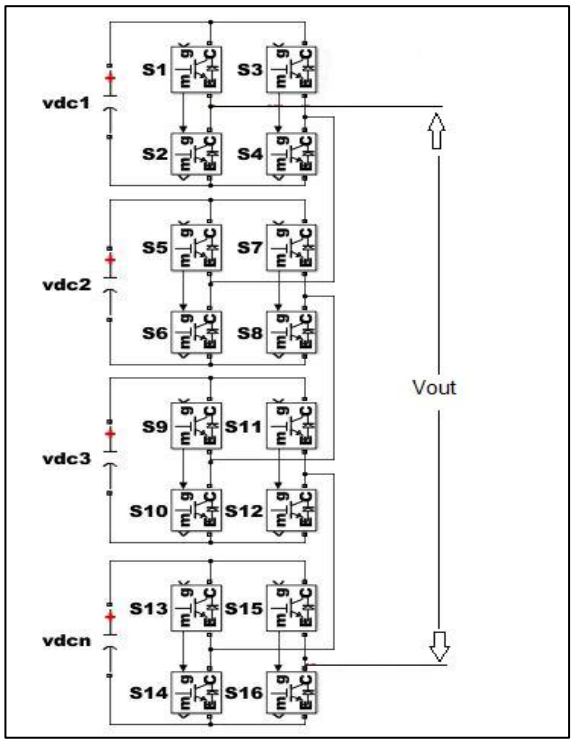

Figure 2: Model of power-stage CHB multilevel converter

3. Overview Of Accelerated Particle Swarm Optimization (APSO)

The optimization method known as particle swarm optimization [14–18] is inspired by natural swarms like those of fish and birds. The PSO algorithm gets the best answer by first producing a random sample of candidates, or particles, and then offering incentives to the candidates still in the running, or particles. Particles may be created via either collaborative or adversarial interactions. The equation allows for a point in D-dimensional space to represent any given particle I. $Xi = (xi1, xi2, \ldots, xiD)$.

The optimal answers in the full collection fall into two distinct categories: $Pbest$, or cognitive learning, is the particle's best response across rounds and is defined as $Pbest = (pi1, pi2, \ldots, piD)$, while Gbest, or the swarm's best solution, is defined as the solution with the highest fitness. (Called social learning). Every repetition k brings the particle located at x(k) one step closer to the $Pbest$ and $Gbest$, and this motion is indicated by its velocity (written v(k)). The speed is determined by combining the knowledge of both individual particles and the collective swarm, and can be written in D-dimensional space as $Vi =$

. $(vi1, vi2, \ldots, viD)$. Each particle then uses the following calculation to make an approximation of its motion for the next cycle:

$$v_i(k+1) = w_{i.}v_i(k) + c_1.rand.\left(P_{best} - x_i(k)\right) + c_2.rand.\left(G_{best} - x_i(k)\right) \quad (1)$$

With the help of the gravitational constant (w), the cognitive constant (c1), and the societal constant (c2), the rand () algorithm generates a random integer between 0 and 1. The rate of convergence is affected by all these factors. Clerc's optimal numbers were c1=1.494, c2=1.494, and w=0.729 [22-25]. PSO's cost function must be adjusted to reflect the intended system behavior under these conditions. The PSO keeps running its procedures for the given amount of time to find the best answer. The next iteration's particle position is calculated using the following algorithm. 'k+1':

$$X_i(k+1) = v_i(k+1) + X_i(k) \quad (2)$$

After making some educated guesses, we can figure out what size community to use to initiate PSO. In spite of the fact that the optimum population is context-dependent, the PSO developers have stated that starting with a population of 20-100 particles typically yields the same outcomes [16], [26]. The Quick Optimization of Particle Swarms (APSO) While standard PSO takes into account both global and local best particle sites when determining particle motion for the next cycle, accelerated PSO only takes into account global best particle locations [17]. In PSO, utilizing local best serves to increase the size of the search area; in APSO, sampling is used to achieve the same effect. Unless the problem is very complex, this quantity causes the strategy to "accelerate" towards optimality [26]. The simplified new algorithm is as follows:

$$v_i(k+1) = w_{i.}v_i(k) + c_1.rand + c_2.rand.\left(G_{best} - x_i(k)\right) \quad (3)$$

4. Implementation Strategy

4.1 Design Objectives

The STATCOM employed in this study has two major purposes:

- To give reactive power to the system when it is operating in capacitive mode and
- To remove reactive power while it is running in inductive mode.

4.2 System Design

STATCOM used in this study consists of nine-level with four similar CHB connected in series, each with its own power supply. (DC Capacitor). Each H-bridge can produce a positive, neutral, or negative voltage at its output. When these energies are added together, a sine pulse is produced. The phase magnitude of an AC output is represented as follows [18-22]:

$$V_{ca} = V_{ca1} + V_{ca2} + V_{ca3} + \ldots\ldots + V_{caM} \quad (4)$$

M denotes the number of inverters per phase. The flexible design of a cascading multilevel inverter (CMI) makes adding more similar H-bridge inverters to the circuit a straightforward way to boost output. Energy from the connection inductance is corrected and supplied through the H-bridge to the DC capacitors attached to the other side of the bridge. Capacitance can be calculated as follows:

$$C = \frac{i_c}{f_{rp} * \Delta V_{DC}} \quad (5)$$

f_{rp} : frequency of ripples

i_c : $maximum\ rms\ \ current$

$$i_c = \frac{Q}{V_{pcc}} \tag{6}$$

Q : the maximum reactive power can be generate or absorb by STATCOM . As a reactive power coupling between the PCC and the STATCOM, the inductor's capacitance is affected by the current harmonics and the CMI. To calculate inductance, use the following formula:

$$L_{fmax} = \frac{v_{PCC}}{2*\pi*f*i_c} \tag{7}$$

F: System fundamental frequency
v_{pcc} : Voltage at PCC

The above solution gives the highest allowable inductance capacity. Due to its massive scale, this inductor effectively dampens current waves and overtones at the PCC Transformer. Due to the need to limit the residual of voltage power networks, the STATCOM cannot be hardwired to the grid. In order to bring the power down to a level that the equipment can manage, a converter is required. However, there may be power deficits associated with using a converter, such as increased compensatory currents on the STATCOM side. Procedure for controlling depending on the PI controller.

The proposed control approach involves the use of PI controllers, one to determine the phase angle from the DC voltage and another to determine the modulation index from the difference between the targeted and measured reactive power. The modulator receives inputs such as the toggling components' on/off states, the current, and the voltages across the capacitors. As shown in Figure3, the control architecture's primary block layout is laid out in logical fashion.

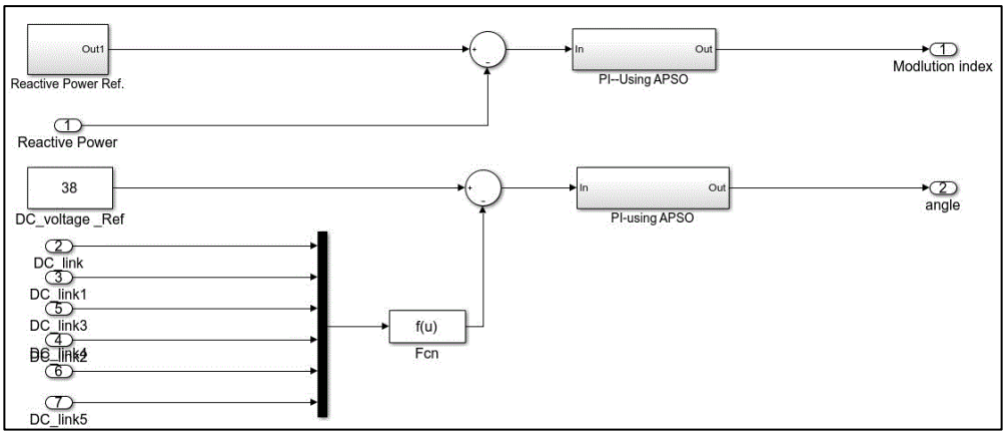

Figure 3: Schematic of proposed control strategy using PI controller

The reactive power that the STATCOM supplies to the line is given by the equation below:

$$Q_s = \frac{{E_c}^2 - E_c E_s cos\delta}{X} \tag{8}$$

Where:

x : the coupling reactance
E_s: RMS value of PCC Voltage
E_c: STATCOM output voltage

The STATCOM's can adjust the reaction strength by adjusting the frequency it operates at. The following is a broad description of the connection between the DC link voltage and the STATCOM output voltage.

$$\frac{V_{out}}{E_{DC}} = m \tag{9}$$

Therefore, the reactive power equation changes to

$$Q_s = \frac{{E_s}^2 - mE_{DC}E_L cos\delta}{X} \quad (10)$$

The solution above illustrates how the STATCOM operates. In the suggested setup, the modulation index regulates the reaction strength of the STATCOM. The primary regulator of the STATCOM. The phase locked loop (PLL) component provides not only the phase but also the phase angle (wt) of a voltage signal for verification purposes.

5. Simulation And Results

The whole form of the modeling software's depiction of the system is shown in Figure 4.

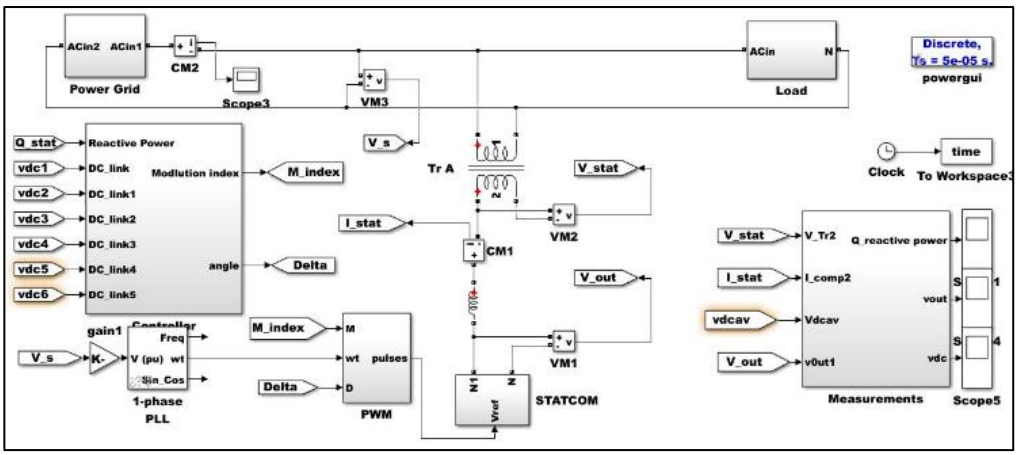

Figure 4: Simulink block diagram of complete system

To cope with a nonlinear load, the H-bridge circuit in Figure5 uses a perfect IGBT and a reactive power reference. The scenario is executed without STATCOM, with a power factor of 0.7 for all loads, and with inductive/capacitive load powers varying from 0 to 14 seconds and capacitive load powers ranging from 14 to 28 seconds. Table 1 contains the model's characteristics.

Table 1: System parameters

Type	Parameter	Value
Source	PCC Voltage (L- L)	311.12 V
	System Frequency (Hz)	50 Hz
Load	Voltage (V)	220Vrms
	Real Power (Watts)	450 W
	Reactive Power Inductive	450 VAR
	Reactive Power Capacitive	450 VAR
Dc Link volt	DC Link reference Voltage (Volts)	27 V
Coupling Transformer	Nominal Power (VA)	5000 VA 220/110 V

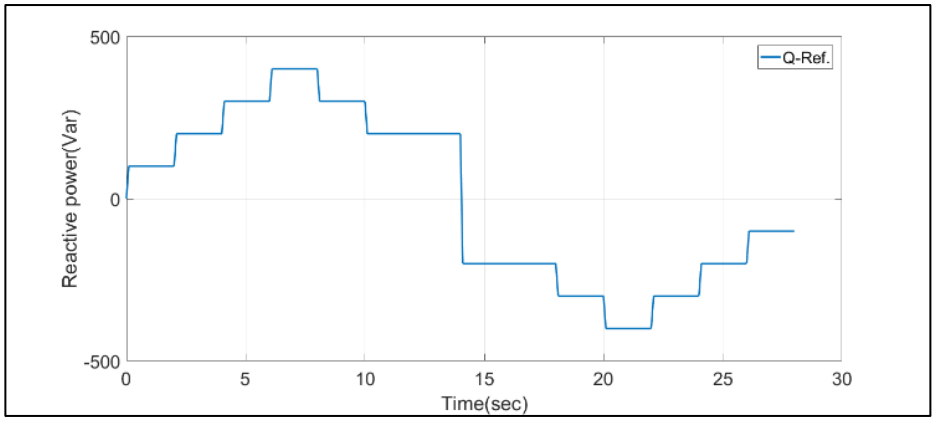

Figure 5: Reactive power reference signal for STATCOM

The PI-based APSO management method is advocated by the computer program. Figure6 displays the layered inverter's output voltage's thirteen discrete steps. The reactionary power of the STACOM is depicted in Figure7, and the APSO technology is what gives the PI control its durability and versatility.

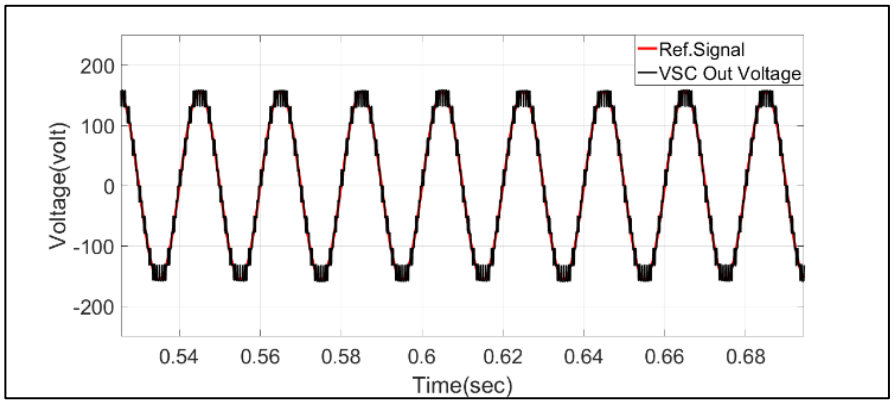

Figure 6: STATCOM-output voltage and reference signal

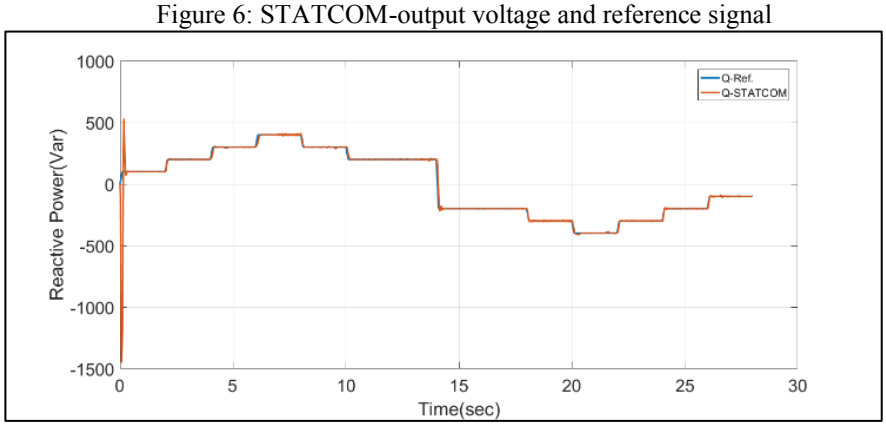

Figure 7: STATCOM- reactive power with APSO

The effectiveness of the APSO method can be further examined by plotting the cost functions for both controllers in addition to the PI controller gains k p and k I. Figure8 displays the gains achieved by the reactive power converter over the course of 50 trials. The advantage in k I increases to 6.1, then drops to the optimal number of 0.1. The k p trajectory, on the other hand, shows a negligible decrease from its initial 0.6 to its ultimate 0.01035.

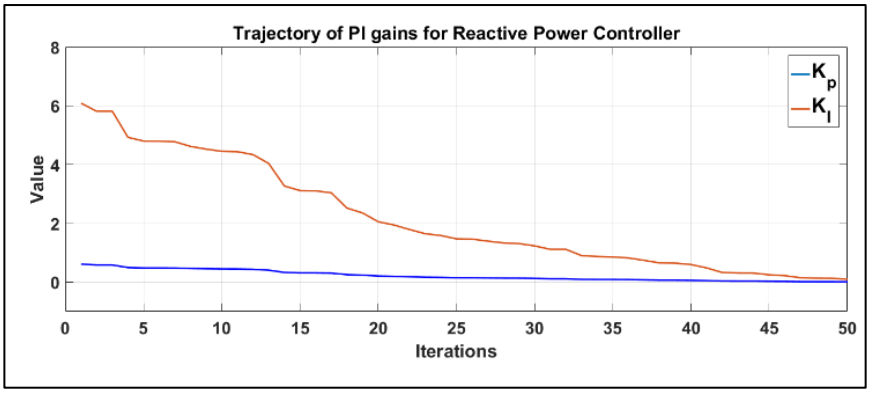

Figure 8: PI parameters for reactive power controller iterations using APSO

The Figure9 depicts the reduction in IAE (cost function) caused by a reactive power converter. After running through APSO's rounds, the cost naturally drops from a high of 1.1 to a low of 0.17, which is an acceptable margin of error.

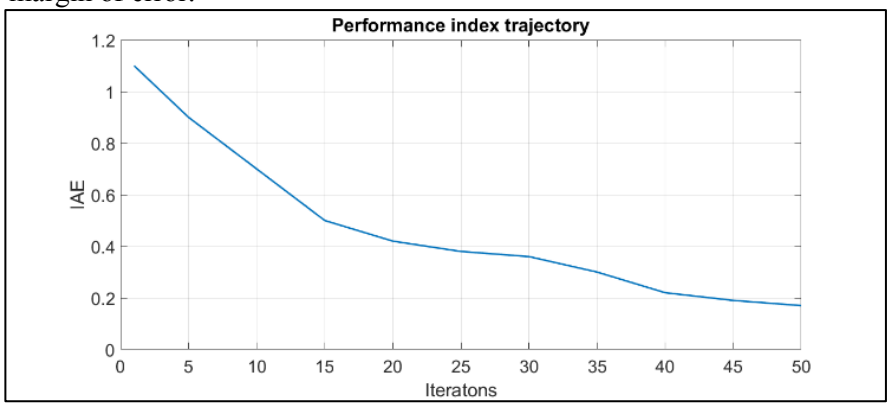

Figure 9: IAE for reactive power controller iterations using APSO

Another controller that provides comparable trajectory options is the APSO-optimized DC-Link PI controller. The Figure10 can be seen, the K_P gain number begins at 11.8 and increases gradually to 3.1. The rise has been larger in recent versions than in previous ones. In a similar vein, the K_I gain, which was originally fixed at 013.9, steadily declines to 0.355 after 50 cycles. Figure11 shows the iterative readings of the IAE. The APSO method fails after 50 rounds, with an initial error of 0.67 and a final error of 0.091.

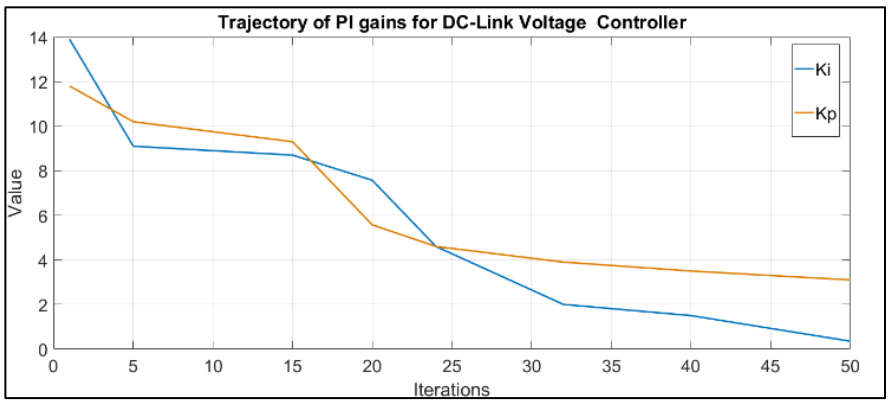

Figure 10: PI parameters for DC-Link Voltage controller with iterations using APSO

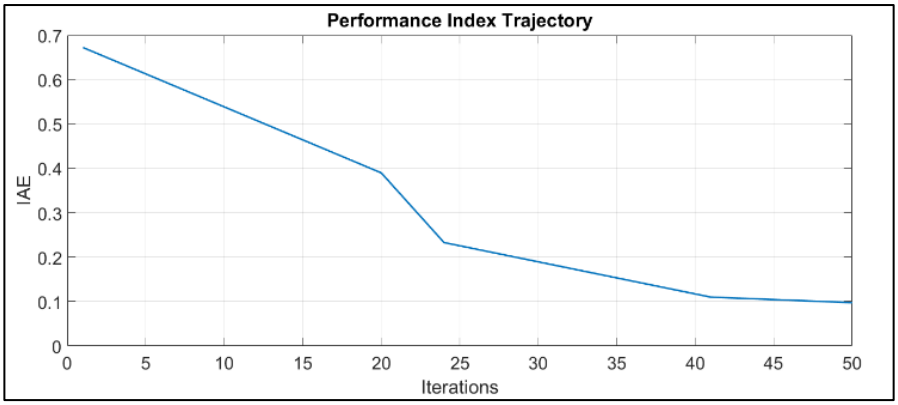

Figure 11:Trajectory of IAE for DC-Link Voltage controller with iterations using APSO

Optimizing the controller parameters of a Multilevel Converter-Based Static Synchronous Compensator for reactive power compensation can offer several advantages in power systems. STATCOMs are a type of Flexible AC Transmission System (FACTS) device used to control and stabilize the voltage and reactive power in electrical grids. Optimization of controller parameters allows for precise control of the STATCOM's output voltage. This helps in maintaining grid voltage within specified limits, reducing voltage fluctuations, and ensuring a stable and reliable power supply. By optimizing controller parameters, the STATCOM can provide efficient reactive power compensation. This helps in minimizing voltage drops, improving power factor, and reducing line losses. Properly tuned controller parameters enable the STATCOM to respond quickly to changes in the grid's reactive power requirements. This rapid response time ensures that voltage and power factor are kept within desired limits, even during transient events. Multilevel converters used in STATCOMs can generate harmonics if not controlled properly. Parameter optimization can mitigate harmonics, ensuring a cleaner and more stable power supply with minimal distortion. A well-tuned STATCOM contributes to grid stability by damping out oscillations, reducing voltage flicker, and preventing voltage sags and swells. This, in turn, enhances the overall reliability of the power system. Optimizing the controller parameters can lead to more efficient operation of the STATCOM. This means that the device consumes less reactive power from the grid, reducing energy losses and improving the overall energy efficiency of the system. Improved voltage regulation and reduced losses result in cost savings for utilities and end-users. With optimized STATCOM control, there is less need for additional equipment to maintain grid quality. STATCOMs are increasingly used in conjunction with renewable energy sources like wind and solar power. Proper parameter optimization ensures seamless integration and improved grid stability in renewable energy systems. Optimization allows for the development of control strategies tailored to specific grid conditions and requirements. This adaptability is crucial in addressing varying grid challenges. Many countries have stringent grid codes that require power quality standards to be met. Optimized STATCOM controllers can help meet these regulatory requirements, avoiding penalties and ensuring compliance.

6. Conclusion

The Adaptive Particle Swarm Optimization (APSO) algorithm is a powerful optimization approach rooted in the principles of swarm intelligence, drawing inspiration from the collective behaviors of natural swarms like fish or birds [14]. Voltage optimization plays a pivotal role in maintaining the operational efficiency and reliability of electrical distribution systems by ensuring voltage levels remain within acceptable parameters. Leveraging the STATCOM (Static Synchronous Compensator) in conjunction with APSO offers a viable strategy for achieving this optimization goal. A STATCOM, as a component of Flexible AC Transmission Systems (FACTS), possesses the capability to control reactive power flow within the electrical grid. This device, consisting of a voltage source converter (VSC) driven by power electronics, can dynamically generate or absorb reactive power as required, providing essential voltage support to the system. APSO, an evolution of the Particle Swarm Optimization (PSO) algorithm, harnesses the innate behaviors of swarming creatures to fine-tune the

settings of STATCOM and effectively regulate the system's voltage in the context of voltage optimization. PSO, a metaheuristic optimization technique, orchestrates a population of potential solutions, referred to as particles, in a dynamic and purposeful manner, much like the cooperative or competitive interactions observed in natural swarms. Each particle, representing a point in a multidimensional space, is guided towards the optimal solution through iterative adjustments, ultimately yielding the best configuration for achieving voltage optimization. The successful optimization of controller parameters not only enhances the STATCOM's ability to provide reactive power compensation but also contributes to the overall stability and reliability of the power system. It allows for better control of voltage levels and mitigation of power quality issues such as voltage sags and swells, thereby improving the quality and efficiency of electricity distribution.

Additionally, the optimization of controller parameters for Multilevel Converter-based STATCOMs represents a critical step towards achieving optimal reactive power compensation and improving the overall performance of power systems. This ongoing research and development effort continue to play a vital role in ensuring a stable, reliable, and high-quality supply of electricity to meet the demands of modern society.

Contribution of Researchers

Conceptualization, Y.A.H. and H.A.S.; methodology, Y.A.H., H.A.S. and M.H.A.; software, H.A.S and A.H.M, validation, M.H.A., A.H.M; formal analysis, A.H.M and H.A.S.; investigation, Y.A.H. and M.H.A.; data curation, Y.A.H. and H.A.S.; writing—original draft preparation, A.H.M,Y.A.H. and A.H.M, writing—review and editing, A.R., Y.A.H.. and M.H.A..; visualization, A.H.M. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors prove that the article without any conflicts of interest.

References

[1]. J. Rodriguez, J. S. Lai and F. Z. Peng, “Multilevel inverters: survey of topologies, controls, and applications,” IEEE Trans. on Industry Applications, Vol. 49, No. 4, pp. 724-738, 2002 .

[2]. S. Panda and N. P. Padhy, “location and controller design of STATCOM for power system stability improvement using PSO,” Journal of the Franklin Institute, (2007).

[3]. Saman Babaei “A Control Structure for Line- Frequency-Switched STATCOMs under System Faults”, Department of Electrical and Computer Engineering, 978-1-4799-0336-8/13 IEEE, Sept 2013

[4]. Verma Amitkumar, Kamani PL, Kapadia RR. A review on gridpower quality improvement in wind energy system using STATCOM with BESS. J Emerg Technol Innov Res (JETIR);2(1):26e31,(2015).

[5]. Neyshabouri, Y., Iman-Eini, H., Miranbeigi, M.: ‘State feedback control strategy and voltage balancing scheme for a transformer-less STATic synchronous. COMpensator based on cascaded H-bridge converter’, IET Power Electron., 8, (6), pp. 906–917, 2015.

[6]. Zotin, A., Hamad, Y., Simonov, K., Kurako, M., & Kents, A. (2020, June). Processing of CT lung images as a part of radiomics. In International Conference on Intelligent Decision Technologies (pp. 243-252). Singapore: Springer Singapore.

[7]. Hamad, Y., Mohammed, O. K. J., & Simonov, K. (2019, March). Evaluating of tissue germination and growth rate of ROI on implants of electron scanning microscopy images. In Proceedings of the 9th international conference on information systems and technologies (pp. 1-7).

[8]. C. Tareila, P. Sotoodeh, R. D. Miller., “Design and control of a singlephase D-STATCOM inverter for wind application”, Power Electronics and Machines in Wind Application PEMWA 2012, Denver, Co, 2012.

[9]. Sun, Y., Zhao, J., Ji, Z., et al.: 'An improved DC capacitor voltage balancing strategy for PWM cascaded H-bridge converter-based STATCOM'. Proc. IEEE 10th Int. Conf. Power Electronics Drive Syst., Kitakyushu, Japan ,pp. 1245–1250, April 2013.

[10]. Vural, A. M. (2016). Self-capacitor voltage balancing method for optimally hybrid modulated cascaded H-bridge D-STATCOM. IET Power Electronics, 9(14), 2731-2740.

[11]. Taha, O.A., Pacas, M.: 'Hardware implementation of balance control for three-phase grid connection 5-level cascaded H-Bridge converter using DSP'.Proc. IEEE 23rd Int. Symp. Industrial Electronics, Istanbul, Turkey ,pp. 1366–1371, June 2014.

[12]. Sotoodeh, Pedram, and Ruth Douglas Miller. "A single-phase 5-level inverter with FACTS capability using modular multi-level converter (MMC) topology." Electric Machines & Drives Conference (IEMDC), 2013 IEEE International. IEEE, 2013.

[13]. Neyshabouri, Y., Iman-Eini, H., Miranbeigi, M.: 'State feedback control strategy and voltage balancing scheme for a transformer-less STATic synchronous. COMpensator based on cascaded H-bridge converter', IET Power Electron., 8, (6), pp. 906–917, 2015.

[14]. Behrouzian, Ehsan, Massimo Bongiorno, and Remus Teodorescu. "Impact of switching harmonics on capacitor cells balancing in phase-shifted PWM-based cascaded H-bridge STATCOM." IEEE Transactions on Power Electronics 32.1 (2017): 815-824.

[15]. S. U. Shinde, M. Sharmila, R. S. Patil and D. V. Malkhede, "Performance comparison of PI & ANN based STATCOM for 132 KV transmission line," in International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT), Chennai, India, 2016.

[16]. Debnath, Suman, et al. "Operation, control, and applications of the modular multilevel converter: A review." IEEE transactions on power electronics 30.1 (2014): 37-53.

[17]. Xu, Jianzhong, Penghao Zhao, and Chengyong Zhao. "Reliability analysis and redundancy configuration of MMC with hybrid submodule topologies." IEEE Transactions on Power Electronics 31.4 (2015): 2720-2729.

[18]. Leon, Jose I., Sergio Vazquez, and Leopoldo G. Franquelo. "Multilevel converters: Control and modulation techniques for their operation and industrial applications." Proceedings of the IEEE 105.11 (2017): 2066-2081.

[19]. M. Moazzami, G. B. Gharehpetian, H. Shahinzadeh, and S.H. Hosseinian, "Optimal locating and sizing of DG and DSTATCOM using Modified Shuffled Frog Leaping Algorithm," in Proceedings of the 2nd Conference on Swarm Intelligence and Evolutionary Computation, CSIEC 2017, pp. 54–59, Iran, March 2017.

[20]. Safonova, A., Hamad, Y., Dmitriev, E., Georgiev, G., Trenkin, V., Georgieva, M., ... & Iliev, M. (2021). Individual tree crown delineation for the species classification and assessment of vital status of forest stands from UAV images. Drones, 5(3), 77.

[21]. Kabaev, E., Hamad, Y., Simonov, K., & Zotin, A. (2020). Visualization and Analysis of the Shoulder Joint Biomechanics in Postoperative Rehabilitation. In SibDATA (pp. 34-41).

[22]. Seno, M. E., Abed, A. A., Hamad, Y. A., Bhatt, U. M., Babu, B. R., & Bansal, S. (2022, December). Cloud Based Smart Kitchen Automation and Monitoring. In 2022 5th International Conference on Contemporary Computing and Informatics (IC3I) (pp. 1544-1550). IEEE.

[23]. Seno, M. E., Abed, A. A., Hamad, Y. A., Pundir, S., Srivastava, A. P., & Ali, S. (2022, December). Forwarding Factor Routing Protocol for Opportunistic Internet of Things Networks. In 2022 5th International Conference on Contemporary Computing and Informatics (IC3I) (pp. 988-995). IEEE.

[24]. Safonova, A., Hamad, Y., Alekhina, A., & Kaplun, D. (2022). Detection of norway spruce trees (Picea Abies) infested by bark beetle in UAV images using YOLOs architectures. IEEE Access, 10, 10384-10392.

[25]. Mustafa, M. O., & Abbas, N. M. (2021). Harmonic Suppression Compensation of Photovoltaic Generation Using Cascaded Active Power Filter. Eastern-European Journal of Enterprise Technologies, 6(8), 114.

[26]. Zainel, Q. M., Darwish, S. M., & Khorsheed, M. B. (2022). Employing quantum fruit fly optimization algorithm for solving three-dimensional chaotic equations. Mathematics, 10(21), 4147.

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Examining the Impact of Entrepreneurial Culture on SME Performance: The Role of Marketing Capabilities and Social Media

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Abstract

The present study examines the impact of entrepreneurial culture on the performance of small and medium-sized enterprises (SMEs) in Tehran Province, Iran, focusing on the mediating effect of marketing capacities and social media usage. A questionnaire of 25 questions, separated into four sections—"Entrepreneurial culture," "SMEs' performance," "Marketing skills," and "Social media usage"—was used to collect data. The replies of 80 SME owners or managers were collected by non-probability sampling, and the validity and dependability of the data were confirmed. For data analysis, the study applied structural equation modeling (SEM) with the partial least squares (PLS) technique and SmartPLS 4 software. The findings indicated that entrepreneurial culture has a favorable and substantial effect on the performance, marketing capacities, and social media usage of SMEs. In addition, marketing capabilities and social media usage have a positive and substantial effect on the performance of SMEs. Additionally, social media utilization has a good impact on marketing capabilities. The study demonstrated the indirect impact of entrepreneurial culture on the performance of SMEs through the mediating roles of marketing capabilities and social media usage. The article concludes with evidence-based, actionable recommendations based on the research findings.

Keywords: Entrepreneurial Culture, SMEs' performance, Marketing Capabilities, Social Media Usage

1. Introduction

SMEs are essential for fostering economic growth in both developed and developing countries, including Iran. Their effects are seen in the growth of the GDP, the creation of jobs, rising incomes, and the establishment of new businesses [1]. As a result, research on SME-related challenges has gained popularity in a number of sectors [2]. It is now even more important to understand entrepreneurship and the use of digital technologies, particularly social media, in order to improve the performance and productivity of SMEs after the COVID-19 pandemic had such a devastating impact on them [3]. In the post-pandemic era, Ratten [4] underlines the value of entrepreneurial expertise. SMEs in difficult circumstances may need to take entrepreneurial actions, such as refocusing innovation resources on obtaining practical insights, selecting the best options for the production or service delivery process, realigning business models with the changing needs and expectations of their customers, and implementing technologies to enhance their operations [5]. Like in any other nation, SMEs are the foundation of the Iranian economy. The success of SMEs is vital to the economic development of nations since they are acknowledged as the engine of economic growth in both developed and developing nations [6]. Even though they have many advantages, SMEs confront a number of common problems, including lower productivity, less legitimacy, and higher capital expenses. Regardless of the business climate they operate in, these challenges pose a danger to the viability and success of SMEs, leading to an alarming failure rate during the first few years of operation [7]. Long-term performance for even those that do survive is frequently only mediocre, which is worrying for both the economy and enterprises. Social and demographic changes are continually changing the entrepreneurial environment, and SMEs struggle to operate in a commercial world that is more controlled by technology. Iran's developing economy presents particular difficulties that call for reconsideration and a better

understanding of Iranian business culture and performance. A definition of entrepreneurial culture (EC) is a setting that fosters creativity and invention and is marked by a set of values, precepts, and anticipated behaviors. As a result, this culture encourages employees at entrepreneurial firms to be proactive and free-thinking when developing and implementing novel ideas. It also encourages a willingness to embrace uncertainty, take chances, and start new projects. As a result, these companies exhibit highly creative workplace behavior. In the quickly changing environment of the fourth industrial revolution, where innovation dynamics are bursting because of the open innovation paradox, understanding the function of EC in fostering inventive work behavior is extremely critical [8]. This study also answers Obschonka's [9] demand for additional research on EC in order to capitalize on unparalleled prospects for entrepreneurial activities while addressing twenty-first-century concerns [10]. In recent years, the marketing paradigm has shifted significantly as a result of the development of technology and the increased use of social media in marketing [11]. Consequently, it is considered that marketing capabilities (MCs) and social media usage (SMU) may impact the connection between EC and the performance of SMEs [12]. However, research on the relevance of these characteristics in the context of SMEs, particularly in developing nations, has been sparse [13]. MCs and SMU should be examined for two reasons. Initially, MCs can strengthen a company's competitive position and customer relationships, resulting in enhanced performance [2]. MC refers to a company's capacity to comprehend and predict the demands of its customers better than its competitors and to engage them successfully. Therefore, it is proposed that SMEs need marketing skills to develop a strong relationship between their EC and performance. In addition, MCs may serve as both a mediator and an influencer on EC performance. This dual role of MCs has not been investigated in the context of emerging markets [14], broadening our understanding of the responsibilities of MCs within the EC-SMEs' performance relationship. Second, SMU platforms such as Facebook, Instagram, WhatsApp, LINE, and WeChat offer multiple chances for SMEs to increase their competitiveness in the social media environment [15]. SMEs can use social media to identify new possibilities, strengthen customer relationships, increase collaboration within the business and with other entities, and advertise their products and services. In addition, social media plays a significant role in establishing consumer interactions, making it an essential part of marketing [16]. The association between EC and SME performance may therefore be moderated by the SMU. The prospective marketing activities via social media show that it can establish the link between EC and MC, and ultimately, EC and the performance of SMEs. Previous studies have neglected the possibility of a serial or double mediator between EC and SMEs' performance [17]. In order to examine the relationship between EC and SMEs' performance, the study has five objectives:

- Analyzing the connection between EC and SMEs' performance.
- Examining the role of MC as a mediator between EC and SME performance.
- Examining SMU as a mediator between EC, SMEs' performance, and MC.
- Examining SMU as a mediator between EC and the SMEs' performance.
- Examining the serial mediation of EC and SME performance via SMU and MC.

These objectives suggest that the study intends to investigate the relationship between EC and SME success, as well as the role that social media and MC may play in this relationship. In order to examine the relationship between EC and SME success, the study has five objectives:

- Analyzing the connection between EC and the SMEs' performance.
- Examining the role of MC as a mediator between EC and SME performance.
- Examining the SMU as a mediator between EC, SME performance, and MC.
- Examining the SMU as a mediator between EC and the SMEs' performance.
- Examining the serial mediation of EC and SME performance via SMU and MC.

These objectives suggest that the study intends to investigate the relationship between EC and SME success, as well as the role that SMU and MC may play in this relationship. It also says that the study would investigate how SMU may moderate the connection between EC and SME performance. It also

says that the study would investigate how SMU may moderate the connection between EC and SME performance.

2. Literature Review

2.1 Entrepreneurial Culture (EC)

EC is the combination of personal values, management expertise, experiences, and behaviors that determine an entrepreneur's spirit of initiative, risk-taking, innovative capability, and ability to manage a company's economic ties [18]. This concept is multifaceted and comprises numerous facets. Despite the fact that multiple features of EC have been found in the relevant literature [19-21], there is a lack of uniformity in how this term is defined and quantified across different disciplines. Leadership is likely the most frequently mentioned aspect of EC, since it entails managers encouraging their people to fulfill their full potential and fostering an entrepreneurial mindset among them. The second factor relates to the characteristics of EC, such as risk-taking and a tolerance for failure, as well as the adoption of innovative techniques by both the firm and its board of directors, as well as human resource (HR) policies and initiatives [10]. Bau and Wagner [22] highlighted four aspects of EC that encompass the aforementioned themes. These are "leadership quality and effectiveness" (LQE), "collaboration, information, and innovation" (CII), "product and market expertise," and "tasks and responsibilities." In addition, this concept incorporates some aspects that were not previously included in research, such as product and market expertise, teamwork, and information exchange [10].

In an entrepreneurial organization, the "LQE" component refers to the significance of competent leadership. This can appear in several ways, such as developing self-governing teams through clear instructions and objectives for all members (as advocated by Bell and Kozlowski [23]) or mentoring and guiding people to nurture innovative thought and the ability to see new opportunities (as proposed by Hisrich and Peters [24]).

The "CII" dimension refers to HR systems that empower employees to act independently and demonstrate entrepreneurial behavior through fostering collaboration, creativity, and information exchange [22]. This includes fostering a supportive workplace culture in which employees are encouraged to collaborate, adopting effective information technologies to allow communication and knowledge exchange, and providing an atmosphere that fosters innovation.

The "product and market expertise" dimension is a cultural quality that emphasizes the significance of having a thorough understanding of a company's goods, customer needs, and industry trends [22]. This includes a thorough understanding of the company's services, an awareness of the changing needs and desires of clients, and an awareness of the most recent industry advances and innovations.

The "tasks and responsibility" factor relates to the clarity with which employees comprehend their job responsibilities. This includes having a full understanding of their jobs and responsibilities, as well as their role within the business. Such clarity enables employees to align their own ambitions with the organization's objectives, thus assisting the organization in achieving its goals [22].

Based on this perspective, the following hypothesis is proposed:

- H1: EC is positively associated with SMEs' performance.

2.2 Social Media Usage (SMU)

Social media is a readily accessible external resource that any SME can utilize. The amount of benefit derived from social media mostly depends on the talents, methods, habits, and decision-making abilities of SME owners [5]. The rise of social media as a meaningful and innovative tool for corporate growth and sustainability has been the subject of extensive academic and managerial discussion [25]. Consequently, entrepreneurship researchers have acknowledged the growing significance of social media, especially for SMEs [26]. Utilizing their real-time market knowledge, resource-matching

abilities, networking, social media customer relationship management (CRM), co-creation of products and services, and overall MCs, social media can provide valuable market intelligence to bridge the resource gap and reduce uncertainty for SMEs [2]. As noted by Sigala [27], the usefulness of social media in increasing SME performance is contingent on the company's total utilization of multiple technologies and the synergy produced between these technologies and the company's internal resources. In addition to utilizing corporate IT resources, social media provides opportunities for networking, knowledge and information sharing between businesses and customers, and other advantages, as mentioned by Trainor et al. [28]. According to this perspective, SMU can strengthen the impact of EC on SMEs.

Effective two-way communication with consumers and the development of long-term relationships are essential to a company's success because they result in enhanced customer happiness, business goodwill, and profitability. By leveraging SMU, SMEs may effectively communicate with customers and collect information about their requirements and problems, enabling them to better comprehend real-time expectations and fluctuating product and service demand. Furthermore, SMU enables SMEs to access wider client groups and demographics, which can increase overall performance. The favorable mediation effects of social media marketing on organizational and brand performance discovered by Wang and Kim [29] and Odoom and Mensah [30], respectively, suggest that SMU likely impacts the relationship between EC and SME success. According to Mason et al. [31], social media marketing has been actively exploited throughout the COVID-19 epidemic.

Therefore, our hypotheses in this stance are as follows:

- H2: EC is positively associated with SMU.
- H3: SMU is positively associated with SMEs' performance.
- H4: EC has an indirect positive effect on SMEs' performance through SMU.

2.3 Marketing Capabilities (MCs)

MCs are the abilities and skills that enable firms to identify and comprehend the needs of their customers and the market through interactions. By exploiting these competencies, businesses can proactively adapt their approach to market conditions and achieve specific performance goals [32]. As a result, MCs have been identified as a crucial company performance determinant [33].

MCs are regarded as an internal asset because it is the obligation of the decision-maker to decide when to engage, publicize, and react. SMEs require an entrepreneurial mindset to produce exceptional results through their MCs. These skills permit the integration of improved services that suit consumer needs, ultimately resulting in stronger customer connections [34]. Utilizing MCs enables SMEs to maximize their potential profit and gain a competitive advantage over other organizations. Consequently, incorporating the market capability element into the interaction between EC and SME is essential for strengthening the model and gaining a thorough grasp of its dynamics. In addition, a number of research papers, including those by [35], [33], and [36], have examined the relationship between MCs and corporate performance. These studies have collectively established a strong and positive association between MCs and organizational performance. Therefore, it is logical to conclude that SMEs could improve their performance by enhancing their MCs. Khan et al. [37] found a positive correlation between entrepreneurial competencies and the performance of enterprises during the COVID-19 pandemic.

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- H5: EC is positively associated with MC.

- H6: MC is positively associated with SMEs' performance.
- H7: SMU is positively associated with MC.
- H8: EC has an indirect positive effect on SMEs' performance through MC.

After building a theoretical basis and assumptions, we suggest the research framework represented in Figure 1.

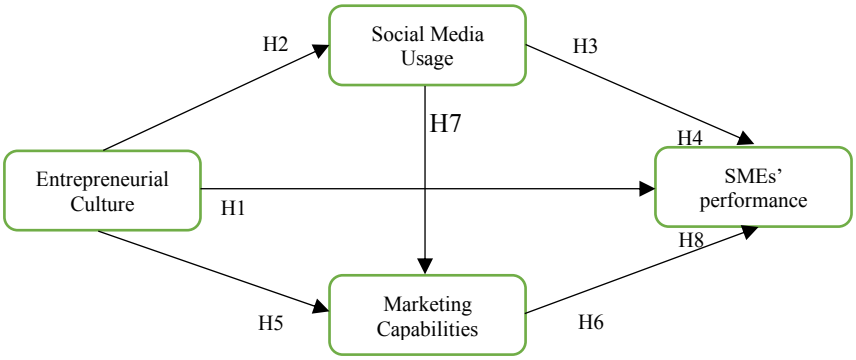

Figure 1: Research Conceptual Model

3. Research Method

This study design adopts a quantitative methodology with closed-ended survey questions. The organizational level will serve as the unit of analysis for this investigation of SME proprietors and managers in Tehran Province, Iran. Due to a dearth of data, this study employed the technique of purposive sampling based on government-defined criteria for SMEs. The research team circulated 90 questionnaires via research assistants and enumerators and gathered 80 completed surveys, which met Hair et al.'s [38] sample requirements. PLS-SEM (partial least squares structural equation modeling) was used in this study to test the conceptual framework and hypotheses. Given the mediation hypothesis, Hair et al. [39] indicated that PLS-SEM was an appropriate approach. For the PLS-SEM analysis, SmartPLS 4 software was utilized.

This study utilized a five-point scale that varied from "strongly disagree" (1) to "strongly agree" (5) for measuring responses. The choice of a five-point scale was made to encourage respondent engagement and reduce the amount of time needed to complete the questionnaire, as compared to an open-ended approach [40]. To verify the validity and reliability of the metrics, each item was adapted from earlier SME research and field-tested in emerging economies.

We used the measurement items for "EC" from Nguyen et al. [10] due to their effective implementation and validation in previous studies on SMEs in developing countries. The "EC" variable consisted of a total of 9 items, including 2 items pertaining to leadership and quality of exchange, 3 items pertaining to creativity, innovation, and risk-taking, 2 items pertaining to product and market knowledge, and 2 items pertaining to task management and responsibility. This variable contains the example "My employer encourages and supports my career development."

To measure "MC", we utilized the measuring items created and validated by Susanto et al. [5], consisting of a total of 4 items. In accordance with their research, we also evaluated a multidimensional construct of "SMU" comprising three dimensions: information search, marketing and branding, and customer relations. Each dimension was measured with two items, for a total of six items derived from Susanto et al. [5].

To assess "SME performance" (PER), we utilized the measurement items created by Susanto et al. [5], which consist of a total of six measures that are centered on efficiency, growth, and profitability.

As a result, a questionnaire with 25 questions was distributed. Prior to dissemination, we did a pilot test of the survey with a small sample of SME owner-managers to check that there were no phrasing, grammar, or readability errors. The pilot study included 30 managers or owners of SMEs, which is regarded as an appropriate quantity according to Hertzog [41] as the minimal criterion for a pilot study. No problems were discovered during the pilot research.

4. Results

4.1 Demographic Statistics

84 out of 90 surveys were returned, for a response rate of 93.3 percent. Eighty percent of the submitted surveys were useful, while the rest could not be utilized due to unanswered questions. Following the recommendations of Hair et al. [38], we are sure that our sample size and response rate are enough for conducting the analysis.

On the basis of a questionnaire given to SME owners and managers, the demographic characteristics of the respondents were identified. These statistics indicate that 56 percent of respondents are male and 44 percent are female. In addition, the ages of the respondents are as follows: 11% are between the ages of 25 and 34, 59% are between the ages of 35 and 44, 21% are between the ages of 45 and 54, and 9% are over the age of 54. Regarding marital status, 63% of respondents are married, while 27% are single. 35 percent of respondents own a bachelor's degree, 55 percent possess a master's degree, and 10 percent possess a doctorate.

In conclusion, the questionnaire issued to SME owners and managers found that the majority of respondents were male, between the ages of 35 and 44, married, and master's degree-educated. However, there was also significant participation from other age groups and educational backgrounds, showing the existence of a broad community of SME owners and managers.

4.2 Measurement Model Evaluation

In accordance with Hair et al. [39], we utilized SEM-PLS to develop a reflecting measurement model (algorithm) and a structural model (bootstrapping). The initial phase entails assessing the quality of measurement, which requires a review of validity and reliability measures to ensure that criteria are met. According to the measurement test and quality standards established by Hair et al. [39], it has been confirmed that each item has a loading factor greater than 0.70. We used the PLS-SEM algorithm to assess the measurement model's internal consistency (Cronbach's alpha, composite reliability), convergent validity (loading factors, average variance extracted), and discriminant validity (e.g., Fornell-Lacker Criterion and Heterotrait-Monotrait ratio/HTMT) in accordance with Hair et al.'s [39] recommendations.

Table 1 provides proof that the measuring model meets the necessary standards. Cronbach's alpha and composite reliability for each construct, which both surpass 0.70, indicate that the internal consistency is dependable. In addition, the average variance extracted (AVE) exceeds 0.50, indicating adequate convergent validity.

Table 1: the status of convergent validity and internal consistency reliability

Construct	AVE	CR	Cronbach's alpha
EC	0.574	0.892	0.866
MC	0.711	0.873	0.863
PER	0.573	0.872	0.840
SMU	0.717	0.926	0.921

Table 2 demonstrates that the square roots of the AVE values are bigger than the correlation between constructs in terms of discriminant validity. Further, Table 3 demonstrates that the HTMT ratio falls

below the crucial value of 0.90, suggesting that discriminant validity is obtained. These outcomes permitted us to proceed with the evaluation of the structural model.

Table 2: the status of discriminant validity (Fornell-Lacker criterion)

	EC	**MC**	**PER**	**SMU**
EC	*0.888*			
MC	0.856	*0.843*		
PER	0.850	0.818	*0.857*	
SMU	0.743	0.800	0.841	*0.847*

Note: The correlation of the latent construct is lower than the square roots of the AVE values (italicized).

Table 3: the status of discriminant validity (Heterotrait-Monotrait ratio (HTMT))

	EC	**MC**	**PER**	**SMU**
EC	-			
MC	0.824	-		
PER	0.873	0.861	-	
SMU	0.765	0.855	0.884	-

4.3 Structural Model Evaluation

According to Hair et al. [39], the evaluation of the structural model consists of a set of consecutive processes. Among these are measuring collinearity, identifying the significance of route coefficients, calculating the R-squared value (R2), and checking predictive significance (Q2). Prior to doing the study, it is essential to test for collinearity using variance inflation factor (VIF) values. The findings of the internal VIF suggest that each construct (EC, MC, and SMU) has a value less than 3 (EC = 2.23, MC = 1.000, and SMU = 2.33), showing that collinearity is not a concern [39].

The coefficient of determination (R^2) reflects the predictive accuracy of MCs (0.845) and SME performance (0.897), which both exhibit high levels of accuracy, while SMU (0.552) demonstrates moderate levels of accuracy. According to [39] and [42], R^2 values of 0.19, 0.33, and 0.67 imply weak, moderate, and strong levels of in-sample predictive power [43]. Our blindfold tests utilizing the cross-validated redundancy method [39] indicated Q^2 values for exogenous constructs (EC) to be greater than zero, suggesting their predictive validity for endogenous constructs (SME performance and MC).

These outcomes suggest that the structural model evaluation requirements have been satisfied. We utilized PLS-SEM bootstrapping with a subsample of 5,000 and used bias-corrected accelerated (BCa) bootstrapping and two-tailed to determine path coefficient significance. We established a significance criterion of 5 percent with a p-value less than or equal to 0.05. The path coefficients can be classified as direct or indirect (mediation) coefficients, which are reported in Table 4.

Figure 2 displays the coefficients and t-values of the model's relationships.

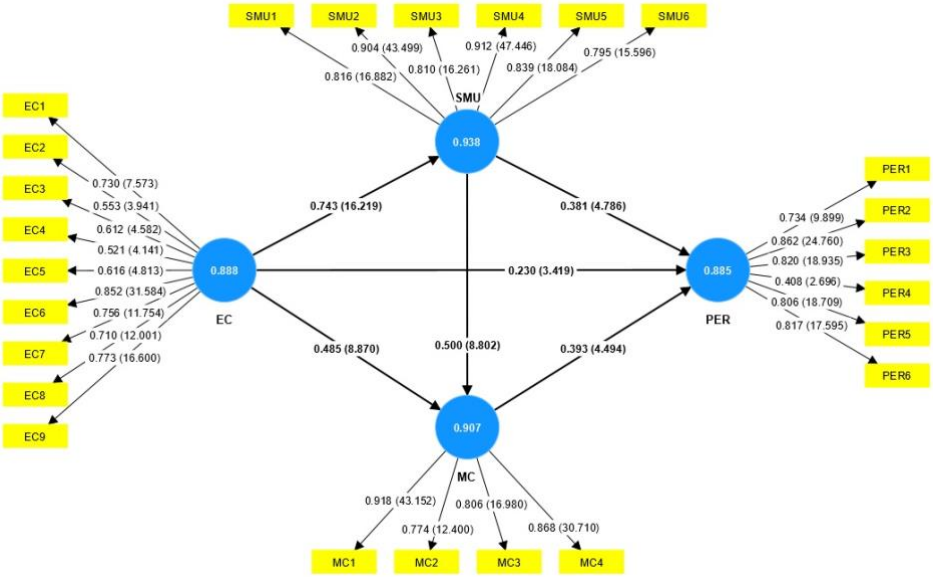

Figure 2: Result of the structural model including path coefficients (t-values)

Table 4: Results for direct effects, mediating effect

Hypotheses	Relationships	β	STDEV	t-value	p-values	Decisions
H1	EC → PER	0.230	0.067	3.419	0.001	Supported
H2	EC → SMU	0.743	0.046	16.219	0.000	Supported
H3	SMU → PER	0.381	0.080	4.786	0.000	Supported
H4	EC → SMU → PER	0.283	0.059	4.779	0.000	Supported
H5	EC → MC	0.485	0.055	8.870	0.000	Supported
H6	MC → PER	0.393	0.088	4.494	0.000	Supported
H7	SMU → MC	0.500	0.057	8.802	0.000	Supported
H8	EC → MC → PER	0.191	0.056	3.418	0.001	Supported

5. Discussion

The study suggests that the presence of an EC can have a significant and positive effect on the performance of SMEs. The statistical analysis demonstrates that the hypothesis H1 is supported, as evidenced by the statistically significant effect size (β = 0.230, p-value = 0.001). This means that SMEs with a greater degree of EC will likely do better. The study underlines the positive impact of EC on the success of SMEs, which may be promoted through a set of values, beliefs, attitudes, and behaviors that encourage innovation, risk-taking, and proactive decision-making. As SMEs are viewed as economic development, job creation, and innovation engines, this conclusion is especially crucial for policymakers, entrepreneurs, and researchers. Thus, organizations should seek to foster an environment that supports innovation and risk-taking, as well as provide the resources necessary to pursue new ideas. In addition to providing financial help, policymakers can assist SMEs by fostering an entrepreneurial mindset. Overall, EC contributes to improved organizational performance, which fosters economic expansion and innovation. This finding is similar to prior research, such as those of [44], [45], and [10], which discovered that businesses with high entrepreneurial behavior are likely to enjoy more success. In addition, this study contradicts previous studies, which revealed only a moderate association between EC and firm performance ([46, 47]).

The study demonstrates that hypothesis H2 is supported, as EC has a significant and positive effect on SMU (β = 0.743, p-value = 0.000). This result suggests that an increase in EC will likely result in a wider SMU for business purposes. Additionally, Amoah et al. [48] have investigated the SMU for business reasons. With an estimated effect size of β = 0.743 and a statistically significant p-value of 0.000, the finding implies that there is a strong association between EC and SMU. This suggests that

individuals or firms with a better entrepreneurial spirit are more likely to use SMU platforms for marketing, networking, and consumer communication. The study also underlines the significance of developing an EC in the digital age in order to capitalize on the potential benefits of SMU. This research provides organizations and governments with useful insights to consider when building policies to promote innovation, growth, and engagement via social media channels.

It has been determined that hypothesis H3 is supported since SME performance is positively affected by SMU ($\beta = 0.0381$, p-value = 0.000). This result is consistent with earlier studies that have proved the significance of social media in increasing the marketing efforts and consumer involvement of businesses. By exploiting social media channels to communicate with customers and advertise their products or services, SME performance and market competitiveness can potentially be enhanced. These findings emphasize the need for SMEs to incorporate social media strategies into their business planning in order to fully enjoy the benefits of these communication channels. It is essential to remember, however, that effective SMU necessitates careful planning and execution, as well as continuous evaluation of its impact on business outcomes. Several past studies have corroborated the positive effects of SMU on the performance of businesses, as have our findings. In particular, [5], [49, 50], and [51, 52] have shown comparable outcomes. In addition, Amoah et al. [48] have backed this view by acknowledging that corporations have been utilizing social media to conduct specific operations.

Table 4 confirms that EC has a favorable indirect influence on SME performance via SMU ($\beta = 0.283$, p-value = 0.000). The result that EC has a positive indirect effect on the performance of SMEs through the SMU underscores the significance of fostering a strong, innovative, and risk-taking culture in SMEs. Such an EC encourages people to take risks, be innovative, and investigate new business ideas. This may result in greater SMU channels for brand promotion and customer outreach. SMU can improve the exposure and reach of SMEs, which has a positive effect on their financial success. Therefore, entrepreneurs should seek to cultivate a culture that fosters innovation and risk-taking while embracing social media platforms to improve the performance of their SME.

The supported hypothesis H5 suggests an association between EC and MC ($\beta = 0.485$, p-value = 0.000). This conclusion emphasizes the significance of developing a culture of innovation and risk-taking in SMEs. When SMEs encourage employees to think creatively, take risks, and investigate new business models, they are more likely to develop robust MCs. This allows them to effectively identify their target market, craft a persuasive message, and design customer-resonating promotional techniques. Entrepreneurs should attempt to construct a culture that supports creativity, innovation, and risk-taking while investing in developing excellent MCs. This can ultimately result in an increase in consumer engagement, brand recognition, and financial performance for the SME.

By accepting hypothesis H6, it was determined that MCs are positively related to SME performance ($\beta = 0.393$, p-value = 0.000). This discovery is a significant advance in our understanding of what makes SMEs successful. This shows that SMEs that invest in enhancing their MCs will likely perform better than those that do not. This is consistent with prior studies that have shown how good marketing tactics may assist organizations in achieving their objectives and gaining a competitive advantage in their respective marketplaces. This conclusion emphasizes the need for SMEs to prioritize and invest in the development of their MCs in order to improve their overall success. Multiple studies have investigated how the MCs of a company or manager can facilitate the appraisal of market needs and the achievement of both financial and non-financial goals ([53, 54]; [33]). Khan et al. [37], who examined the effects of COVID-19, and our own findings are consistent. In addition, the positive influence of MCs on SME performance gives additional support for prior studies, such as [5], [33], [35, 36], and [53] among others.

According to Table 4, hypothesis H7 is supported since SMU is positively linked with MC ($\beta = 0.50$, p = 0.000). The result that SMU is positively linked with MC is not surprising. With the rising significance of social media platforms in the digital age of today, it has become essential for businesses to develop a strong online presence and utilize social media platforms for marketing reasons. When businesses actively connect with customers on social media, not only can they enhance brand exposure, but they may also get vital insights about customer preferences and behavior. This allows businesses to better customize their marketing tactics and offers to their target audience's requirements and expectations. Therefore, it is essential for businesses to cultivate their social media community managers in order to

remain competitive in the market and promote development. This conclusion is consistent with those of [31] and [5], who found that marketing via social media platforms attracted more attention.

Finally, hypothesis H8 results show that EC has an indirect positive effect on SMEs' performance through MC ($\beta = 0.191$, p-value = 0.001). This discovery provides a fresh perspective on how MCs mediation impacts the relationship between EC and SME performance, thereby enriching the research findings of previous studies such as [55-57], [14], and [5]. This finding highlights the importance of nurturing a culture of entrepreneurship in SMEs. The study suggests that firms with a strong EC are better equipped to develop effective MCs, which in turn leads to improved business performance. This indicates that investing in developing an entrepreneurial mindset among employees and fostering a culture of innovation can yield significant benefits for SMEs. By recognizing the mediating role of MCs, policymakers and managers can focus on building a robust marketing function within their organizations and provide opportunities for employees to enhance their entrepreneurial skills. Overall, this finding underscores the need for SMEs to prioritize the development of an EC as a critical foundation for achieving sustained growth and success.

6. Conclusion

SEM-PLS was utilized to analyze the association between EC and the performance of Iranian SMEs. The study also considered the mediating effects of MC and SMU. The primary result of this study is that the European Union has a positive effect on the performance of Iran's SMEs. In addition, the SMU and MC impact the interaction between the two as intermediary factors.

SMEs that develop an atmosphere that supports innovation, risk-taking, and creativity are more likely to achieve greater levels of company success, according to the research. In addition, this study emphasizes the significance of social media and management communication in mediating the link between an EC and SME performance. By effectively utilizing social media platforms and implementing effective marketing strategies, SMEs can increase their reach and visibility, attract new customers, and ultimately improve their bottom line. These findings have important implications for policymakers and business leaders in Iran. Not only can encouraging the growth and development of entrepreneurship assist individual enterprises, but it may also contribute to the economic growth and development of the nation as a whole. Governments can support this by providing funding and resources for entrepreneurial training programs and incentives for starting small businesses.

For SME owners and managers, this research underscores the need to focus not only on product or service quality but also on creating a supportive environment that fosters innovation and creativity. Additionally, investing in MCs and building a strong online presence can be crucial for achieving long-term success. This study contributes to the expanding body of knowledge regarding the importance of entrepreneurship and innovation for economic progress and growth. By understanding the factors that facilitate SME success, policymakers and business leaders can make informed decisions that promote sustainable business growth and create a thriving economy.

Overall, this study indicates that SMEs should concentrate on enhancing their MCs and social media abilities in order to boost sales, profitability, and sustainability. Social media may give real-time market intelligence, enabling proactive analysis and the implementation of suitable measures to establish customer connections and enhance corporate performance. Additionally, it might be advantageous to encourage entrepreneurs to create company concepts and provide social marketing training to those who lack the necessary abilities. Social media networks such as Facebook, Twitter, and Instagram may connect clients and expedite business transactions, particularly when paired with a home delivery service, due to the prevalence and widespread usage of smartphones and Internet-based applications. Therefore, SMU and MC are crucial for both consumer connections and commercial transactions.

According to the results of this study, here are some practical recommendations for SMEs in Iran to improve their performance:

- Foster an EC: It is important for SMEs to cultivate a culture that encourages innovation, risk-taking, and creativity. This can be achieved by promoting a work environment that values ideas and encourages employees to take initiative.
- Improve social media presence: Since SMU and MCs serve as intermediate variables between an EC and a SME's success, it is suggested that SMEs concentrate on enhancing their social media presence and MCs. They can do this by creating engaging content, using relevant hashtags, collaborating with influencers, and analyzing their metrics to determine what works best.
- Ensure work-life balance: It is essential for small business owners to consider their own and their workers' health. This can be done by establishing clear boundaries between work and personal life and providing flexible working arrangements.
- Seek policy support: SMEs can benefit from policy support that provides them with access to resources and facilitates their growth. Therefore, it is recommended that SME owners seek out policies and initiatives that support the development of SMEs in Iran.

Future research recommendations are as follows:

- Consider niche categories: Future study can investigate particular elements, such as cost issues, that may be critical to the sustainability of each SME group. In order to make decisions that will contribute to their company's growth and long-term viability, SME owners need conduct research and gain a thorough awareness of their industry's distinctive qualities.
- Longitudinal design testing: Since the current study is based on cross-sectional data, it is suggested that future research employ a longitudinal design to examine the mode. This will result in a more accurate grasp of the model's genuine dynamic effects.
- Compare and contrast emerging markets: The market in Iran is the topic of this investigation. However, future research may concentrate on other emerging areas in order to simplify the comparison and contrast of SME behavior in these markets. This will enable SME owners to acquire insight into the methods that worked for their competitors in other marketplaces and adopt them within their own enterprises.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] B. M. Sopha, F. Jie, M. J. J. o. S. B. Himadhani, and Entrepreneurship, "Analysis of the uncertainty sources and SMEs' performance," vol. 33, no. 1, pp. 1-27, 2021.

[2] N. A. Omar, A. S. Kassim, N. U. Shah, S. Shah Alam, and C. A. J. I. J. o. M. S. Che Wel, "The influence of customer value co-creation behavior on SME brand equity: An empirical analysis," vol. 13, no. 2, pp. 165-196, 2020.

[3] T. Papadopoulos, K. N. Baltas, and M. E. J. I. j. o. i. m. Balta, "The use of digital technologies by small and medium enterprises during COVID-19: Implications for theory and practice," vol. 55, p. 102192, 2020.

[4] V. J. J. o. S. B. Ratten and Entrepreneurship, "Coronavirus (covid-19) and entrepreneurship: changing life and work landscape," vol. 32, no. 5, pp. 503-516, 2020.

[5] P. Susanto, M. E. Hoque, N. U. Shah, A. H. Candra, N. M. H. N. Hashim, and N. L. J. J. o. E. i. E. E. Abdullah, "Entrepreneurial orientation and performance of SMEs: the roles of marketing capabilities and social media usage," vol. 15, no. 2, pp. 379-403, 2023.

[6] N. Singh, U. Bamel, and V. J. E. R. T. I. J. Vohra, "The mediating effect of meaningful work between human resource practices and innovative work behavior: a study of emerging market," vol. 43, no. 2, pp. 459-478, 2021.

[7] A. J. T. J. o. H. T. M. R. Sadeghi, "Success factors of high-tech SMEs in Iran: A fuzzy MCDM approach," vol. 29, no. 1, pp. 71-87, 2018.

[8] J. J. Yun, X. Zhao, K. Jung, and T. J. S. Yigitcanlar, "The culture for open innovation dynamics," vol. 12, ed: MDPI, 2020, p. 5076.

[9] M. J. C. o. i. b. s. Obschonka, "The quest for the entrepreneurial culture: psychological big data in entrepreneurship research," vol. 18, pp. 69-74, 2017.

[10] H. T. N. Nguyen, H. T. T. Nguyen, A. T. L. Truong, T. T. P. Nguyen, and A. V. J. J. o. E. i. E. E. Nguyen, "Entrepreneurial culture and innovative work behaviour: the mediating effect of psychological empowerment," vol. 15, no. 2, pp. 254-277, 2023.

[11] S. A. Qalati, L. W. Yuan, M. A. S. Khan, and F. J. T. i. S. Anwar, "A mediated model on the adoption of social media and SMEs' performance in developing countries," vol. 64, p. 101513, 2021.

[12] V. J. Pascal and S. J. J. o. I. M. S. Shin, "The role of marketing capabilities and entrepreneurial orientation on SME performance," vol. 3, no. 1, pp. 37-54, 2015.

[13] K. J. J. J. o. P. S. Trainor and S. Management, "Relating social media technologies to performance: A capabilities-based perspective," vol. 32, no. 3, pp. 317-331, 2012.

[14] G. Wiwoho, A. Suroso, and S. J. M. S. L. Wulandari, "Linking adaptive capability, product innovation and marketing performance: results from Indonesian SMEs," vol. 10, no. 10, pp. 2379-2384, 2020.

[15] P. Gillin and E. Schwartzman, *Social marketing to the business customer: Listen to your B2B market, generate major account leads, and build client relationships*. John Wiley & Sons, 2010.

[16] G. Appel, L. Grewal, R. Hadi, and A. T. J. J. o. t. A. o. M. s. Stephen, "The future of social media in marketing," vol. 48, no. 1, pp. 79-95, 2020.

[17] W. J. Wales, S. Kraus, M. Filser, C. Stöckmann, and J. G. J. J. o. B. R. Covin, "The status quo of research on entrepreneurial orientation: Conversational landmarks and theoretical scaffolding," vol. 128, pp. 564-577, 2021.

[18] A. Minguzzi and R. J. J. o. B. V. Passaro, "The network of relationships between the economic environment and the entrepreneurial culture in small firms," vol. 16, no. 2, pp. 181-207, 2001.

[19] R. J. J. o. b. v. Kanter, "Supporting innovation and venture development in established companies," vol. 1, no. 1, pp. 47-60, 1985.

[20] J. S. Hornsby, D. F. Kuratko, R. V. J. E. T. Montagno, and Practice, "Perception of internal factors for corporate entrepreneurship: A comparison of Canadian and US managers," vol. 24, no. 2, pp. 9-24, 1999.

[21] R. D. Ireland, M. A. Hitt, and D. G. J. J. o. m. Sirmon, "A model of strategic entrepreneurship: The construct and its dimensions," vol. 29, no. 6, pp. 963-989, 2003.

[22] F. Bau, K. J. I. J. o. E. Wagner, and S. Business, "Measuring corporate entrepreneurship culture," vol. 25, no. 2, pp. 231-244, 2015.

[23] B. S. Bell, S. W. J. G. Kozlowski, and o. management, "A typology of virtual teams: Implications for effective leadership," vol. 27, no. 1, pp. 14-49, 2002.

[24] R. D. Hisrich and M. P. J. J. o. b. v. Peters, "Establishing a new business venture unit within a firm," vol. 1, no. 3, pp. 307-322, 1986.

[25] C. J. C. Jabbour, A. B. L. de Sousa Jabbour, J. Sarkis, M. J. T. F. Godinho Filho, and S. Change, "Unlocking the circular economy through new business models based on large-scale data: an integrative framework and research agenda," vol. 144, pp. 546-552, 2019.

[26] S. F. Wamba and L. Carter, "Social media tools adoption and use by SMEs: An empirical study," in Social media and *Networking: Concepts, methodologies, tools, and applications*: IGI Global, 2016, pp. 791-806.

[27] M. J. P. Sigala and Cases, "Web 2.0 and customer involvement in new service development: a framework, cases and implications in tourism. Tourism and Hospitality: Theory," vol. 44, no. 3, 2012.

[28] K. J. Trainor, J. M. Andzulis, A. Rapp, and R. J. J. o. b. r. Agnihotri, "Social media technology usage and customer relationship performance: A capabilities-based examination of social CRM," vol. 67, no. 6, pp. 1201-1208, 2014.

[29] Z. Wang and H. G. J. J. o. I. m. Kim, "Can social media marketing improve customer relationship capabilities and firm performance? Dynamic capability perspective," vol. 39, no. 1, pp. 15-26, 2017.

[30] R. Odoom and P. J. M. R. R. Mensah, "Brand orientation and brand performance in SMEs: The moderating effects of social media and innovation capabilities," vol. 42, no. 1, pp. 155-171, 2019.

[31] A. N. Mason, J. Narcum, K. J. C. B. Mason, and Management, "Social media marketing gains importance after Covid-19," vol. 8, no. 1, p. 1870797, 2021.

[32] T. H. Elsharnouby and S. J. T. M. Elbanna, "Change or perish: Examining the role of human capital and dynamic marketing capabilities in the hospitality sector," vol. 82, p. 104184, 2021.

[33] S. L. Martin and R. R. G. J. J. o. B. r. Javalgi, "Entrepreneurial orientation, marketing capabilities and performance: the moderating role of competitive intensity on Latin American International new ventures," vol. 69, no. 6, pp. 2040-2051, 2016.

[34] M. Kohtamaki, H. Hakala, J. Partanen, V. Parida, J. J. J. o. S. T. Wincent, and Practice, "The performance impact of industrial services and service orientation on manufacturing companies," vol. 25, no. 4, pp. 463-485, 2015.

[35] J. Y. Murray, G. Y. Gao, and M. J. J. o. t. a. o. m. s. Kotabe, "Market orientation and performance of export ventures: the process through marketing capabilities and competitive advantages," vol. 39, pp. 252-269, 2011.

[36] Z. Su, D. Ahlstrom, J. Li, D. J. R. Cheng, and D. Management, "Knowledge creation capability, absorptive capacity, and product innovativeness," vol. 43, no. 5, pp. 473-485, 2013.

[37] M. A. Khan *et al.*, "Impact of entrepreneurial orientation dimensions on performance of small enterprises: do entrepreneurial competencies matter?," vol. 8, no. 1, p. 1943241, 2021.

[38] J. F. Hair, "Multivariate data analysis," 2009.

[39] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. J. E. b. r. Ringle, "When to use and how to report the results of PLS-SEM," vol. 31, no. 1, pp. 2-24, 2019.

[40] G. A. J. J. o. m. r. Churchill Jr, "A paradigm for developing better measures of marketing constructs," vol. 16, no. 1, pp. 64-73, 1979.

[41] M. A. J. R. i. n. Hertzog and health, "Considerations in determining sample size for pilot studies," vol. 31, no. 2, pp. 180-191, 2008.

[42] J. Henseler, C. M. Ringle, and M. J. J. o. t. a. o. m. s. Sarstedt, "A new criterion for assessing discriminant validity in variance-based structural equation modeling," vol. 43, pp. 115-135, 2015.

[43] M. Sarstedt, J. F. Hair Jr, J.-H. Cheah, J.-M. Becker, and C. M. J. A. m. j. Ringle, "How to specify, estimate, and validate higher-order constructs in PLS-SEM," vol. 27, no. 3, pp. 197-211, 2019.

[44] Y. Wardi, P. Susanto, A. Abror, N. L. J. P. J. S. S. Abdullah, and Hum, "Impact of entrepreneurial proclivity on firm performance: The role of market and technology turbulence," vol. 26, pp. 241-250, 2018.

[45] N. A. Omar, H. M. Aris, and M. A. J. J. P. Nazri, "The effect of entrepreneurial orientation, innovation capability and knowledge creation on firm performance: A perspective on small scale entrepreneurs," vol. 48, no. 1, pp. 187-200, 2016.

[46] P. Dimitratos, S. Lioukas, and S. J. I. B. R. Carter, "The relationship between entrepreneurship and international performance: the importance of domestic environment," vol. 13, no. 1, pp. 19-41, 2004.

[47] G. T. Lumpkin and G. G. J. J. o. b. v. Dess, "Linking two dimensions of entrepreneurial orientation to firm performance: The moderating role of environment and industry life cycle," vol. 16, no. 5, pp. 429-451, 2001.

[48] J. Amoah, J. Belás, K. A. Khan, Z. J. M. Metzker, and M. C. f. t. K. Society, "Antecedents of sustainable SMEs in the social media space: A partial least square-structural equation modeling (PLS-SEM) approach," vol. 16, no. 1, pp. 26-46, 2021.

[49] A. Dodokh, M. A. J. E. J. o. B. Al-Maaitah, and Management, "Impact of social media usage on organizational performance in the Jordanian dead sea cosmetic sector," vol. 11, no. 2, pp. 75-91, 2019.

[50] F. P. Tajudeen, N. I. Jaafar, S. J. I. Ainin, and management, "Understanding the impact of social media usage among organizations," vol. 55, no. 3, pp. 308-321, 2018.

[51] F. Parveen, N. I. Jaafar, and S. J. M. D. Ainin, "Social media's impact on organizational performance and entrepreneurial orientation in organizations," vol. 54, no. 9, pp. 2208-2234, 2016.

[52] S. Ainin, F. Parveen, S. Moghavvemi, N. I. Jaafar, N. L. J. I. M. Mohd Shuib, and D. Systems, "Factors influencing the use of social media by SMEs and its performance outcomes," vol. 115, no. 3, pp. 570-588, 2015.

[53] A. Krasnikov and S. J. J. o. m. Jayachandran, "The relative impact of marketing, research-and-development, and operations capabilities on firm performance," vol. 72, no. 4, pp. 1-11, 2008.

[54] N. A. Morgan, R. J. Slotegraaf, and D. W. J. I. J. o. R. i. M. Vorhies, "Linking marketing capabilities with profit growth," vol. 26, no. 4, pp. 284-293, 2009.

[55] M. U. Ahmed, M. M. Kristal, and M. J. I. J. o. P. E. Pagell, "Impact of operational and marketing capabilities on firm

performance: Evidence from economic growth and downturns," vol. 154, pp. 59-71, 2014.

[56] M. Ju, J. L. Jin, and K. Z. J. J. o. I. M. Zhou, "How can international ventures utilize marketing capability in emerging markets? Its contingent effect on new product development," vol. 26, no. 4, pp. 1-17, 2018.

[57] Y. Dirgiatmo, Z. Abdullah, R. H. R. M. J. I. J. o. T. Ali, and G. Markets, "The role of entrepreneurial orientation in intervening the relationship between social media usage and performance enhancement of exporter SMEs in Indonesia," vol. 12, no. 2, pp. 97-129, 2019.

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Dissecting the Economic Feasibility and Life Cycle Assessment of Battery Electric and Internal Combustion Engine Vehicles: A Case Study of India

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Abstract

Fuel supplies for conventional vehicles are vulnerable to scarcity, which could ultimately lead to an increase in fuel prices. There has been a realization regarding national energy security as a result of these high gasoline costs, which further increase the overall cost of ownership. Additionally, the emissions from burning conventional fuels make consideration of the already pressing environmental issues necessary. On the other hand, because they have low running costs and no tailpipe emissions, electric vehicles are being considered as a viable alternative to conventional automobiles. But when a vehicle's whole life cycle is taken into account, the common-sense belief that electric vehicles are cheaper and emit no emissions may be misleading. Therefore, it is necessary to consider both the economic and environmental elements of whether electric vehicles are a viable alternative to conventional automobiles. In this article, a life cycle analysis—both economic and environmental—between battery-electric and conventional automobiles is presented in the context of India. For financial analysis, a Total Cost of Ownership (TCO) model is created to show how compatible battery-electric vehicles are. OpenLCA software, which is based on the ReCePi 2016 technique, is used to conduct the environmental analysis for all impact categories at both the mid-point and end-point levels. According to the findings, electric vehicles are more expensive than conventional automobiles in India based on current data and regulations. However, it is shown that electric vehicles have cost parity and can sometimes even become more inexpensive than conventional automobiles by using specific optimizing factors in sensitivity analysis. The results of environmental studies show that battery electric vehicles emit fewer greenhouse gases (GHGs) than do conventional automobiles. Battery electric vehicles, however, had less of an impact in ten of the eighteen impact categories that were examined, and they even have a lower impact score at the end-point level.

Keywords: Life Cycle Analysis, Economic Compatibility, Total cost of Ownership, Electric vehicles in India

1. Introduction

Researchers from all around the world are being pushed to develop more sustainable transportation solutions as the drive to convert to carbon-neutral transportation becomes more intense. Consequently, the global vehicle fleet is witnessing an abundance of electric vehicles. The main factors driving the adoption of electric vehicles are the avoidance of exhaust emissions from tailpipes and the achievement of national energy security through the use of an affordable fuel substitute [1]. Among the EV research community, there is currently no agreement on the sustainability, viability, techno-economic, and environmental aspects of electric vehicles (EVs). It's still uncertain if electric cars would work as a reliable substitute and, if so, in what circumstances. According to Gautam [2], fully electrified vehicles won't be practical by 2040, but electric-hybrid cars will be a preferable choice over traditional fuel-

powered automobiles. Conversely, for a variety of reasons, including technical, financial, and environmental, experts Hauschild et al. [3] support electric vehicles as the superior choice.

The inconsistent adoption of battery-powered cars around the world is shown in the Global EV Outlook report [4]. Similarly, a variety of literary works highlight the obstacles to the widespread adoption of electric vehicles, as well as the public's perceptions and regulations aimed at promoting their use. Lieven et al. [5], Heidrich et al. [6]. These publications **also emphasize that the absence of reliable facilities, financial concerns, and environmental issues** are the main obstacles to the widespread use of electric vehicles. These obstacles become increasingly important for nations such as India. Given that the Indian auto industry is price-sensitive, a comprehensive cost study is crucial. Furthermore, it is evident from the regional energy mix—which primarily consists of coal—that environmental analysis is also necessary in order to power electric vehicles.

The sluggish adoption of electrically powered cars is also intimately related to India's national energy security. India is the third-most populous crude oil importer because less than 20% of the country's crude oil is derived from domestic sources [7]. The fiscal year 2022 saw a nearly twofold increase in the crude oil import cost, amounting to $120 billion [8]. Furthermore, India is ranked second in Asia for CO2 emissions, with a significant majority of these emissions coming from the transportation sector, primarily from road transportation [9]. To increase the market share and accelerate the deployment of electric vehicles, these complex barriers need to be carefully considered. But even after the Indian government implemented programs like the National Electric Mobility Mission Plan (NEMMP 2020) and Faster Adoption and Manufacturing of (hybrid &) Electric vehicles (FAME I & II), there was a gap among the plan and its implementation, which undermined the mission and made it necessary to think more deeply about the problem. The worldwide market contribution of battery-powered two-wheelers is consistent with the worldwide marketplace, but the numbers for electric four-wheelers are significantly worse [10]. In order to determine the sustainability implications, this article compares the economic viability of battery electric vehicles (BEVs) with internal combustion engine vehicles (ICEVs). Additionally, an environmental evaluation is conducted to compare the two vehicle types.

2. Literature Review

The literature on the environmental and economic aspects of battery-electric cars is highlighted in this section. According to J. Seixas et al.'s literature [11], one of the main obstacles to the widespread use of electric vehicles is their somewhat greater cost than internal combustion engines. On the other hand, electric cars may be more affordable than internal combustion engines (ICEVs) when taking into account their entire life cycle. Persuading potential buyers of the long-term advantages of electric cars can increase sales of the type and entice them to change their minds. et al. Bhosale [12]. Numerous academic works disclose that variations in local rules, exemptions, and limits can cause the Total Cost of Ownership (TCO) to fluctuate across various parts of the world. Even after accounting for incentives, battery electric vehicles seem to be more expensive in China than ICEVs Zhao et al. [13]. However, when certain intangible costs are taken into consideration, ICEVs become far more costly than BEVs, according to a related study done in China Diao et al. [14]. Even in Singapore and Australia, battery powered cars have higher total costs than internal combustion engines (ICEVs) for many reasons. Electric vehicles with batteries have a higher total cost of ownership (TCO) in Singapore due to high local and customs duties as well as excise taxes [12], while in Australia, peak and off-peak electricity prices cause the TCO of battery electric vehicles to be significantly lower. Kara and others [15].

Norway is at the top of the European economic chart, which is explained by the combination of clean and renewable energy. L´evay et al al. [16]. Following Norway on the list are France, the UK, and the Netherlands, whose TCOs are cheaper than ICEVs but still somewhat higher than Norway's. In contrast to ICEV, other nations fare poorly when the entire cost of ownership is taken into account. When compared to the TCO of BEVs in Japan, roaming incentives are an elixir for BEVs in the US and the UK, according to comprehensive research by Palmer et al. [17]. Potk'any et al. [18] reported similar findings in Slovakia, where providing subsidies had a significant impact on lowering the TCO of BEVs. While some studies categorize TCO comparisons based on geographic regions, others differentiate TCO

based on governing characteristics such gasoline prices, incentives, and annual kilometers traveled (AKT). Many governments use incentives as their main policy instrument, but how effective is this strategy has to be examined? According to Levey et al. [16], incentives are determined to be adequate in some areas, such as Norway and other European and American nations. Lieven et al. [19] observed similar things in roughly 20 other countries, demonstrating that the monetary grant is the most valued incentive. However, incentives don't seem to work all that well in various parts of the world. In Germany, it is determined that a 4,000 Euro incentive is insufficient. According to Bubeck et al. [20], battery-electric cars are still 5% more expensive than gas-powered cars. In Germany, it is determined that a 4,000 Euro incentive is insufficient. According to Bubeck et al. [20], battery-electric cars are still 5% more expensive than gas-powered cars. After receiving government grants et al. Tseng [21]. A year AKT, or kilometers traveled, is a metric that also influences Wu et al.'s TCO on Battery Electric Vehicles [22]. AKT has been referenced in literature which is upto 20,000 kms in order to cover the entire expenses between the automobiles Mitropoulos et al. [23] recommend at least 23,000 kms AKT for BEVs to surpass gasoline in efficiency and Italian cars using diesel fuel. Some literatures have placed emphasis on the battery price, battery replacement cost, and its prognosis, in addition to incentives and yearly kilometers traveled. When battery prices for battery electric vehicles drop to less than $300/kWh and €240/kWh for various parts of the world, the vehicles become economically competitive. Newbery, David, and others [24]. In addition to the cost of the batteries, high depreciation rates are also thought to contribute to the total cost of ownership (TCO), making battery-electric vehicles more expensive than internal combustion engines. The literature shows that while battery electric vehicles (BEVs) were initially welcomed with gusto, buyers are becoming hesitant to purchase BEVs due to their higher total cost of ownership. One of the most challenging problems is minimizing the total cost of ownership (TCO), which is determined by a complex interplay of characteristics that needs to be addressed giving priority.

When it comes to battery-electric vehicles, environmental damage is the main worry in addition to the barrier of economic compatibility. The battery-electric cars produce no emissions is a frequent trick that should be watched out for as the tail pipe's emissions are being transferred to Kalghatgi is another website [4]. But we can't ignore it. The traditional automobiles' emissions have been a significant problem since there are more cars on the road Lucas [25] but examining the emissions of both kinds of vehicles grounds will be used to assess these cars' prospects. When driving a battery-electric car, greenhouse emissions come from a variety of sources, including material extraction, transit, the amount of energy used in manufacturing and its nature Ma et al. (energy-mix utilized) [26]. However, rather than focusing on just one effect category (greenhouse gases), a whole life cycle study should be carried out taking into account all of the impact categories in order to obtain a panoramic emission impact. It makes sense that, if a clean energy source is utilized to charge the BEVs, emissions from battery electric vehicles might be substantial during the manufacture phase of the two phases (use and production). Although the battery pack is thought to contribute significantly to overall emissions, differences in emissions from various battery technologies also need to be taken into consideration. According to research by Premrudee et al. [27], Li-Ion batteries have the least number of pollutants when compared to Lead Acid batteries. According to Held et al. [28], the primary cause of the twice-as-high global warming potential impact category for battery-electric vehicles compared to equivalent internal combustion engines is battery production. Remarkably, with Belgium's existing energy mix, electric cars are discovered to be releasing fewer emissions. While gasoline and diesel vehicles emit more than 200 g/km CO2eq, battery powered cars emit less than 52 g/km CO2eq [29]. Picirelli de Souza et al.'s [30] observations from Brazil, where they estimated the emissions from BEVs compared with ethanol mixed gasoline, show that while BEVs perform well overall in terms of emissions, ethanol blended fuel has less of an influence on human toxicity and global warming. In the global warming category, BEV emissions exceed 140 g/km CO2eq, while ICEVs using an ethanol mix fuel emit less than 100 g/km CO2eq. The average greenhouse gas emissions from battery electric cars (BEVs) in China are 210 g/km CO2eq, according to Zhou et al. [31]. The carbon footprints from BEVs vary across China, ranging from 160 to 245 g/km CO2eq. Comparably, Qiao et al. [32] propose that by choosing the battery recycling option, BEV GHG emissions can be lowered below 50% of those of ICEVs, while current evidence shows that BEV emissions are 18% lower than those of equivalent ICEVs. In tandem with the development of BEVs, laws pertaining to their emissions must be upheld. As the technology behind

electric cars develops, regulations (such as ICEV emission standards, such as EURO 2, 3...) will become stricter, hence it will be crucial to monitor BEV emissions lest the whole transformation in transportation modes be jeopardized.

3 Motivation and Objectives

In order to replace the whole fleet of vehicles with 100% electric vehicles by 2030, the government created the National Electric Mobility Mission Plan 2020 (NEMMP). Regrettably, taking into account the present pace of the market, the goal has been reverted to electrifying thirty percent of the whole fleet of electric vehicles by 2030. The original impetus for the study was these "Unachieved Targets". Second, the "Current Market Status" shows that conditions for electric four-wheelers in India are still unfriendly, even with the introduction of incentive schemes like FAME I & II. The third factor is "Anxiety," which arises from the fact that the Indian market is extremely receptive to cost. This leads to erroneous concerns such as "Are electric vehicles in India cost-competitive with traditional automobiles?" Therefore, the primary goal of this study is to expedite the launch of electric vehicles in India, allay public anxiety (deception questions), pursue the target as soon as possible, and revitalize the electric 4-wheeler market in India.

In the context of India, this article examines how battery electric vehicles compare economically and environmentally against vehicles with similar internal combustion engines. to conduct life cycle environmental and economic analyses while taking into account more accurate data and Indian conditions as opposed to depending solely on general information. Additionally, conduct sensitivity analysis taking into account various regulating factors and recommend appropriate inputs to policy drafters to increase the acceptance of BEVs

4 Methodology

4.1 Economic Analysis

Life cycle economics accounts for the Total Cost of Ownership (TCO), which includes all costs from the time a vehicle is built to the end of its useful life. In order to conduct a fair comparison, the pairing approach—as recommended by Gilmore et al. [33]—is chosen to estimate total cost of ownership. With the matching vehicle approach, automobiles with nearly comparable dimensions and attributes are compared in order to confirm that the estimations are produced using the right datum. Figure 1 shows the TCO block diagram, several phases, and significant obstacles. As shown in Figure 1, the TCO is divided into three phases: acquisition phase, utilization phase, and end-life phase.

The total cost of ownership (TCO) for the base case is first evaluated. Afterwards, optimization is chosen with the aid of sensitivity analysis to determine the optimum alternative that may be recommended to the strategy drafters. Evaluations of sensitivity take into account a number of factors, including Annual Kilometer Traveled (AKT), Battery Replacement Cost, Incentives/Subsidies, Finance Interest Rates, and EV-PV Integration (Battery electric vehicles utilized in combination with solar energy alternative)

The TCO/km is computed by Equation 1:

$$TCO/km = \sum_{n=1}^{N} \frac{[\mathrm{IC_n}+\mathrm{RC_n}+(\mathrm{PVC}-\mathrm{PVS})_n-\mathrm{RS_n}]-\mathrm{I}+\mathrm{B_n}}{(\mathrm{AKT}*\mathrm{n})} \qquad (1)$$

Here, IC is the possession cost, RC is Operating cost, PVC and PSS are the associated with the solar energy (cost and sale respectively), RS is salvage cost, and I is subsidies/Incentives/ other exemptions and B is loading principal balance, D is annual distance travelled in kilometers, n is number of years vehicle used.

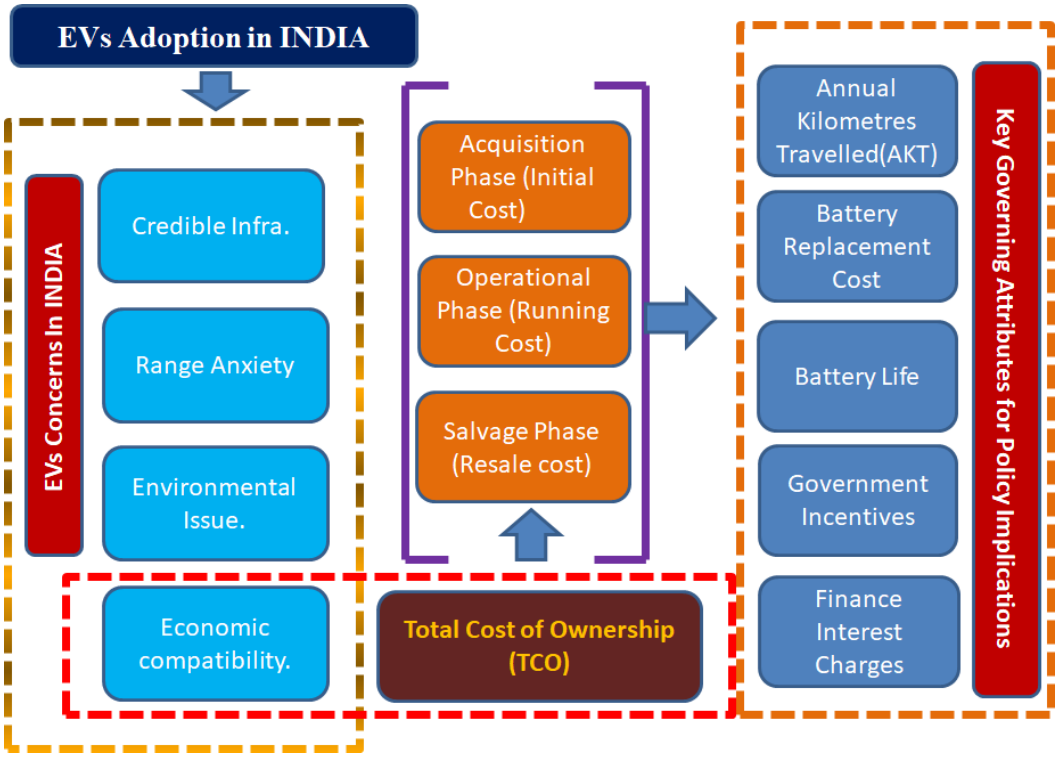

Figure 1: Approaching the Total Cost of Ownership

The acronyms Finance TCO (FTCO) and Purchase TCO (PTCO) are used to calculate the effects of financing and not financing on the TCO. The total cost of acquisition is the amount the owner must pay to purchase the car. Ex-showroom costs, government taxes, road taxes, registration fees, additional ancillary charges from the vehicle's manufacturer company, and interest if the car is financed are all included. During the vehicle's use phase, expenses include fuel, upkeep, parking fees, municipal entry taxes, tire replacement, and other parts. Estimating the fuel cost (Petrol/Diesel and Electricity) involves taking the timeline's inflation rates into consideration. General inflation rates, or around 3.98%, are applied whenever necessary to account for inflation. According to literature, electric vehicles typically require 30% less maintenance than internal combustion engines (ICEVs), and their tires have a 50,000 km lifespan. Ultimately, the salvage phase includes the car's market value for that year, which is calculated using the car's depreciation. In line with the trend in the literature, which is reported by Messagie et al. [34], battery-electric cars lose value faster than internal combustion engines.

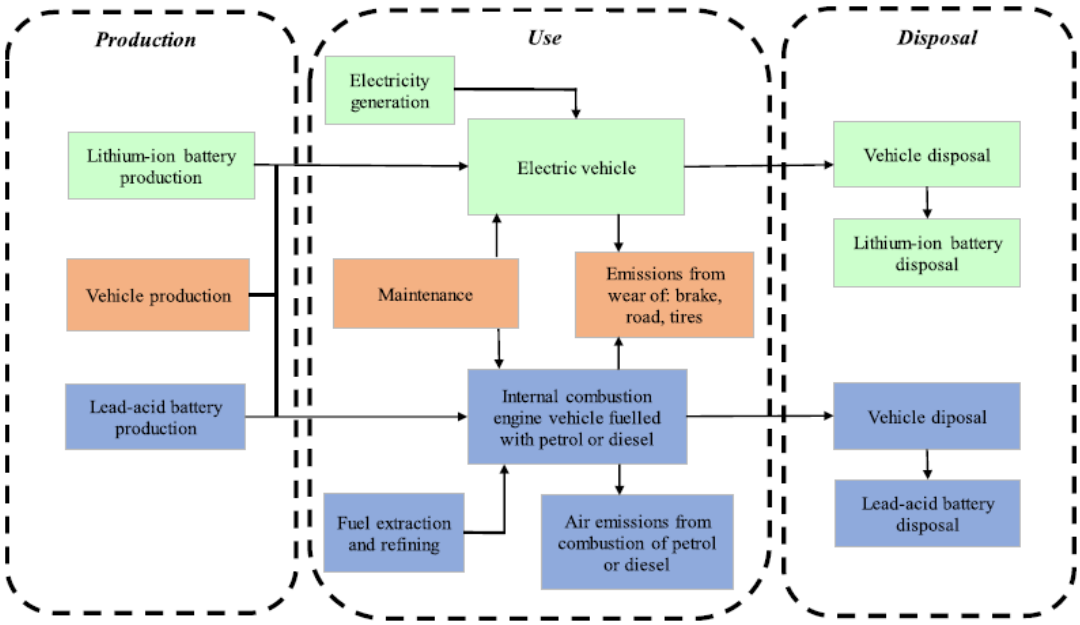

Figure 2: Various Phases in an Environmental Life Cycle Analysis of an automobile application.

The assumptions and usage statistics for the vehicles can be summed up as follows: Two sets of cars are compared in this TCO model; pair A comprises a TATA pair that contrasts the TATA Nexon EV and TATA Nexon Diesel/Petrol. Hyundai Kona EV and Hyundai Creta are contrasted for pair B. To complete the paired vehicle technique, the appropriate model variant is chosen. For the basic case, with a loan tenure of five years and an annual kilometer traveled of 15,000 km, the financing interest rate of 9.7% is taken into account for FTCO computation. According to FAME I & II standards, pair A BEV is eligible for an incentive of ₹115,000, and pair B BEV is presumed to have an incentive of ₹ 400,000. The battery replacement is done after 8 years/ 160,000 km.

4.2 Environmental Analysis

The Life Cycle Environmental Analysis, which follows the ISO 14040 and ISO 14044 European standard series, assesses a product's emissions during its whole life. Here, the consequences and emissions from ICEVs and BEVs that have been modelled are contrasted in relation to the Indian setting. The extraction of materials, transportation, the production and consumption of energy, the usage phase, and lastly the end of life phase are all included in the emissions.

The comparison of emissions from both internal combustion engines (ICEVs) and BEVs from birth to death is known as "cradle-to-grave" analysis.

An examination that solely considers the route of fuel from production to combustion or consumption is referred to as a "Well to Wheel" analysis; well-to-tank and tank-to-wheel analyses are also included in this phrase. Environmental analysis is divided into three parts, much like economic analysis is, as Figure 2 shows. Pollution from the mining and processing of raw materials to the construction of the vehicle and other essential parts like battery packs are included in the manufacturing phase. Emissions from the extraction of fuel, the production of power, and other incidental elements like tire and brake wear are all taken into account throughout the use phase. The vehicle's disassembly and recycling of its required pieces are the last steps in the disposal phase.

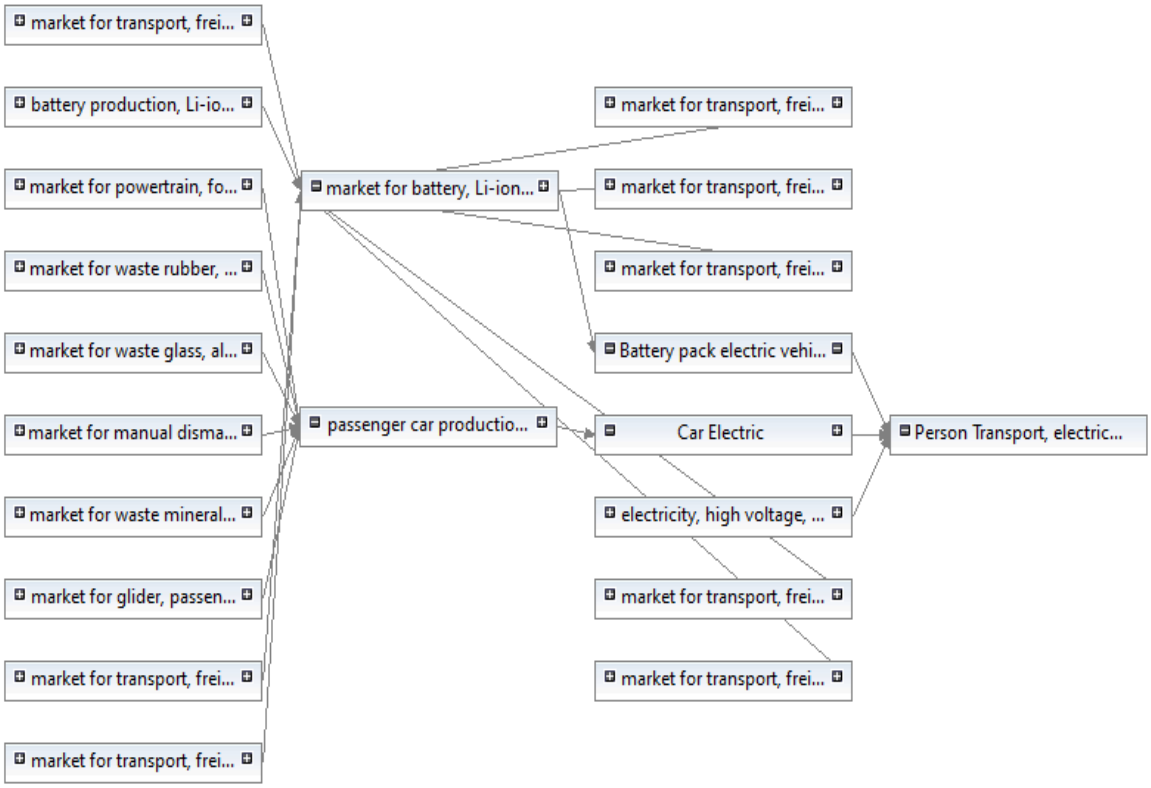

Figure 3: Interlinking of various processes for BEV production

With the aid of the software OpenLCA, which estimates emissions for each effect category, the LCA is carried out. Ecoinvent-3 is the compatible database that is utilized for data inventory. The modeling process incorporates the essential product flows, systems, and processes before being compared to a real project. Figure 3 depicts the prototype product system for battery-electric vehicles. It shows the main processes, with over 9000 processes or flows interacting with the end flow diagram. ReCePi 2016 is the impact assessment approach that was employed; all 16 effect categories are taken into consideration in the evaluation, both at the mid- and end-points.

5. Results and Discussion

5.1 Economic Analysis results

Figures 4a and 4b's results indicate that for parings in this study, the financed overall cost (TCO) of the BEV (F-BEV) is higher than the corresponding TCO of the ICEV (F-ICEV D & F-ICEV P). In a similar vein, for both pairs, the purchased TCO of the BEV is higher than the comparable ICEV. Nonetheless, there is a slight difference in the pair A (TATA pair) purchase TCO between the I.C.V. purchases TCO. However, even pair A's financed TCO is significantly lower than ICEV TCOs. Sadly, pair B (the Hyundai pair) has dismal performance for both purchased and financed choices, highlighting the TCO discrepancies more clearly. An additional intriguing discovery indicates a significant increase in the TCOs of BEVs in both pairings at the eighth year. This sudden rise is due to the high battery replacement cost. The citations should be given in IEEE Style. Authors can get help from citation management applications (tools) when preparing their papers. The title of the citations section should be “References”. A sample reference list is shown at the end of this document in the “References” section.

In-text citations should be written in square brackets like [1], [2]–[4], [2–4], [5], [6].

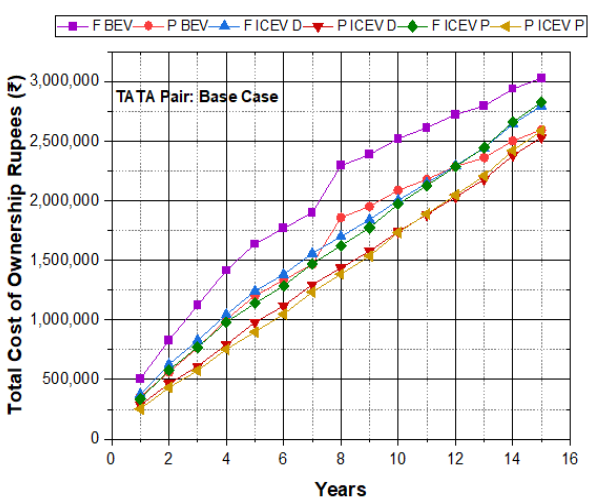

Figure 4: TCO for TATA pair

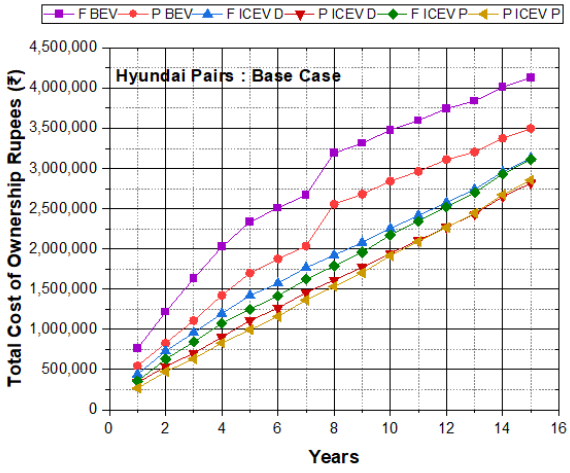

Figure 5: TCO for Hyundai pair

5.1.1 Sensitivity Analysis

According to the base case study, no pair's BEV becomes more cost-effective than an ICEV or reaches cost equality. In order to accomplish the economic compatibility of BEVs, it becomes necessary to examine the TCO in combination with a few extra variables. Aspects of the sensitivity analysis include Policy Governed: offering incentives (discussed in the preceding section), Technology governed: a 50% decrease in battery replacement costs; Extended Policy governed: a reduction in financing interest rates (ROI to 6% from 9.75%) Consumer-Governed: using BEVs with EV+PV integration and imposing a higher Annual Kilometer Traveled (AKT) of 20,000 AKT rather than 15,000 AKT.

According to the findings of the sensitivity analysis, pair A (TATA)'s purchased TCO of a BEV is lower than that of an ICEV for each of the previously mentioned parameters. When the "reduction battery replacement cost" feature is taken into account, the funded TCO for pair A BEV is also equated with the TCO of an ICEV. When examining every variable separately, the funded TCO of pair A BEV is still higher than the TCO of an ICEV. In every variable, outcomes for pair B don't appear sides the electric vehicles. In every sensitivity characteristic listed above, the TCO of the BEV in pair B (the Hyundai) is still greater than that of a comparable ICEV.

It only happens once the BEV's purchase TCO in pair B approaches the ICEV's buy TCO for the "reduction battery replacement cost" criterion just a little bit. The sensitivity analysis reveals that, in the majority of circumstances, the individual variables are insufficient to make the pair's costs competitive; this can only be accomplished by combining the aforementioned characteristics.

As seen in Figure 6, a "compatibility wheel" is created for this. This wheel shows the many variable configurations that were used, as well as how both couples performed under 12 different sets of situations. The planes indicate finance and purchase TCO for the corresponding pairs, while the orbits represent a collection of conditions and parameters.

The wheel consists of 12 different sets of variables (called "orbits") that range from O to K and are listed in the sensitivity analysis. For example, Orbit "A," also known as "Policy Governed," has a set of settings consisting of 15,000 AKT, incentives, a finance interest rate of 9.75%, and no integration of EV and PV. Compare the financed/purchased TCO of a BEV with the financed/purchased TCO of an ICEV within a pair (for example, Planet 1 compares the FTCO of a Hyundai pair of BEVs with the FTCO of an ICEV). These comparisons are known as the planets.

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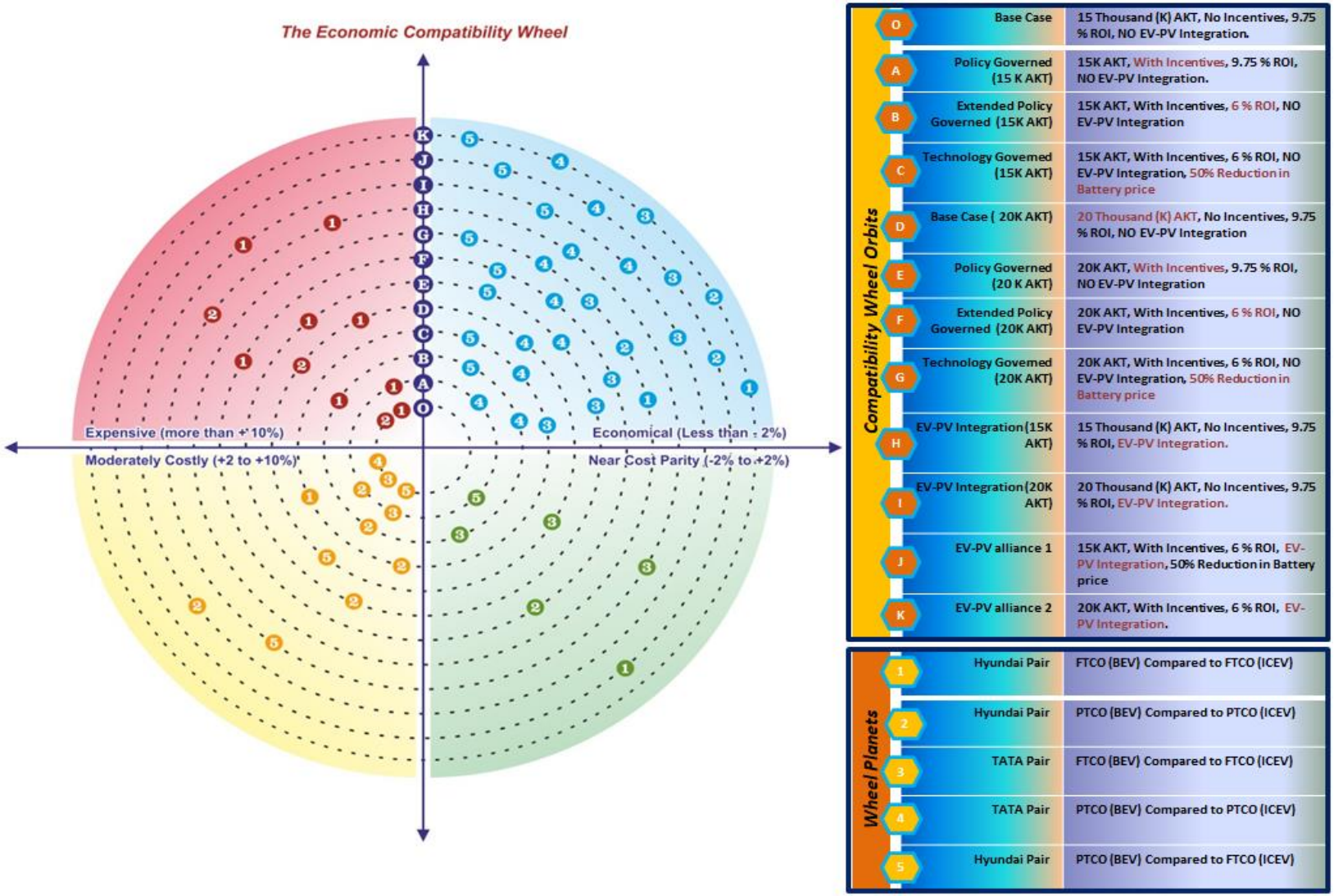

Figure 6: The Economic Compatibility Wheel for the TCO analysis of battery electric vehicles compared to ICEVs

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The following is an explanation of the economic compatibility wheel using an example: The parameters considered are 15000 AKT with incentives, 6% interest rate, and no integration of PV and EV. An orbit "B" is observed. For the previously described orbit (set of conditions), Planet 1 (the FTCO of the Hyundai pair BEV compared to the FTCO of the ICEV) is situated in a costly zone or quadrant, meaning that the FTCO of the Hyundai pair BEV is more than 10% more expensive than the FTCO of the Hyundai pair ICEV. Planet 2, on the other hand, is in the moderately expensive range when compared to the PTCO of the ICEV. This implies that the PTCO of the Hyundai pair BEV is 2–10% more expensive than the PTCO of the Hyundai pair ICEV.

The FTOC and PTCO of TATA pair BEVs are situated in the economic and near cost parity zones, respectively, in contrast to ICEV. In a nutshell, the economic compatibility wheel shows how each pair's TCO functions in different scenarios in a simple and visual manner.

The graphic shows that the Hyundai pair BEV's FTCO (planet 1) mainly falls in the expensive zone when compared to ICEV FTCO. Almost all of the orbits for the TATA pair, with the exception of the base orbit "O," put BEV's PTCO (planet 4) in the economic zone. Known as orbits 'G' and 'K,' we have found two intriguing orbits (set of conditions) in which every planet is in the economic zone. This implies that the sponsored and acquired TCOs (FTCO and PTCO) of the TATA pair and the Hyundai pair are more economical than the TCOs of ICEV. We also find that in orbit 'J', the Hyundai pair FTCO reaches the cost parity zone, which is around 2% economical. In conclusion, the Hyundai dual BEV financing option may also prove to be economical when the proper arrangements are made.

5.2 Environmental Analysis Results

Figure 7 (a-g) shows the climatic implications for the simulated ICEV and BEV in the OpenLCA for the Indian setting. To further aid in mitigating the problem, the total impacts are further divided into the pre-use and usage phases. This allows for a clearer knowledge of the primary emitter source.

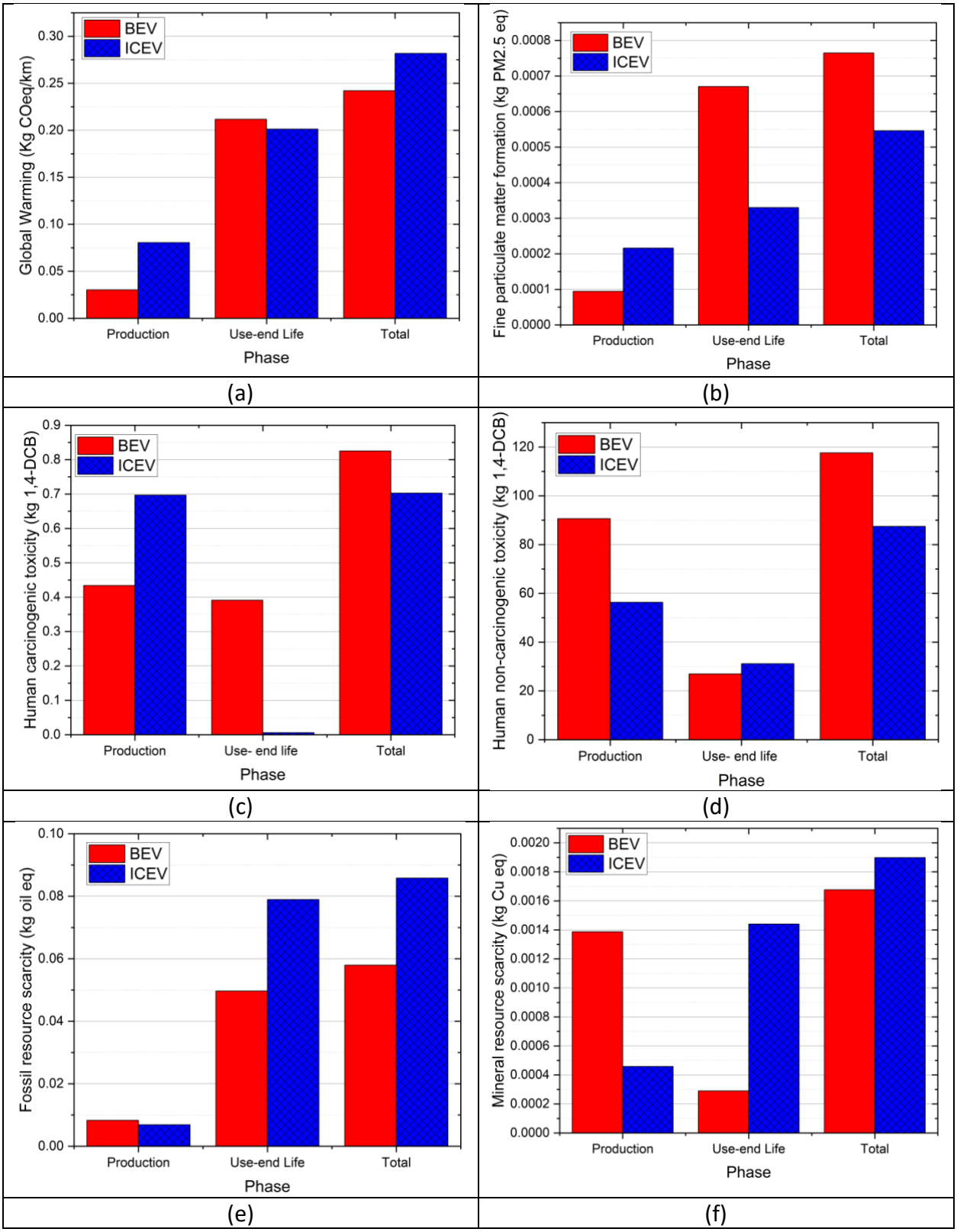
The results' primary effect categories—which are frequently discussed in the literature—are displayed in Figure 7(a–g).

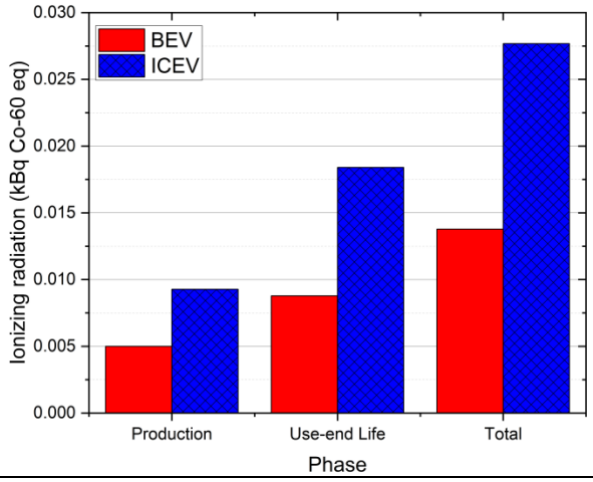
The global warming gases (GHG) emissions are the subject of the most frequent plot literature discussion; it is discovered that BEVs emit fewer GHGs than ICEVs.

Wu et al.'s findings are also consistent with other literature [40]. Though in a distributed study, the GHG emissions from BEVs during the use phase are somewhat higher than those from ICEVs, the GHG emissions from BEVs are still only 15% of those from ICEVs. This could be explained by the fact that coal-powered facilities already make up a sizable portion of India's electricity mix.

Beyond the production of greenhouse gases, BEVs do well in impact categories like resource scarcity and ionizing radiation. In ionizing radiation impact categories, where emissions from BEVs are nearly half those of ICEVs, the emissions gap is observed rather clearly. When there is a shortage of mineral resources, the BEV has very high emissions during the production phase, but these emissions are closed during use, resulting in lower overall emissions than ICEVs. However, when taking into account all the impact areas, ICEV do not always end out negatively. ICV emit equivalent levels of pollution that are lower in categories including human toxicity and finite particle matter. In contrast with BEVs, IEVs' emissions in the human carcinogenic toxicity impact category during use are essentially insignificant.

The findings show that neither the BEV nor the ICEV benefit from the emissions in the various effect categories. Figure 8's relative graph, which displays all of the impact categories for both automobiles, can be used to get deeper understanding. It is discovered that the BEV emits less in nearly ten of the eighteen categories; the category with the least variation in emissions each category is terrestrial acidification, at roughly 7%. The impact category of freshwater eutrophication has the largest range, with nearly over 73% of the total.


BEV
ICEV
Global Warming (Kg COeq/km)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Production
Use-end Life
Total
Phase
(a)
Fine particulate matter formation (kg PM2.5 eq)
0.0000
0.0001
0.0002
0.0003
0.0004
0.0005
0.0006
0.0007
0.0008
Production
Use-end Life
Total
Phase
(b)
Human carcinogenic toxicity (kg 1,4-DCB)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Production
Use- end life
Total
Phase
(c)
Human non-carcinogenic toxicity (kg 1,4-DCB)
0
20
40
60
80
100
120
Production
Use- end life
Total
Phase
(d)
Fossil resource scarcity (kg oil eq)
0.00
0.02
0.04
0.06
0.08
0.10
Production
Use-end Life
Total
Phase
(e)
Mineral resource scarcity (kg Cu eq)
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
0.0012
0.0014
0.0016
0.0018
0.0020
Production
Use-end Life
Total
Phase
(f)



(g)

Figure 7: Impact assessment of BEV in comparison to ICEV for a) Global warming b) fine particulate matter c) human toxicity (carcinogenic) d) human toxicity (non-carcinogenic) e) Fossil resource scarcity f) Mineral resource scarcity g) Ionizing radiation.

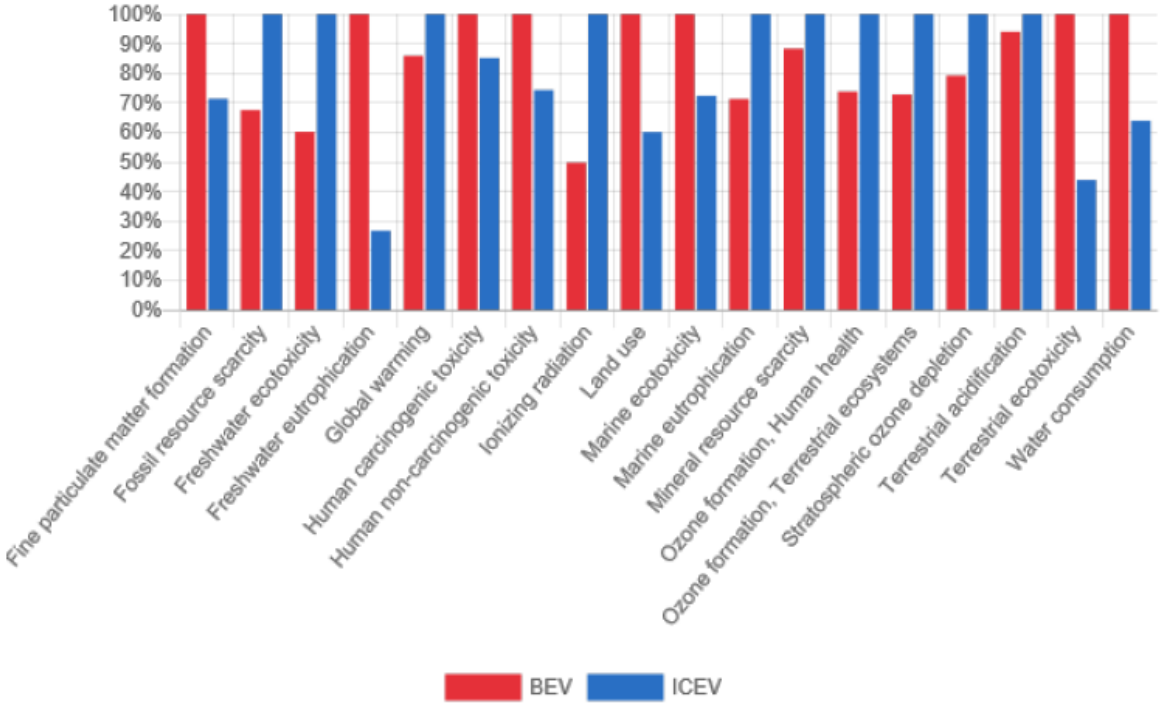


Figure 8: LCA relative results.

Last but not least, a single point score is obtained from the end-point analysis, showing that battery electric vehicles are more cost-effective when the total score—0.59 kpt—is taken into account, compared to the traditional vehicle's 2.12 kpt score.

6. Conclusion

For the Indian setting, a life cycle analysis comparison between a modeled or chosen battery electric vehicle and an internal combustion engine is conducted, taking into account both environmental and economic factors. This page assists end users in addressing the highly complex question of whether BEVs are environmentally and economically viable in India. Regarding economic compatibility, the base case taken into consideration here is significantly closer to actual data of the current situation and

finds that BEVs are not financially compatible with ICEV for both financed and purchased options in both pairings. In contrast, pair A's (TATA) total cost of ownership (TCO) gap is lower than pair B's (Hyundai). Additionally, a sensitivity analysis was conducted with various parameters considered in order to reduce the total cost of ownership (TCO) of BEVs in both pairs. The examination of sensitivity clarifies that aside from the component handled by technology (a 50% decrease in the cost of replacing batteries) not another each of the parameters alone can determine the BEVs' TCO. To be more affordable than ICEVs or almost cost parity. It's just with the parameter combinations from the sensitivity analysis the BEV attains cost parity and even gains enough efficiencies that the similar ICEV that is seen in the compatibility diagram. The compatibility wheel shows the financial performance of cars with twelve distinct parameter configurations, two of which (in orbits G and K) allow the BEV's total cost of ownership to enter the profitable range. With an annual mileage of roughly 20,000 km, the usage of EV+PV integration, 6% loan ROI, and incentives, battery electric vehicles seem to be the answer.

Environmental friendliness analysis was used to resolve the disturbed greenhouse gas emissions, and the result was an agreement that, in the Indian context, the greenhouse gas emissions from BEVs are lower than those from ICEVs. BEVs do not, however, perform better than ICEVs in all impact categories when it comes to emissions. Although not in the vast majority of cases, ICEVs have less emissions in 8 out of the 18 impact areas. The class with the least amount of emissions difference between BEVs and ICEVs is the one that affects terrestrial acidification the least, while freshwater eutrophication varies the most.

By dividing the overall emissions into the pre-use and usage phases, one may identify the real significant source of emissions, which in turn helps to reduce or remove the source of concern. The BEV has a significantly lower overall emission score (0.59 kpt) than the ICEV (2.12 kpt) based on the end-point study. Lastly, switching to renewable energy sources can make this battle for environmental compatibility worse. Recycling the products and using correct production techniques will also assist to carefully reduce the emissions from battery-electric vehicles.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] K. Petrauskieneˇ , M. Skvarnavicˇi_uteˇ , J. Dvarioneneˇ , Comparative environmental life cycle assessment of electric and conventional vehicles in Lithuania, J. Clean.Prod. 246.

[2] Kalghatgi, G., 2018. Is it really the end of internal combustion engines and petroleum in transport? Appl. Energy 225 (May), 965.

[3] Hauschild, M.Z., Rosenbaum, R.K. and Olsen, S.I., 2018. Life cycle assessment. Springer International Publishing, Cham.

[4] Global EV Outlook 2022, available at https://www.iea.org/reports/global-ev-outlook-2022.

[5] Lieven, T., Mühlmeier, S., Henkel, S., Waller, J.F., 2011. Who will buy electric cars? An empirical study in Germany. Transport. Res. Transport Environ. 16 (3), 236–243.

[6] O. Heidrich, G. A. Hill, M. Neaimeh, Y. Huebner, P. T. Blythe, and R. J. Dawson, "How do cities support electric vehicles and what difference does it make?," Technol. Forecast. Soc. Change, vol. 123, no. May, pp. 17–23, 2017

[7] India's crude imports from Russia up 7.2 times in April-May 2022. Available at : https://www.newindianexpress.com/business/2022/jul/14/indiascrude-imports-from-russia-up-72-timesin-april-may-2022-2476374.html#:~:text=India%20is%20the%20world's%20third,and%2014%25%20from%20the%20US

[8] India's oil import bill doubles to $119 billion in FY22. Available at: https://economictimes.indiatimes.com/industry/energy/oilgas/indias-oil-import-bill-doubles-to-usd-119-bn-infy22/articleshow/91049349.cms

[9] Total CO2 emissions-India. available at: https://www.iea.org/countries/india

[10] Sales of electric vehicles across India from financial year 2020 to 2022, by type, available at:

https://www.statista.com/statistics/1234761/india-electric-vehiclesales-by-type/

[11] Seixas, J., Sim˜oes, S., Dias, L., Kanudia, A., Fortes, P., Gargiulo, M., 2015. Assessing the cost-effectiveness of electric vehicles in European countries using integrated modeling. Energy Pol. 80, 165–176.

[12] A. P. Bhosale, S. Sharma, and S. A. Mastud, "Characterizing the economic competitiveness of battery electric vehicles in India," Asian Transp. Stud., vol. 8, no. 274, p. 100069, 2022.

[13] Zhao, X., Doering, O.C., Tyner, W.E., 2015. The economic competitiveness and emissions of battery electric vehicles in China. Appl. Energy 156, 666–675.

[14] Diao, Q., Sun, W., Yuan, X., Li, L., Zheng, Z., 2016. Life-cycle private-cost-based competitiveness analysis of electric vehicles in China considering the intangible cost of traffic policies. Appl.Energy 178, 567–578.

[15] Kara, S., Li, W., Sadjiva, N., 2017. Life cycle cost analysis of electrical vehicles in Australia. Procedia CIRP 61, 767–772.

[16] L´evay, P.Z., Drossinos, Y., Thiel, C., 2017. The effect of fiscal incentives on market penetration of electric vehicles: a pairwise comparison of total cost of ownership. Energy Pol. 105 (October2016), 524–533.

[17] Palmer, K., Tate, J.E., Wadud, Z., Nellthorp, J., 2018. Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan. Appl. Energy 209 (November 2017), 108–119.

[18] Potk´any, M., Lesníkov´a, P., 2019. The amount of subsidy for the electric vehicle in Slovakia through a strategic cost calculation.Transport. Res. Proc. 40, 1168–1175.

[19] Lieven, T., Mühlmeier, S., Henkel, S., Waller, J.F., 2011. Who will buy electric cars? An empirical study in Germany. Transport. Res. Transport Environ. 16 (3), 236–243.

[20] Bubeck, S., Tomaschek, J., Fahl, U., 2016. Perspectives of electric mobility: total cost of ownership of electric vehicles in Germany.Transport Pol. 50, 63–77.

[21] Tseng, H.K., Wu, J.S., Liu, X., 2013. Affordability of electric vehicles for a sustainable transport system: an economic and environmental analysis. Energy Pol. 61, 441–447.

[22] Wu, L., Liu, S., Liu, D., Fang, Z., Xu, H., 2015a. Modelling and forecasting CO2 emissions in the BRICS (Brazil, Russia, India, China, and South Africa) countries using a novel multi-variable grey model. Energy 79 (C), 489–495

[23] Mitropoulos, L.K., Prevedouros, P.D., Kopelias, P., 2017. Total cost of ownership and externalities of conventional, hybrid and electric vehicle. Transport. Res. Proc. 24, 267–274.

[24] Newbery, D., Strbac, G., 2016. What is needed for battery electric vehicles to become socially cost competitive? Econ. Transport. 5.

[25] Lucas A, Civa CA, Neto RC. Life cycle analysis of energy supply infrastructure for conventional and electric vehicles. Energy Pol 2012;41:537–47

[26] Ma H, Balthasar F, Tait N, Riera-Palou X, Harrison A. A new comparison between the life cycle greenhouse gas emissions of battery electric vehicles and internal combustion vehicles. Energy Pol 2012;44:160–73

[27] K. Premrudee, U. Jantima, A. Kittinan, L. Naruetep, K. Kittiwan, B. Sudkla, Life cycle assessment of lead acid battery. case study for Thailand, Environ. Prot. Eng. 39 (1) (2013) 101–114,

[28] M. Held and M. Baumann, "Towards Life Cycle Sustainability Management," Towar. Life Cycle Sustain. Manag., pp. 535–546, 2011, doi: 10.1007/978-94-007-1899-9.

[29] J. Van Mierlo, M. Messagie, and S. Rangaraju, "Comparative environmental assessment of alternative fueled vehicles using a life cycle assessment," Transp. Res. Procedia, vol. 25, pp. 3435–3445.

[30] L. L. P. de Souza, E. E. S. Lora, J. C. E. Palacio, M. H. Rocha, M., "Comparative environmental life cycle assessment of conventional vehicles with different fuel options, plug-in hybrid and electric vehicles for a sustainable transportation system in Brazil," J.Clean. Prod., vol. 203, pp. 444–468, 2018.

[31] G. Zhou, X. Ou, and X. Zhang, "Development of electric vehicles use in China: A study from the perspective of life-cycle energy consumption and greenhouse gas emissions," Energy Policy, vol. 59, no. 2013, pp. 875–884, 2013.

[32] Q. Qiao, F. Zhao, Z. Liu, and H. Hao, "Electric vehicle recycling in China: Economic and environmental benefits," Resour. Conserv. Recycl., vol. 140, no. July 2018, pp. 45–53, 2019.

[33] Gilmore, E.A., Patwardhan, A., 2016. Passenger vehicles that minimize the costs of ownership and environmental damages in the Indian market. Appl. Energy 184, 863–872.

[34] Messagie, M., Lebeau, K., Coosemans, T., Macharis, C., van Mierlo, J., 2013. Environmental and financial evaluation of passenger vehicle technologies in Belgium. Sustainability 5 (12),5020–5033..

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Assignment of Search and Rescue Teams to Adalar District: Possible Marmara Earthquake

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Abstract

Disaster management includes efforts to reduce the negative effects of a disaster. This management system has various challenges. Teams need to be sent to disaster areas as soon as possible to reduce losses and damages. Turkey, which frequently experiences earthquake disasters, has recently experienced the 2023 Kahramanmaraş earthquakes. After the recent earthquakes, the Great Marmara Earthquake, which scientists emphasize the most, has started to be discussed. It is said that Istanbul will be affected very much. Possible earthquake scenarios with a magnitude of 7.5 have been produced. In this study, Adalar district, which will be affected by the Great Marmara Earthquake, is considered and the problem of assigning teams to very heavily damaged buildings is discussed. For the continuation of the study, the data in the Istanbul Province Adalar District Possible Earthquake Loss Estimates Booklet is used. The 413 severely damaged buildings in the 5 neighborhoods where the destruction will occur and the number of building floors in the neighborhoods are taken into consideration. A mathematical model was created for the problem with the goal programming method. The model was solved with the Cplex solver of IBM ILOG optimization program. Thus, the optimal team assignment was realized.

Keywords: disaster management, search and rescue, marmara earthquake, istanbul, optimization, goal programming

1. Introduction

Turkey is an earthquake country that frequently experiences tectonic earthquakes caused by the movement of plates. According to the Earthquake Zones Map, 92% of Turkey is an earthquake zone and 95% of its population lives at risk of earthquakes. An earthquake is an event that causes loss of life by shaking the surface we know as motionless and damaging the structures on it.

It is unknown when the earthquake will occur, but all efforts to reduce the damages are the subject of disaster management. When an earthquake occurs, search and rescue, first aid, evacuation, prevention of secondary disasters, etc., are carried out by the necessary search and rescue teams. The earthquake, which causes significant damage, makes it difficult to carry out search and rescue activities in a coordinated manner. This reveals the difficulty of sending teams to disaster areas. It requires effective organization for emergency decision-makers to dispatch teams to disaster areas in a reasonable but rapid manner [1]. The complexity of disasters and emergencies affects the rapidity of this decision. Search and rescue operations that start immediately after the collapse of structures and trapping of people inside these structures continue sequentially and continuously. As soon as the disaster strikes, people in the immediate vicinity rush to help with their means. Search and rescue teams reaching the disaster areas face challenging tasks in multiple and dispersed disaster areas.

As a result of risk assessment studies, earthquake scenarios are created to estimate losses and damages in case of hazards at various locations and regions. These scenarios differ according to the time of the earthquake as day and night earthquake scenarios. In nighttime earthquakes, most people are considered to be in their homes. Accordingly, loss of life may be caused by damage to residential buildings.

In this study, we consider the problem of assigning search and rescue teams to the Adalar district of Istanbul in the event of a 7.5-magnitude Marmara Earthquake. According to this deterministic earthquake scenario, the earthquake will occur at night and search and rescue teams will be dispatched to heavily damaged buildings in 5 neighborhoods in the district.

2. The Seismicity of Istanbul Province

The tectonic structures controlling the earthquake hazard of Istanbul are expected to be the northern branch segments of the North Anatolian Fault, also called the Main Marmara Fault, located within the Marmara Sea. The western part of the North Anatolian Fault in the Sea of Marmara was ruptured in the 1912 earthquake, and the eastern part was ruptured in the 1999 Kocaeli Earthquake. It is thought that a Marmara Earthquake that will affect Istanbul will occur on one or more of the central segments that have not yet broken.

Due to its earthquake hazard, population size, building inventory stock and economic characteristics, Istanbul has become a region where earthquake risk should be determined as soon as possible. Seismic hazard studies of a possible earthquake and the extent to which settlement centers can be affected are tried to be analyzed by earthquake scenarios [2]. The map showing the risky earthquake zones for Istanbul is shown in Figure 1.

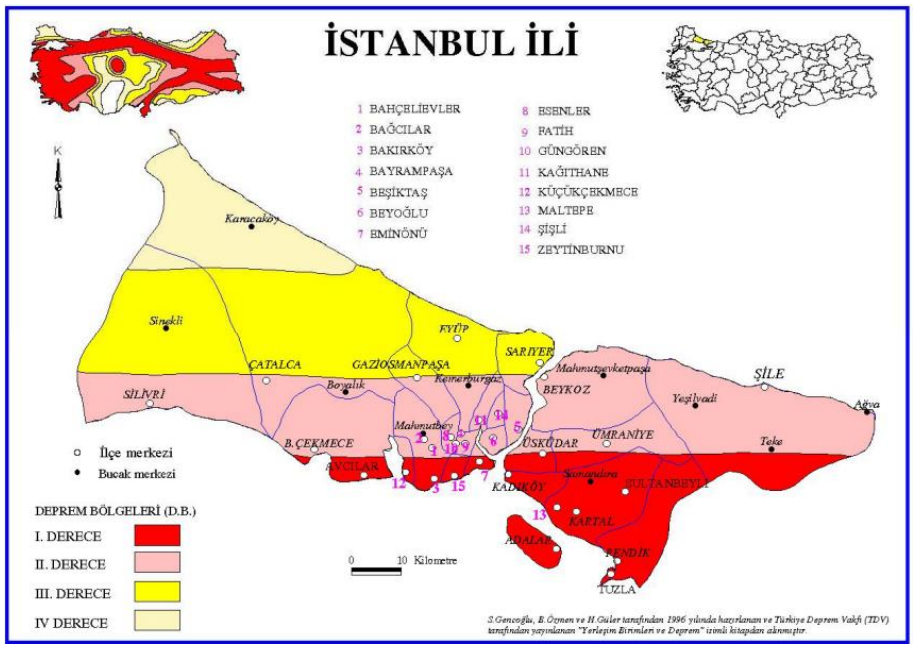

Figure 1: Istanbul Earthquake Zones (Source: [2])

Adalar district consists of 9 islands in Istanbul Province and its distance to the city center is 30 km. Kartal and Maltepe districts are the closest neighboring districts to Adalar district. This district has five neighborhoods: Burgazada, Heybeliada, Kınalıada, Maden and Nizam. According to 2019 TURKSTAT data, the population of the district is 15,238. There are 3,584 houses in the district before 1980. In addition, there are 6,155 houses with 1-4 floors and 538 houses with 5-8 floors, which make up 96%.

3. Literature Review

This study addresses the issue of assigning and scheduling search and rescue teams in disaster management, and the literature review on the related topic is presented in this section. The studies reviewed for the problem addressed in this study are summarized in Table 1.

Table 1: Literature Review

Author	Goal	Method
[3]	Assignment during the search and rescue period	Dynamic optimization, simulated annealing and tabu search
[4]	Planning rescue units and assigning units to incidents	Linear optimization, Monte Carlo based heuristic solution
[5]	Assigning and scheduling rescue units	Complex integer programming, GRASP metaheuristic approach
[6]	Allocating and scheduling rescue units under uncertainty	Biased random-key genetic algorithm
[7]	Assign rescue and medical units and allocate medical units to casualties at incident scenes	Optimization model proposal
[8]	Assigning teams	Multi-objective optimization
[9]	Assign rescue units in a multi-disaster area	Optimization model proposal
[10]	Assignment and scheduling of rescue units with fatigue effect	Three metaheuristic algorithms and TOPSIS
[11]	Assigning and scheduling rescue units	Complex integer programming and GRASP metaheuristic
[12]	Team planning taking into account the characteristics of the rescue team	Non-dominated sorting genetic algorithm and fuzzy logic method
[13]	Assignment and scheduling of recovery units with fatigue effect and withdrawal time	Multi-objective complex integer programming, Lp-metric method and two metaheuristics
[14]	Assignment and scheduling of rescue units with learning effect	Bi-objective complex integer linear programming
[15]	Duty assignment of rescuers	Agent-based simulation
[16]	Assignment and schedule of fatigue-impact recovery units	Two-objective complex integer programming
[17]	Search and rescue resource deployment planning	Complex integer programming
[1]	The problem of dispatching rescuers to multiple disaster areas	Dempster-Shafer theory with evidence-based best-worst method
[18]	Minimize the weighted completion time of rescue operations	Fuzzy robust optimization, hybrid metaheuristic algorithm
[19]	Assigning rescuers by calculating their synergy rating, fitness for duty rating and rescue time satisfaction rating	Optimization model proposal
[20]	Assignment of search and rescue and psychosocial support teams	Goal programming
[21]	Scheduling search and rescue teams to disaster districts	Goal programming
[22]	Scheduling search and rescue and psychosocial support teams to disaster areas	Goal programming
[23]	Scheduling search and rescue teams to disaster districts	Goal programming
[24]	Formation of search and rescue teams	Goal programming
[25]	Scheduling psychosocial support teams	Goal programming
[26]	Assignment of search and rescue teams	Goal programming

The goal programming method used in the considered problem has been widely used in the literature to solve many problems. [27] addressed the ergonomic staff scheduling problem in the retail sector with goal programming and AHP. [28] conducted a literature review on scheduling and planning in service systems with goal programming. [29] utilized goal programming and the ANP method in task-based personnel shift scheduling problems. [30] formulated the monthly staff assignment and scheduling problem during the pandemic period with the goal programming method. [31] addressed the operating room scheduling problem using constraint and goal programming methods. [32] used the goal programming method for shift scheduling of male and female security personnel. [33] addressed the ergonomic staff scheduling problem for female staff working in the textile industry with goal programming and the REBA method.

4. Application

The Adalar district of Istanbul Province, which will be affected by the expected Great Marmara Earthquake, which scientists have been discussing in recent years, has been taken as the place of application. The reason for considering the Adalar district, which will be significantly affected in population density, is to prevent a great tragedy due to the expected Marmara Earthquake. In this context, a sample planning study is presented on the problem of assigning search and rescue teams to disaster areas. The flowchart of the problem is given in Figure 2.

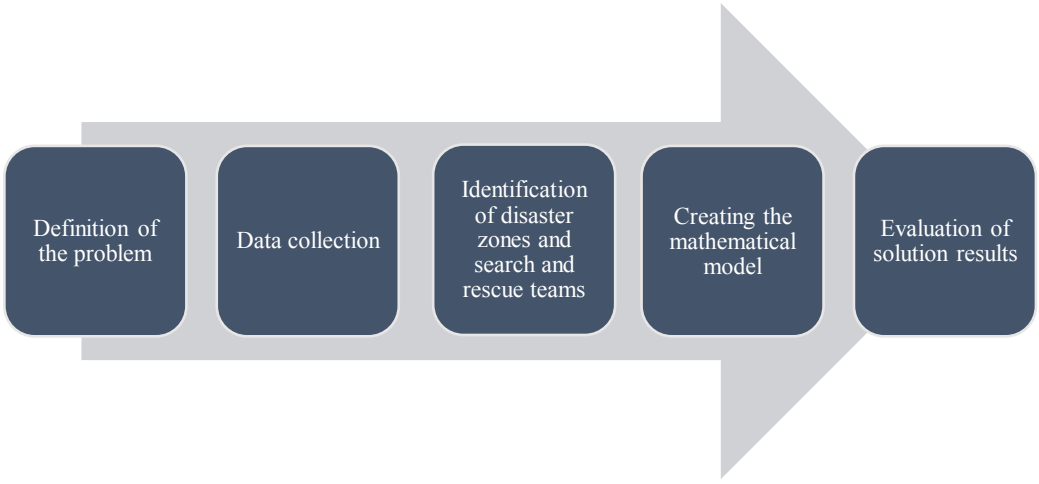

Figure 2: Flow Chart of the Problem

4.1. Problem Definition

This study addresses the problem of assigning teams to very heavily damaged buildings by considering the Adalar district, which will be affected by the Great Marmara Earthquake. The study is continued by using the 7.5 magnitude night earthquake scenario of the Main Marmara Fault, which has yet to be broken recently, included in the Istanbul Province Adalar District Possible Earthquake Loss Estimations Booklet. The data used in the study were the number of very heavily damaged buildings on a neighborhood basis calculated by the risk analysis module of the ELER software. To solve the problem, a mathematical model was created with the goal programming method, taking into account the number of building floors. The model was solved with the IBM ILOG program.

4.2. Data Collection

The data used in this study are listed below.

- ✓ Adalar district earthquake scenario
- ✓ The number of damaged buildings was calculated with ELER software
- ✓ Neighborhood-based building floor numbers
- ✓ Information about search and rescue teams

4.3. Identification of Disaster Zones and Search and Rescue Teams

When the results of the estimates of the number of damaged buildings in the Adalar district are examined, it is seen that five neighborhoods that require search and rescue operations were severely damaged. These neighborhoods are Burgazada, Heybeliada, Kınalıada, Maden and Nizam. In total, 413 buildings were severely damaged.

4.4. Creating the Mathematical Model

4.4.1. Goal Programming

The goal programming method, used to solve many problems in the literature, simultaneously provides conflicting objectives. There are multiple objectives in this method. The method achieves the desired objective by minimizing the deviation variables that express the deviations of the constraints from the objectives [34], [35]. The mathematical form of the method is as follows.

$x_j: j.\,decision\ variable$

$a: decision\ variable\ coefficient\ parameter$

$r: goal\ constraint\ right\ side\ value\ parameter$

$d_i^+: i.\,positive\ deviation\ value\ of\ goal$

$d_i^-: i.\,negative\ deviation\ value\ of\ goal$

$$Min\ Z = \sum_{i=1}^{n} (d_i^+ + d_i^-) \tag{1}$$

$$\sum_{j=1}^{m} a * x_j - d_i^+ + d_i^- = r \tag{2}$$

$$x_j, d_i^+, d_i^- \geq 0 \qquad \forall_{i,j} \tag{3}$$

Equation (1) is the objective function of the model. Equation (2) is the objective constraint of the model, where r is the desired right-hand side value. Equation (3) is the rigid constraint of the model; if it is not satisfied, the model is unsolvable.

4.4.2. Mathematical Model Created

Parameters

$n = number\ of\ teams$

$m = number\ of\ neighborhoods$

$i = team\ index \qquad i = 1,2,\dots,330$

$j = neighborhood\ index \qquad j = 1,2,\dots,5$

Decision variables

$$x_{ij} = \begin{cases} 1, if\ team\ i\ is\ assigned\ to\ neighborhood\ j. \\ 0, other\ situations \end{cases} \qquad \forall_{i,j}$$

$$\sum_{i=1}^{n} x_{ij} \geq 1 \qquad \forall_j \tag{1}$$

$$\sum_{j=1}^{m} x_{ij} \leq 1 \qquad \forall_i \tag{2}$$

$$\sum_{i=1}^{n} x_{i1} - d_{i1}^{+} + d_{i1}^{-} = 45 \tag{3}$$

$$\sum_{i=1}^{n} x_{i2} - d_{i2}^{+} + d_{i2}^{-} = 75 \tag{4}$$

$$\sum_{i=1}^{n} x_{i3} - d_{i3}^{+} + d_{i3}^{-} = 50 \tag{5}$$

$$\sum_{i=1}^{n} x_{ij} - d_{i4}^{+} + d_{i4}^{-} = 80 \quad j = (4,5) \tag{6}$$

$$min\, Z = \sum_{i=1}^{n} (d_{i1}^{+} + d_{i1}^{-} + d_{i2}^{+} + d_{i2}^{-} + d_{i3}^{+} + d_{i3}^{-} + d_{i4}^{+} + d_{i4}^{-}) \tag{7}$$

$$x_{ij} = 0\ veya\ 1 \quad \forall_{i,j} \tag{8}$$

$$d_{i1}^{+}, d_{i1}^{-}, d_{i2}^{+}, d_{i2}^{-}, d_{i3}^{+}, d_{i3}^{-}, d_{i4}^{+}, d_{i4}^{-} \geq 0 \qquad \forall_i \tag{9}$$

Equation (1) refers to assigning at least 1 team to each neighborhood and Equation (2) refers to assigning each team to at most one neighborhood. Equations (3)-(6) are the objective constraints of the problem. Equation (3) aims to assign 45 teams to the Burgazada neighborhood, Equation (4) aims to assign 75 teams to the Heybeliada neighborhood, Equation (5) aims to assign 50 teams to the Kınalıada neighborhood, Equation (6) aims to assign 80 teams to the Maden and Nizam neighborhoods. Equation (7) is the objective function of the problem. Equations (8)-(9) are the sign constraints of the problem's decision variables.

4.5. Evaluation of Solution Results

According to the solution results, 45 search and rescue teams were assigned to the Burgazada neighborhood, 75 to the Heybeliada neighborhood, 50 to the Kınalıada neighborhood, 80 to the Maden neighborhood, and 80 to the Nizam neighborhood. All 330 search and rescue teams considered in the problem were assigned to the disaster areas and all objective constraints were met. The solution results are given in Figure 3.

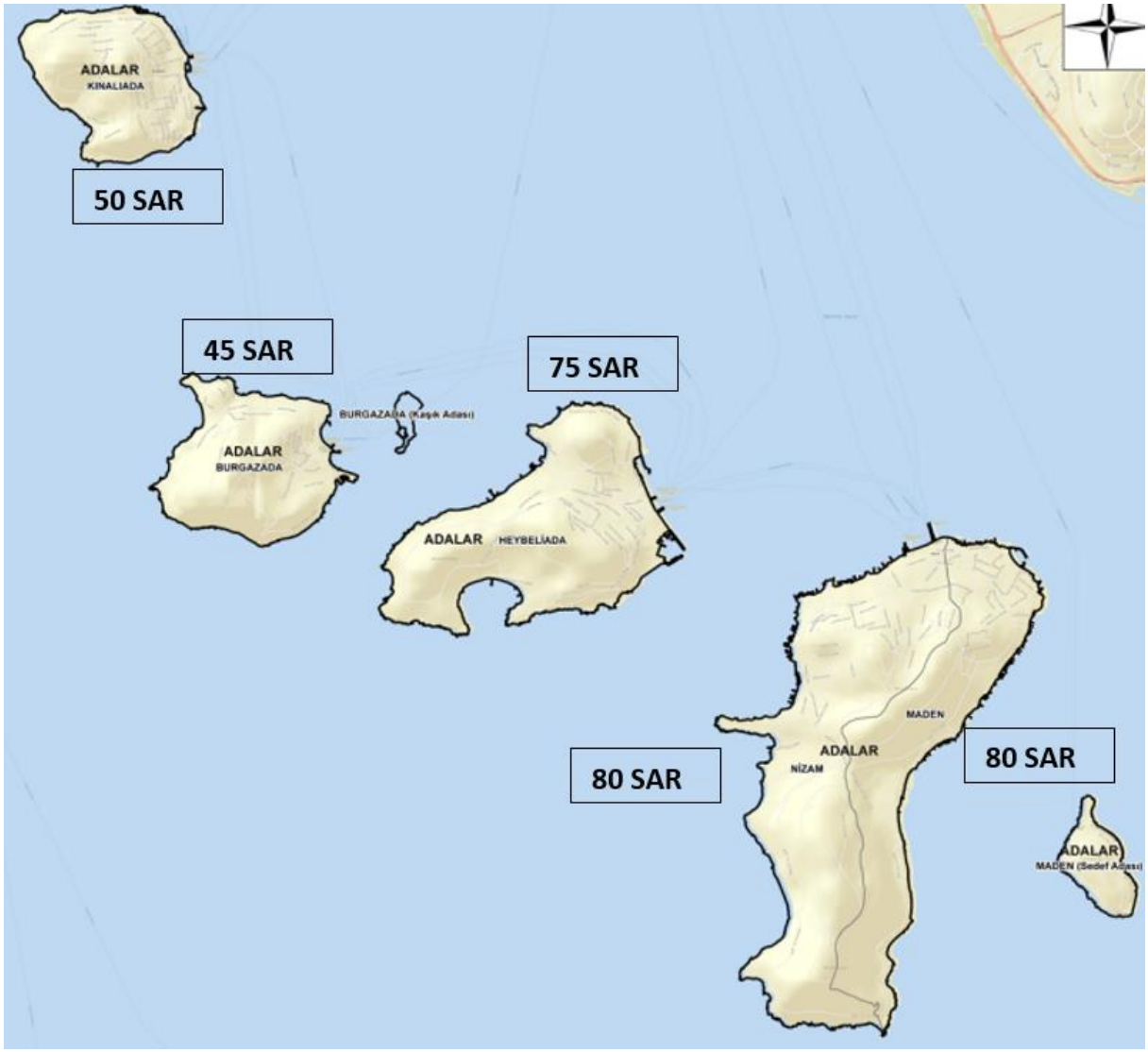

Figure 3: Solution Results (SAR: Search and Rescue Teams)

5. Conclusions And Recommendations

It aims to minimize losses and damages by assigning teams to disaster areas with a deterministic earthquake scenario. Thanks to the results obtained from the problem, it will plan which number of teams should go to which neighborhood in the Adalar district, which is predicted to be heavily damaged in the expected Marmara earthquake. It will support decision-makers by eliminating the chaos that may occur during the disaster. Thus, the response phase will start as soon as possible. 413 buildings in 5 neighborhoods in Adalar district are severely damaged. Looking at the solution results obtained, all of the search and rescue teams available in the targeted numbers were assigned to the neighborhoods of Adalar district.

In this study, the teams were assigned assuming the destruction would occur only in Adalar district. In future studies, the mathematical model created by including other districts where the destruction will occur in the problem can be used again.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Fei, L. and Wang, Y., "An Optimization Model For Rescuer Assignments Under An Uncertain Environment By Using Dempster–Shafer Theory", *Knowledge-Based Systems*, no. 255, 109680, 2022.

[2] Özmen, B., "İstanbul İli İçin Deprem Senaryosu", *Türkiye Mühendislik Haberleri*, no. 47(417), pp. 23-28, 2002.

[3] Fiedrich, F., Gehbauer, F. and Rickers, U., "Optimized Resource Allocation For Emergency Response After Earthquake Disasters", *Safety Science*, no. 35, pp. 41-57, 2000.

[4] Wex, F., Schryen, G. and Neumann, D., "Decision Modeling for Assignments of Collaborative Rescue Units during Emergency Response", *In 2013 46th Hawaii International Conference on System Sciences, IEEE*, pp. 166-175, 2013.

[5] Santoso, A., Prayogo, D.N., Parung, J., Iswadi, H. and Rizqi, D.A., "Model Development of Rescue Assignment and Scheduling Problem Using Grasp Metaheuristic", *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2017. https://doi.org/10.1109/IEEM.2017.8290124

[6] Cunha, V., Pessoa, L., Vellasco, M., Tanscheit R. and Pacheco, M.A., "A Biased Random-Key Genetic Algorithm for the Rescue Unit Allocation and Scheduling Problem", *IEEE Congress on Evolutionary Computation (CEC)*, pp. 1-6, 2018.

[7] Rezapour, S., Nader, N., Morshedlou, N. and Rezapourbehnagh, S., "Optimal deployment of emergency resources in sudden onset disasters", *International Journal of Production Economics*, no. 204, pp. 365-382, 2018.

[8] Song, Y., Song, Y.H., Liu, D. and Wang, Z., "Earthquake emergency rescue teams assignment model based on time satisfaction and competence", *China Safety Science Journal*, no. 28(8), pp. 180–184, 2018.

[9] Li, M.Y., Zhao, X.J., Fan, Z.P., Cao, P.P. and Qu, X.N., "A Model For Assignment of Rescuers Considering Multiple Disaster Areas", *International Journal of Disaster Risk Reduction*, no. 38, 101201, 2019.

[10] Nayeri, S., Asadi-Gangraj, E. and Emami, S., "Metaheuristic Algorithms To Allocate And Schedule of The Rescue Units In The Natural Disaster With Fatigue Effect", *Neural Computing and Applications*, no. 31(11), 7517-7537, 2019.

[11] Santoso, A., Sutanto, R.A.P., Prayogo, D.N. and Parung, J., "Development of fuzzy RUASP model-Grasp metaheuristics with time window: Case study of Mount Semeru eruption in East Java", *In IOP Conference Series: Earth and Environmental Science*, no. 235(1), 012081, 2019.

[12] Shuwen, Z., Can, L., Kejun, Z. and Shiwei, Y., "Optimal Scheduling Strategy with Emergency Rescue Team's Characteristics Taken into Consideration", *Management Review*, no. 31(2), pp. 225-237, 2019.

[13] Nayeri, S., Tavakkoli-Moghaddam, R., Sazvar, Z. and Heydari, J., "Solving An Emergency Resource Planning Problem With Deprivation Time By A Hybrid Metaheuristic Algorithm", *Journal of Quality Engineering and Production Optimization*, no. 5(1), pp. 65-86, 2020.

[14] Tirkolaee, E.B., Aydın S.N., Ranjbar-Bourani, M. and Weber, G.W., "A Robust Bi-Objective Mathematical Model For Disaster Rescue Units Allocation And Scheduling With Learning Effect", *Computers & Industrial Engineering*, no. 149, 106790, 2020.

[15] Hooshangi, N., Alesheikh, A.A., Panahi, M. and Lee, S., "Urban Search And Rescue (USAR) Simulation System: Spatial Strategies For Agent Task Allocation Under Uncertain Conditions", *Natural Hazards and Earth System Sciences*, no. 21(11), pp. 3449-3463, 2021.

[16] Nayeri, S., Asadi-Gangraj, E., Emami, S. and Rezaeian, J., "Designing A Bi-Objective Decision Support Model For The Disaster Management", *RAIRO-Operations Research*, no. 55(6), pp. 3399-3426, 2021.

[17] Ahmadi, G., Tavakkoli-Moghaddam, R., Baboli, A. and Najafi, M., "A decision support model for robust allocation and routing of search and rescue resources after earthquake: a case study", *Operational Research*, pp. 1039-1081, 2022.

[18] Nayeri, S., Sazvar, Z. and Heydari, J., "A Fuzzy Robust Planning Model In The Disaster Management Response Phase Under Precedence Constraints", *Operational Research*, no. 22, pp. 3571-3605, 2022.

[19] Cao, P., Zheng, J., Li, M. and Fu, Y., "A Model for the Assignment of Emergency Rescuers Considering Collaborative Information", *Sustainability*, no. 15(2), 1203, 2023.

[20] Akdaş, E., "Afet Yönetiminde Arama-Kurtarma ve Psikososyal Destek Ekiplerinin Atanması", *Yüksek Lisans Tezi*, Kırıkkale Üniversitesi, Fen Bilimleri Enstitüsü, 2023.

[21] Akdaş, E. and Eren, T., "Deprem Afetinde Arama Kurtarma Ekiplerinin Çizelgelenmesi İçin Örnek Bir Uygulama", S*igma Journal of Engineering and Natural Sciences*, Basımda, 2023(a).

[22] Akdaş, E. and Eren, T., "Arama Kurtarma ve Psikosoyal Destek Ekiplerinin Afet İllerine Atanması ve Çizelgelenmesi: Erzincan Depremi Örneği", *Uluslararası Veri Bilimi ve Güvenliği Konferansı, ICDASS2023, 6-7 Temmuz 2023*, Atatürk Üniversitesi, Erzurum, Türkiye, 2023(b).

[23] Akdaş, E. and Eren, T., "Doğal Afetlerde Arama Kurtarma Ekiplerinin Çizelgelenmesi: Aydın Depremi Senaryosu", *5th Conference on Applied Engineering and Natural Sciences*, no. 1(1), pp. 718-724, Konya, Türkiye, 2023(c).

[24] Akdaş, E. and Eren, T., "Afet ve Acil Durum Yönetiminde Arama Kurtarma Ekiplerinin Oluşturulması", *Afet ve Risk Dergisi*, no. 6(3), pp. 1060-1073, 2023(d).

[25] Akdaş, E. and Eren, T., "Afet ve Acil Durum Yönetiminde Psikososyal Destek Ekiplerinin Çizelgelenmesi: Bingöl Örneği", *Disaster Science and Engineering*, no. 9(1), pp. 23-332023(e).

[26] Akdaş, E. and Eren, T. "Arama Kurtarma Ekiplerinin Atanması: Olası Bingöl Depremi Örneği", *Türk Deprem Araştırma Dergisi*, no. 5(2), pp. 128-147, 2023(f).

[27] Bedir, N., Eren, T. and Dizdar, E.N., "Ergonomik personel çizelgeleme ve perakende sektöründe bir uygulama", *Mühendislik Bilimleri ve Tasarım Dergisi*, no. 5(3), pp. 657-674, 2017.

[28] Gür, Ş. and Eren, T., "Scheduling and planning in service systems with goal programming: Literature review", *Mathematics*, no. 6(11), 265, 2018.

[29] Özder, E. H., Özcan, E. and Eren, T., "Staff task-based shift scheduling solution with an ANP and goal programming method in a natural gas combined cycle power plant", *Mathematics*, no. 7(2), 192, 2019.

[30] Cürebal, A., Koçtepe, S. and Eren, T., "Organizasyon firması için COVID-19 pandemi döneminde aylık personel atama ve çizelgeleme probleminin çözümü: bir uygulama", *Journal of Turkish Operations Management*, no. 4(2), pp. 479-493, 2020.

[31] Gür, Ş., Pınarbaşı, M., Alakaş, H. M. and Eren, T., "Operating room scheduling with surgical team: a new approach with constraint programming and goal programming", *Central European Journal of Operations Research*, no. 31(4), 1061-1085, 2023.

[32] Eren, T. and Akdaş, E., "Devlet Tiyatroları Genel Müdürlüğü'nde Güvenlik Personeli Vardiya Çizelgelemesi", *Uluslararası İşletme Bilimi ve Uygulamaları Dergisi*, no. 3(1), pp. 1-18, 2023.

[33] Aksüt, G., Alakaş, H. M., Eren, T. and Karaçam, H., "Fiziksel ergonomik riskli personel çizelgeleme problemi için model önerisi: Kadın çalışanlar için tekstil sektöründe bir uygulama", *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, no. 38(1), pp. 245-256, 2023.

[34] Eren, T., Özder, E.H. and Varlı, E., "Hedef Programlama Yaklaşımı İle Temizlik Personeli Çizelgeleme Problemi İçin Bir Model Önerisi", *Karadeniz Fen Bilimleri Dergisi*, no. 7(2), pp. 114-127, 2017.

[35] Tamiz, M., Jones, D.F., "Interactive Framework For Investigation Of Goal Programming Models: Theory And Practice", *Journal of Multi-Criteria Decision Analysis*, no. 6, pp. 52-60, 1997.

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İkincil Afetlerden Deprem Sonrası Yangına Yönelik Simülasyon Metodolojileri: Kavramsal Bir Bakış Açısı

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Özet

Deprem sonrası yangınlar; önemli bir ikincil afet olarak yaşam kaybı, yapı hasarı ve finansal zarar açısından deprem kaynaklı sismik hasarın boyutlarını büyük ölçüde artırma potansiyeline sahiptir. Yoğun nüfusa sahip kentsel bölgelerde deprem nedeniyle yangınla mücadele ekipmanlarının zarar görmesi, yolların gerekli itfaiye ve acil müdahale faaliyetlerini engelleyecek biçimde tıkanması, yangına sebebiyet verebilecek elektrik ve gaz hatlarında meydana gelebilecek hasarlar ve iletişim hatlarındaki olası kesintiler sebebiyle deprem sonrası yangın riski üzerinde durulması gereken önemli bir risktir. Simülasyon metodolojileri, deprem sonrası yangın riskinin değerlendirilmesinde ve mevcut risklere karşı topluluk direncini artırabilecek önlemlerin belirlenmesinde literatürde en yaygın kullanılan yöntemlerden biridir. Bu çalışmada, 2000 yılı sonrasında yayımlanan, deprem sonrası yangın riskinin ele alınmasında ve bu afetlere karşı yürütülebilecek faaliyetlerin değerlendirilmesinde simülasyon metodolojilerini kullanan makaleler incelenmiştir. İlgili anahtar kelimeler kullanılarak ulaşılan çalışmaların bibliyografik özellikleri sunularak, deprem sonrası yangını simülasyon odağında ele alan çalışmalara kavramsal bir bakış açısı sunulmuştur.

Anahtar Kelimeler: deprem sonrası yangın, ikincil afet, simülasyon, bibliyografik analiz, literatür araştırması

Simulation Methodologies for Post Earthquake Fire as a Secondary Disaster: A Conceptual Framework

Abstract

As a major secondary disaster, post earthquake fires have the potential to significantly enhance the extent of seismic damage caused by earthquakes in terms of fatalities, structural damage and financial loss. Due to possible damage to firefighting equipment, road blockages that restrict the requirement for emergency response and firefighting operations, potential damage to gas and electricity lines that could result in fires and potential disruptions to communication lines, there is a significant risk of post earthquake fire that should be assessed in densely populated urban areas. Simulation methodologies are one of the most widely used techniques in the literature in assessing post earthquake fire risk and determining actions that may improve community resilience against existing risks. This study examines articles published after 2000 that use simulation methodologies to address post earthquake fire risk and evaluate preventative actions that can be taken against these disasters. A conceptual framework is provided to the studies that address post earthquake fire in a simulation focus by displaying the bibliographic features of the studies that are accessed using the relevant keywords.

Keywords: post earthquake fire, secondary disaster, simulation, bibliographic analysis, literature review

1. Giriş

Depremler, afet yönetimi literatüründe en sık ele alınan doğal afetler arasında yer almaktadır. Çeşitli ikincil afetleri tetikleme potansiyeli bulunan depremlerin topluluk üzerinde birçok yıkıcı etkisi bulunmakta olup, bunlar arasından en önemlisi şüphesiz can kaybına neden olma potansiyelidir. İstatiksel veriler, deprem nedenli can kayıplarının deprem sonrası yangınlar, tsunami ve heyelan gibi diğer tehlikeleri de içeren çeşitli nedenlerden kaynaklandığını ortaya koymaktadır [1]. Deprem kaynaklı olarak meydana gelen ve depremin meydana getirdiği kayıpları ileri boyutlara ulaştırma potansiyeline sahip bu tehlikeler arasında, deprem sonrası yangınlar kentsel bölgelerde yaygın olarak yaşanan en yıkıcı olaylardan biri olarak kabul edilmektedir [2].

Deprem sonrası yangınlar, genellikle büyük depremler nedeniyle meydana gelen, geniş boyutta mali ve insani kayıplara yol açabilen ciddi bir ikincil afet olarak kabul edilmektedir [3]. Deprem sonrası yangınlar; doğal gaz kaynaklı tutuşmalar, bitki örtüsü ve çarpık kentleşme nedenli tutuşmalar, depremi takip eden kaos durumunun ortaya çıkardığı olaylar, binalarda aktif yangınla mücadele sistemlerinin yer almaması, yangın koruma sistemlerinde deprem kaynaklı meydana gelen hasar, rüzgar kuvveti ve potansiyel hava hareketi gibi çok çeşitli faktörler nedeniyle meydana gelebilmektedir [4]. Deprem sonrasında binalardaki yangınla mücadele ekipmanlarının zarar görmesi, yıkılan binalar nedeniyle yolların tıkanması ve bu nedenle kurtarma faaliyetlerinin zorluğunun artması gibi faktörler deprem sonrası yangın kayıplarının boyutunu büyük ölçüde artırmaktadır [2].

Tarihsel deprem sonrası yangın olayları incelendiğinde, 1906 San Francisco depreminde meydana gelen güçlü sarsıntıya rağmen oluşan hasarın büyük çoğunluğu deprem kaynaklı yangınlardan kaynaklanmış ve sonuç olarak 28,000'den fazla bina etkilenmiştir [5]. 1923 Kanto depremini takiben iki gün süren yangınlar meydana gelmiş ve 694,000'den fazla binayı etkileyerek 140,000'den fazla can kaybına neden olmuştur [2]. 1994 Northridge depreminde ortalama 110 yangın rapor edilmiş, 1995 Kobe depreminde ise özellikle şehir merkezinin yoğun yapılaşmış bölgelerinde meydana gelen 108 yangın rapor edilmiştir [5]. Tarihsel olaylara dair verilerin de ortaya koyduğu üzere, deprem sonrası yangınlar depremin yıkıcı etkilerini daha ileri seviyeye taşıma potansiyeline sahip önemli ikincil afetler olup, bu afetlerin incelenmesi etkili afet yönetimi ve topluluk direncinin artırılması açısından oldukça önemlidir.

Bu çalışmada, literatürde deprem sonrası yangın afetini incelemede simülasyon yaklaşımlarını ele alan çalışmalar incelenmiştir. Bu çalışmaların literatürdeki yeri ve üzerine yoğunlaştıkları konuları değerlendirmek üzere bibliyografik analizler yürütülmüştür.

Çalışmanın ikinci bölümünde, literatür araştırması sürecinde izlenen metot ve ilgili anahtar kelimelerle ulaşılan çalışmaların bibliyografik analiz sonuçları sunulmuştur.

Çalışmanın üçüncü bölümünde, simülasyon metodolojileri çerçevesinde deprem sonrası yangın riskine odaklanan çalışmalar ele alınarak bu çalışmalar detaylı olarak incelenmiş ve elde edilen bulgular sunulmuştur.

Çalışmanın dördüncü ve son bölümünde ise uygulanan bibliyografik analizler ile literatür incelemesi ile elde edilen çıkarımlar ve sonuçlara yer verilmiştir.

2. Literatür Araştırması ve Bibliyografik Analiz

Literatürde deprem sonrası yangın afetini simülasyon yaklaşımları ile ele alan çalışmalara kavramsal bir bakış açısı sunmak üzere; deprem sonrası yangın literatüründe sıklıkla kullanılan "post earthquake fire (deprem sonrası yangın)" ve "fire following earthquake (depremi takip eden yangın)" anahtar kelimeleri, "simulation (simülasyon)" anahtar kelimesi ile birlikte ilgili veri tabanları üzerinde aratılmıştır. Çalışmada, araştırmacılar tarafından en sık kullanılan akademik veri tabanları arasında olmaları sebebiyle Scopus ve Web of Science veri tabanlarından yararlanılmıştır. Bibliyografik analiz için bu iki veri tabanından elde edilen sonuçlar bir araya getirilmiştir.

İlgili anahtar kelimeler için literatür araştırması adımları Tablo 2.1 ve Tablo 2.2'de sunulmuştur:

Tablo 1: "Post Earthquake Fire (Deprem Sonrası Yangın)" ve "Simulation (Simülasyon)" Anahtar Kelimeleri için Literatür Araştırması Adımları

"Post Earthquake Fire (Deprem Sonrası Yangın)" ve "Simulation (Simülasyon)" Anahtar Kelimeleri için Literatür Araştırması Adımları	***Veri Tabanları***	
	Scopus	**Web of Science**
1) Anahtar kelimelerin makale başlığı, özet ve anahtar kelimeler içerisinde aratılması sonucu ulaşılan doküman sayısı	66	32
2) 2000 ve 2023 arasında yayımlanan çalışmaların filtrelenmesi sonucunda ulaşılan doküman sayısı	65	32
3) Doküman tipinin "Makale (Article)" olarak filtrelenmesi sonucunda ulaşılan doküman sayısı	48	27
4) Doküman dilinin "İngilizce" olarak filtrelenmesi sonucunda ulaşılan doküman sayısı	37	27

Tablo 2: "Fire Following Earthquake (Depremi Takip Eden Yangın)" ve "Simulation (Simülasyon)" Anahtar Kelimeleri için Literatür Araştırması Adımları

"Fire Following Earthquake (Depremi Takip Eden Yangın)" ve "Simulation (Simülasyon)" Anahtar Kelimeleri için Literatür Araştırması Adımları	***Veri Tabanları***	
	Scopus	**Web of Science**
1) Anahtar kelimelerin makale başlığı, özet ve anahtar kelimeler içerisinde aratılması sonucu ulaşılan doküman sayısı	31	19
2) 2000 ve 2023 arasında yayımlanan çalışmaların filtrelenmesi sonucunda ulaşılan doküman sayısı	29	19
3) Doküman tipinin "Makale (Article)" olarak filtrelenmesi sonucunda ulaşılan doküman sayısı	20	16
4) Doküman dilinin "İngilizce" olarak filtrelenmesi sonucunda ulaşılan doküman sayısı	18	15

Veri tabanları üzerinden ulaşılan ve ilgili filtrelemeler sonucunda elde edilen çalışmaların kayıtları RStudio'da kullanılmak üzere BibTeX formatında dışarıya aktarılmıştır. BibTeX dokümanları, R programının "bibliometrix" kütüphanesinin "convert2df" fonksiyonu kullanılarak okunmuştur. Scopus ve Web of Science için final doküman sayıları sırasıyla 55 ve 42 olmuştur.

R programının "bibliometrix" kütüphanesinin "mergeDbsources" fonksiyonu kullanılarak, iki veri tabanından elde edilen dokümanlar bir araya getirilmiş ve tekrarlanan dokümanların elenmesi sağlanmıştır. 42 adet dokümanın yinelendiği belirlenmiştir. Bir araya getirme ve yinelenen dokümanları eleme süreçlerinden sonra elde edilen doküman sayısı 55 olarak belirlenmiştir. Bu 55 çalışmaya ait veriler, Bibliometrix ve VOSViewer yazılımlarında kullanılmak üzere ".xlsx" ve ".txt" formatlarına çevrilmiştir.

Bibliometrix, R üzerine kurulu bir açık kaynak uygulaması olup kapsamlı bilimsel haritalama analizi için kullanılmaktadır [6]. Bibliometrix, birçok farklı bibliyometrik veri öğesinin derinlemesine analizini

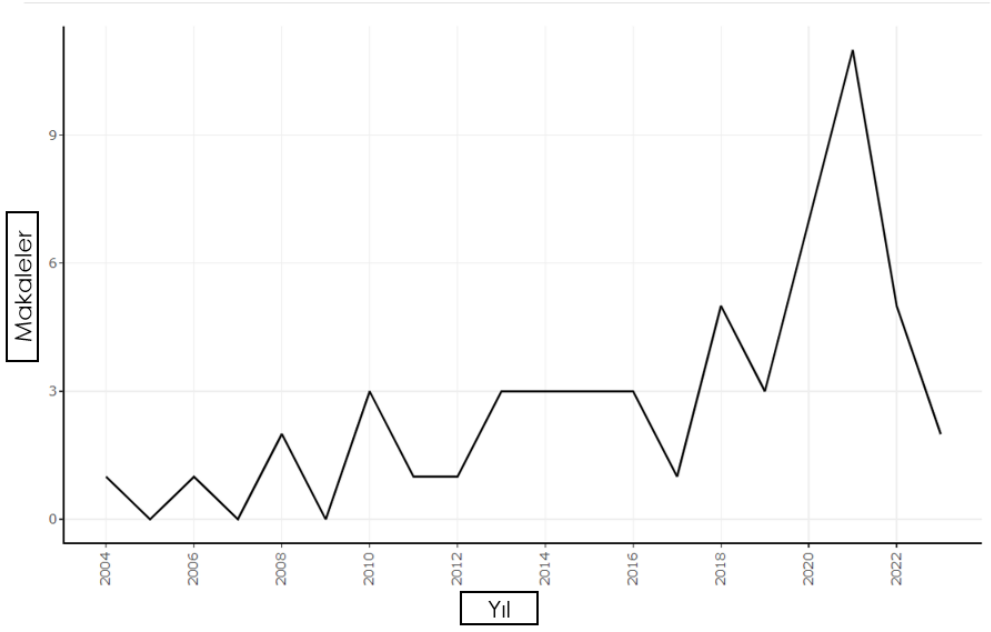
sağlamaktadır. VOSViewer ise çok sayıda farklı bibliyografik veri öğesi arasındaki ilişkilerin haritalanması ve görsel tasvirini sağlayan bir yazılımdır [7].

Bibliometrix üzerinden elde edilen, analizde kullanılan çalışmaların verisi hakkındaki temel bilgiler Tablo 2.3'te sunulmuştur.

Tablo 3: Anahtar Kelimelerin Bibliyografik Verisi için Temel Bilgiler

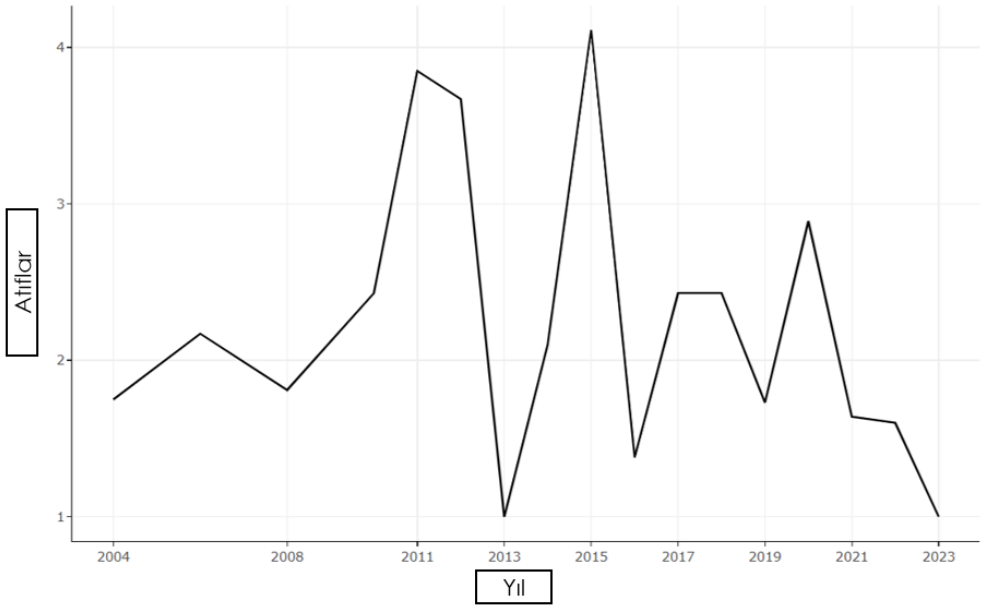
BİBLİYOGRAFİK VERİ İÇİN TEMEL BİLGİLER	
Zaman Aralığı	2004:2023
Kaynaklar (Dergiler, Kitaplar vb.)	32
Dokümanlar	55
Yıllık Büyüme Oranı %	3.72
Dokümanların Ortalama Yaşı	6.84
Doküman Başına Ortalama Alıntılar	15.22
DOKÜMAN İÇERİĞİ	
Artı Anahtar Kelimeler	495
Yazarın Anahtar Kelimeleri	201

Bibliyografik verilerin Bibliometrix'e aktarılmasından sonra bu veriler kullanılarak çeşitli analizler yürütülmüştür. İlk olarak yıllık bilimsel üretkenlik ve yıllık ortalama atıflar analiz edilmiştir. Yıllık bilimsel üretkenlik analizi sonuçları Şekil 2.1'de sunulmuştur. 2020 ve 2023 yılları arasındaki makale sayıları sırasıyla 7, 11, 5 ve 2'dir. 2021 yılı 11 makale ile bu konuda en çok yayın yapılan yıldır.



Şekil 1: Anahtar Kelimeler için Yıllık Bilimsel Üretkenlik Analizi

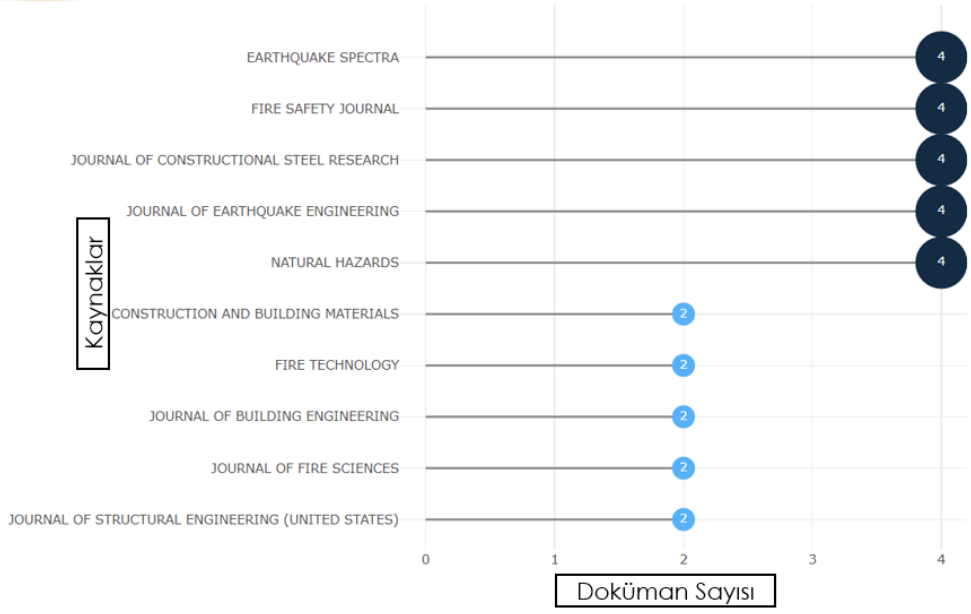
Anahtar kelimeler için yıllık ortalama atıflara yönelik analiz sonucu Şekil 2.2'de sunulmuştur. 2020 ve 2023 yılları arasındaki yıllık ortalama atıf sayıları sırasıyla 2.89, 1.64, 1.60 ve 1 olmuştur. En yüksek ortalama atıf sayısına sahip olan yıl 4.11 ile 2015 olmuştur.



Şekil 2: Anahtar Kelimeler için Yıllık Ortalama Atıflar Analizi

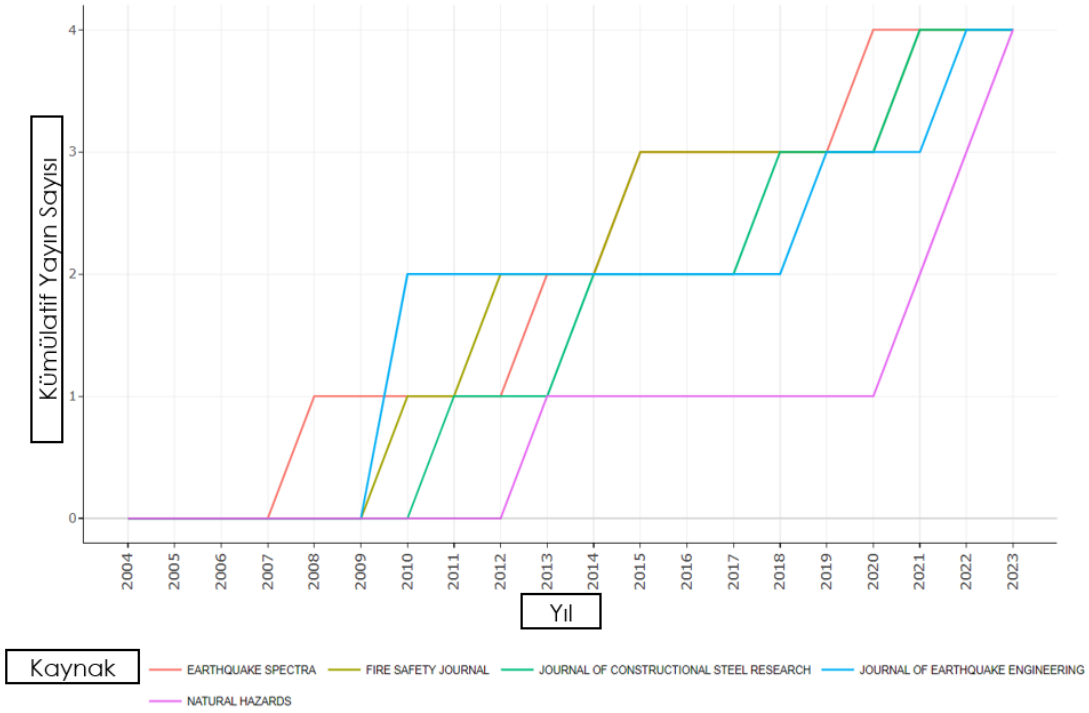
Bibliyografik verinin temel özelliklerinin incelenmesinden sonra; kaynaklar, yazarlar ve dokümanlar olmak üzere üç temel başlık üzerinde bibliyografik veriyi daha detaylı değerlendirmek üzere çeşitli analizler yürütülmüştür.

Kaynaklar başlığı altında en ilgili kaynakların belirlenmesine yönelik analiz yürütülmüştür. Bu analizin sonuçları Şekil 2.3'te sunulmuştur. Earthquake Spectra, Fire Safety Journal, Journal of Constructional Steel Research, Journal of Earthquake Engineering ve Natural Hazards isimli kaynaklar, her biri için 4 doküman sayısı ile, anahtar kelimeler için en ilgili kaynaklar olmuştur.



Şekil 3: Anahtar Kelimeler için En İlgili Kaynaklar Analizi

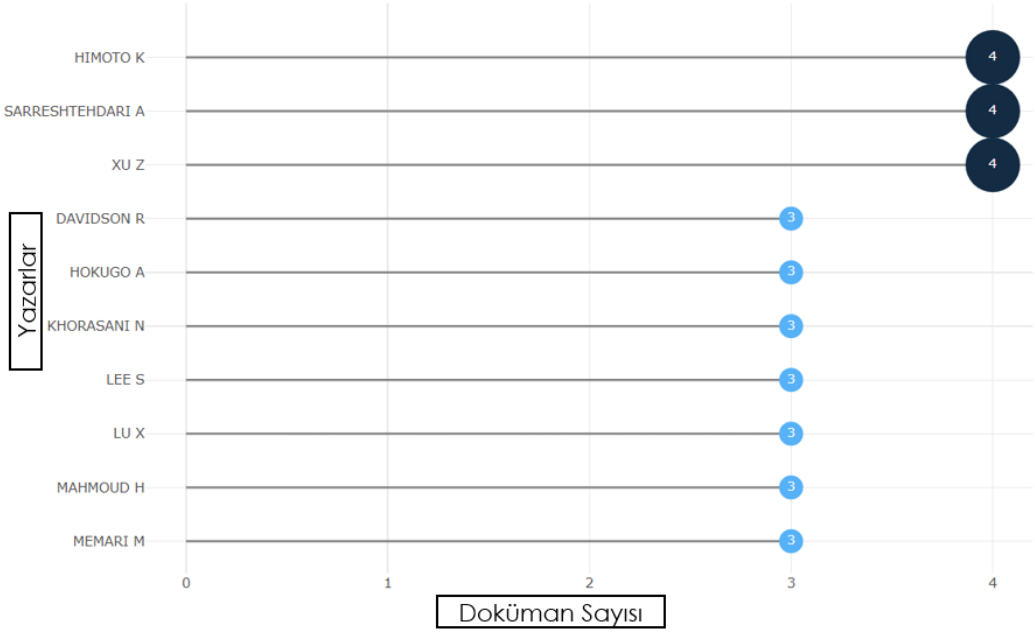
Devamında, ilgili anahtar kelimeler için en yüksek doküman sayısına sahip kaynakların zaman içerisindeki üretkenlikleri incelenmiştir. Bu analizin sonuçları Şekil 2.4'te sunulmuştur.



Şekil 4: En İlgili Kaynakların Zaman İçerisindeki Üretkenlik Analizi

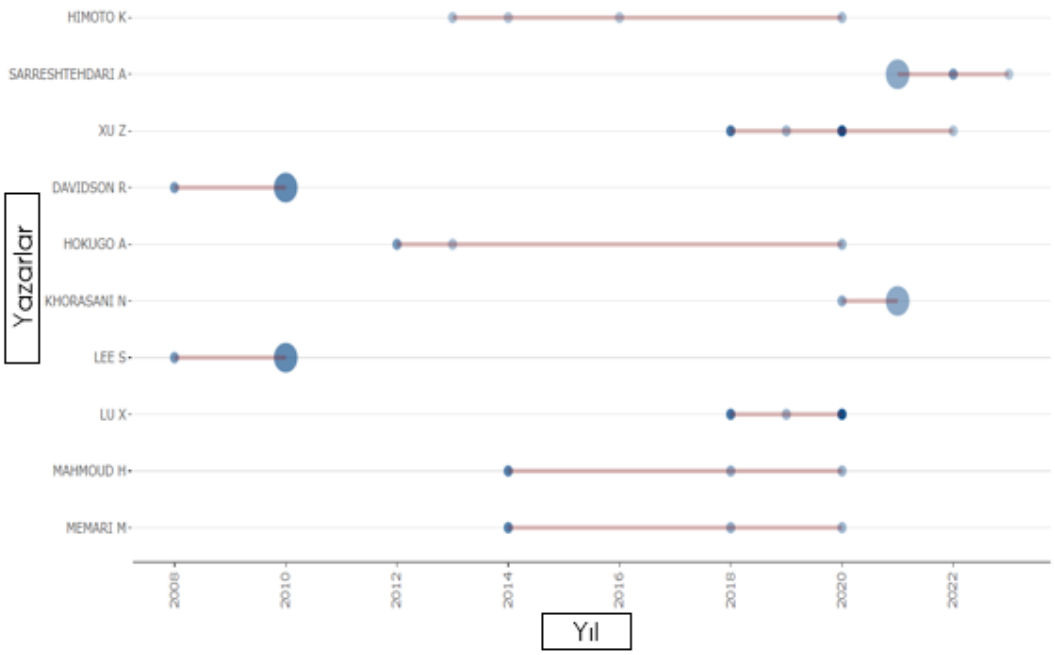
Yazarlar başlığı altında; yazarlar ve ülkeler için iki farklı alanda analizler yürütülmüştür.

Doküman sayısına bağlı olarak ele alınan anahtar kelimeler için en ilgili yazarlara yönelik analiz sonucu Şekil 2.5'te sunulmuştur. Himoto K., Sarreshtehdari A. Ve Xu Z., ilgili anahtar kelimeler için en yüksek doküman sayısını sağlayan yazarlar olarak belirlenmiştir.



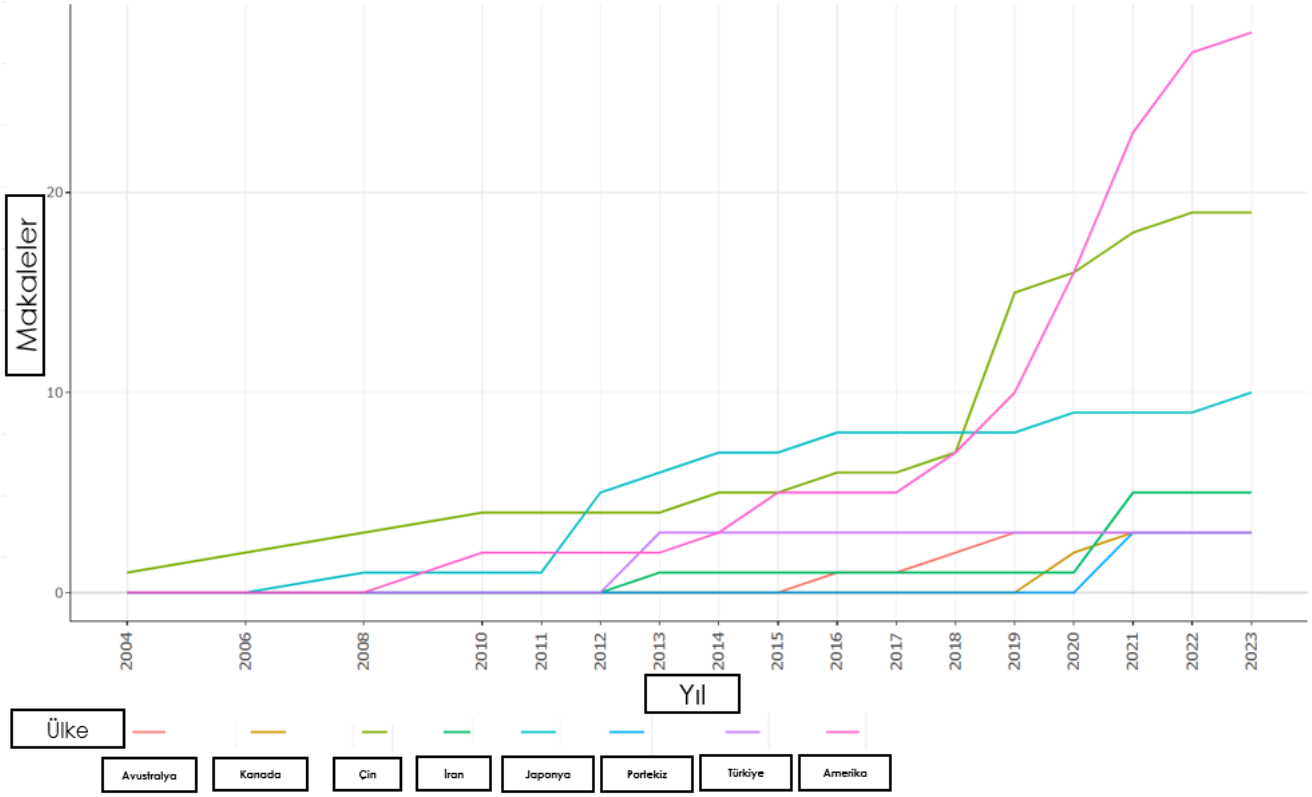
Şekil 5: Anahtar Kelimeler için En İlgili Yazarlar Analizi

En ilgili yazarların belirlenmesini takiben, ele alınan anahtar kelimeler için en ilgili yazarların zaman içerisindeki üretkenlikleri incelenmiştir. Bu analizin çıktıları Şekil 2.6'da sunulmuştur.



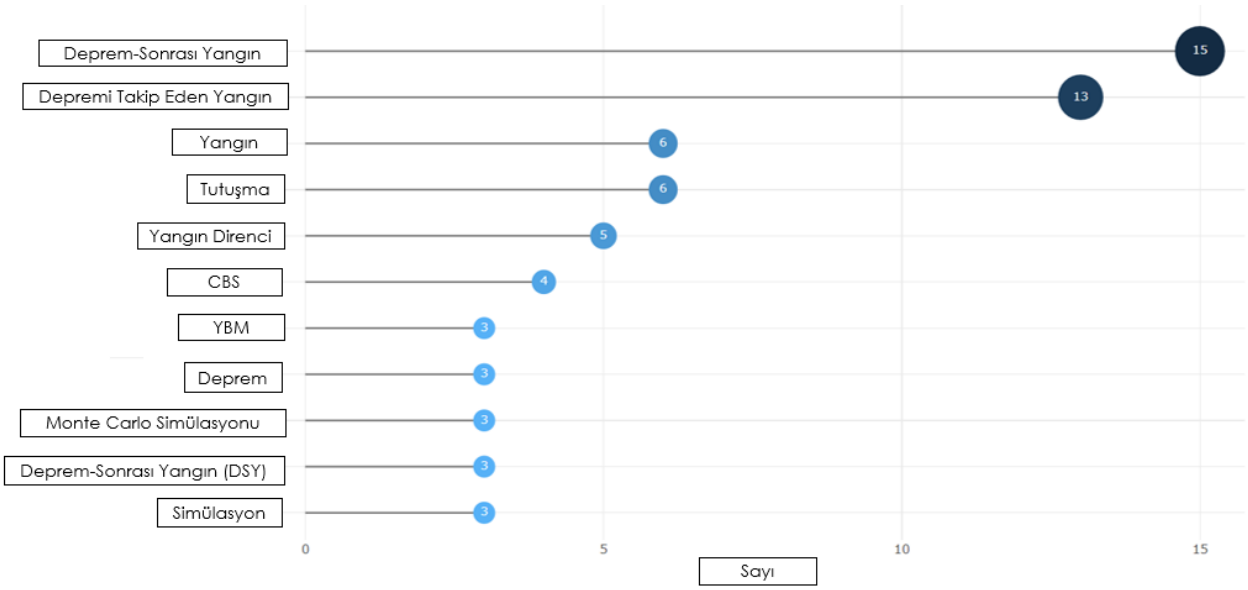
Şekil 6: En İlgili Yazarların Zaman İçerisindeki Üretkenlik Analizi

Ülkeler alanında, ilgili anahtar kelimeler için ülkelerin zamana bağlı üretkenliği analiz edilmiştir. Ülkelerin zamana içerisindeki üretkenliklerine ilişkin analizin sonuçları Şekil 2.7'de sunulmuştur. Bilimsel üretkenliği en yüksek ülkeler sıklık dereceleri sırasıyla 28, 19 ve 10 olmak üzere Amerika, Çin ve Japonya olmuştur. Son yıllarda özellikle Amerika'da bu konudaki çalışmaların artış gösterdiği görülmektedir.



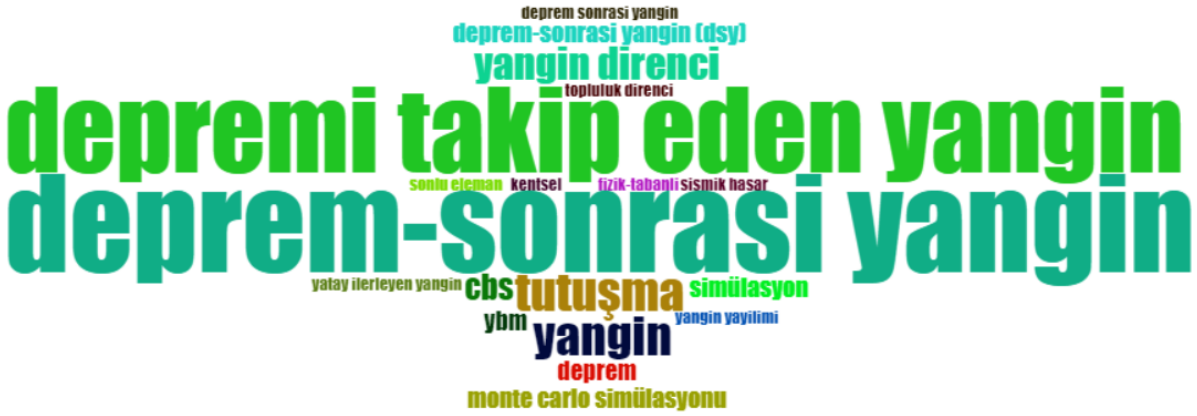
Şekil 7: Anahtar Kelimeler için Ülkelerin Zaman İçerisindeki Üretkenlikleri Analizi

Dokümanlar başlığı altında anahtar kelimeler hakkında çeşitli analizler yürütülmüştür. Yazar anahtar kelimeleri arasında en çok tekrar eden anahtar kelimeler belirlendikten sonra, bu anahtar kelimeler için bir kelime bulutu oluşturulmuş ve artı anahtar kelimeler için popüler terimlerin analizi gerçekleştirilmiştir. En sık tekrar eden yazar anahtar kelimeleri Şekil 2.8'de sunulmuştur. Sıklıklarına göre en çok yinelenen anahtar kelimeler; "deprem-sonrası yangın", "depremi takip eden yangın", "yangın", "tutuşma" ve "yangın direnci" olmuştur. "CBS", Coğrafi Bilgi Sistemi'ni, "YBM" ise Yapı Bilgi Modellemesi'ni temsil etmektedir.



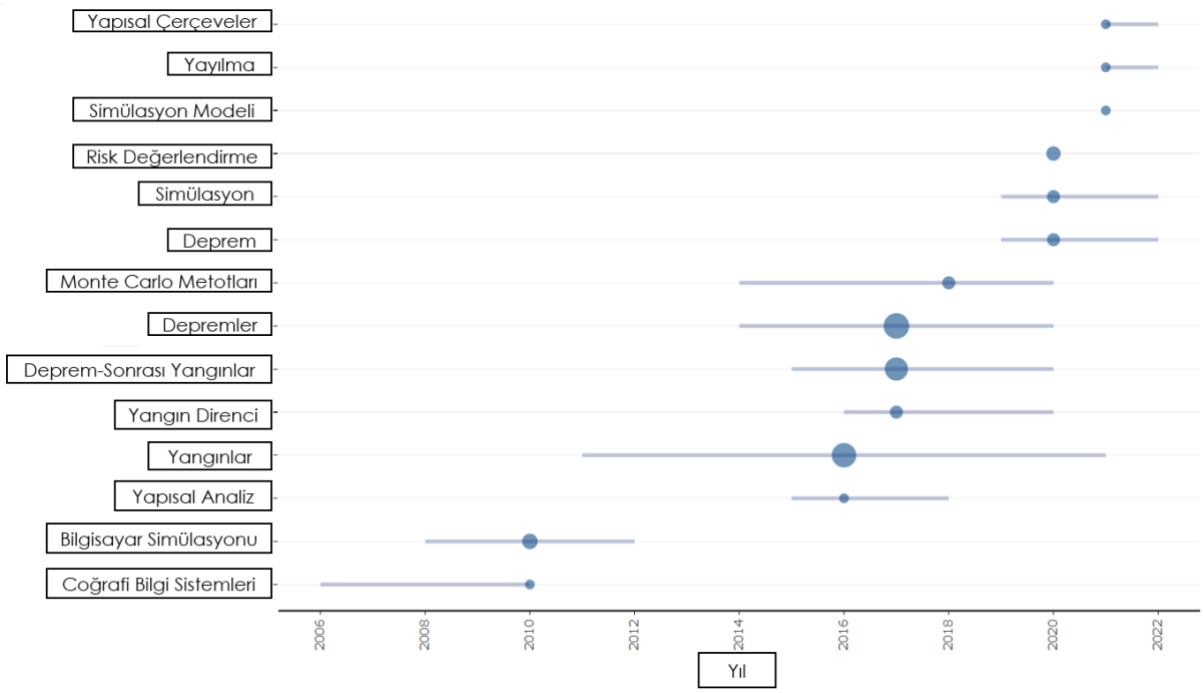
Şekil 8: En Sık Tekrarlanan Yazar Anahtar Kelimeleri Analizi

Yazar anahtar kelimeleri arasında en sık tekrar eden anahtar kelimeler için oluşturulan kelime bulutu, Şekil 2.9'da sunulmuştur.



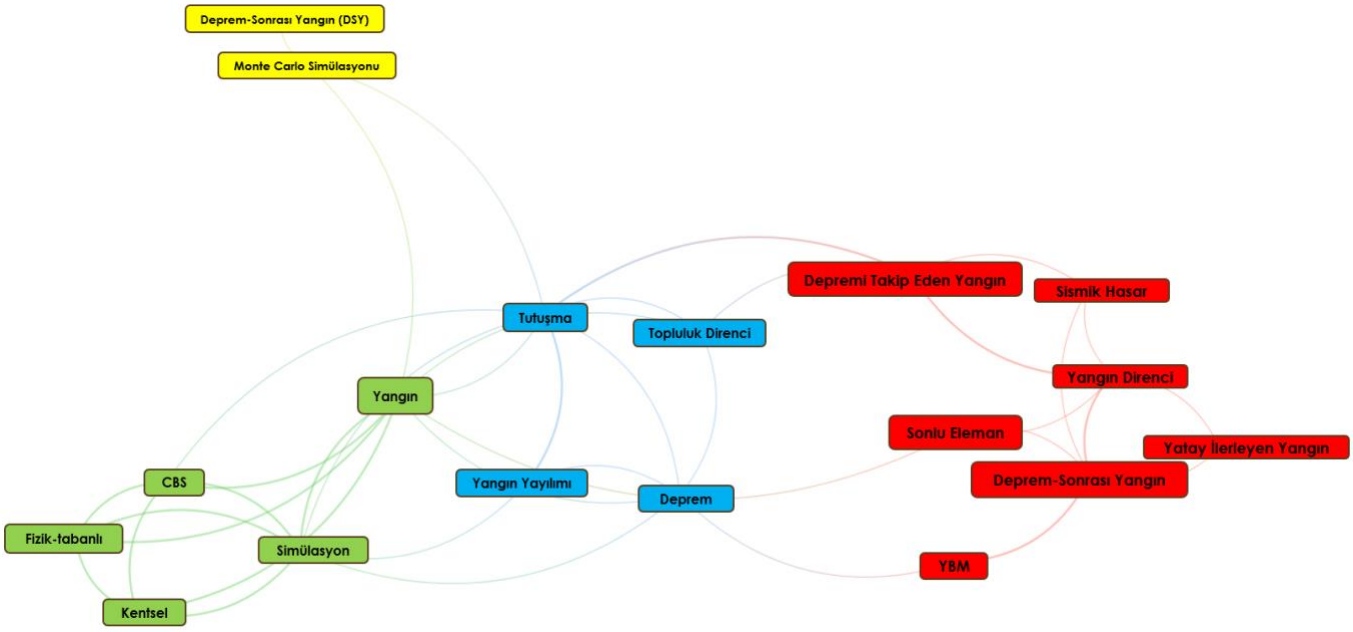
Şekil 9: En Sık Tekrarlanan Yazar Anahtar Kelimeleri İçin Kelime Bulutu

2004 ve 2023 yılları arasında ele alınan tüm makalelerin artı anahtar kelimeleri ele alınarak popüler terimler için bir analiz yürütülmüştür. Elde edilen sonuçlar Şekil 2.10'da sunulmuştur. Simülasyon ile ilgili anahtar kelimelerin özellikle son yıllardaki popülerliği görülmektedir.



Şekil 10: Artı Anahtar Kelimeler için Popüler Terimler Analizi

Bibliometrix üzerinde ilgili anahtar kelimeler için elde edilen bibliyografik verinin analizi sonrasında, Scopus ve Web of Science veri tabanlarından elde edilen dokümanların birleştirilmiş veri seti VOSViewer üzerinde anahtar kelime haritalama analizi yürütmek üzere kullanılmıştır. Haritalama sürecinde, anahtar kelimeler için minimum tekrarlama sayısı iki olarak belirlenmiş ve böylece haritada birbiriyle ilişkili 18 adet anahtar kelime içerilmiştir. Oluşturulan anahtar kelime haritası dört sınıftan meydana gelmektedir. VOSViewer tarafından oluşturulan anahtar kelime haritası Şekil 2.11'de sunulmuştur.



Şekil 11: Anahtar Kelimeler için Ortak Haritalama Analizi

"Deprem-sonrası yangın", 15 ile en çok tekrar eden anahtar kelime olmuş ve toplam bağlantı gücü 7 olarak belirlenmiştir. "Depremi takip eden yangın" anahtar kelimesinin bağlantı gücü ise 6 olarak belirlenmiştir. "Simülasyon" anahtar kelimesinin bağlantı gücü ise 11 olarak belirlenmiştir.

3. Deprem Sonrası Yangın Riskini Ele Almada Simülasyon Yaklaşımlarını Kullanan Çalışmaların İncelenmesi

Bu bölümde, deprem sonrası yangın riskini ele almada simülasyon metodolojilerini kullanan çalışmalar detaylı olarak incelenmiştir. Literatürde yer alan çalışmaların bir bölümü deprem sonrası yangın nedeniyle meydana gelen risk faktörlerinin tahmini, değerlendirilmesi ve analizine odaklanırken, bir kısmı ise binaların deprem kaynaklı sismik sarsıntı sonrası yapısal olarak yangına dayanıklılığını ele alan çalışmalardan meydana gelmektedir. Deprem sonrası yangın için risk faktörlerinin belirlenmesi ve bunların neden olacağı kayıpların analizine yönelik simülasyon metodolojilerini ele alan çalışmalar bu çalışmanın ana odak noktası olduğundan, ulaşılan dokümanlar arasında çalışmanın odağı dışında kalan 21 adet çalışma elenerek geriye kalan 34 çalışma incelenmiş ve araştırma çerçevesi kapsamında en ilgili olan çalışmalar detaylı olarak ele alınmıştır.

Ren ve Xi tarafından yapılan çalışmada, deprem sonrasında yangınların meydana gelebileceği yerleri belirlemek üzere Japonya, Amerika ve Çin'deki tarihi verilerine dayalı olan, Huygens prensibi kullanılarak gerçekleştirilen dinamik bir yangın yayılma süreci simüle edilmiştir. Deprem sonrası yangınların yayılabileceği alanların simülasyonu amacıyla Arc Info'ya dayalı bir bilgisayar sistemi de geliştirilerek, bu sistemin şehir imarında ve acil müdahale planlamasında kullanılabileceği belirtilmiştir [8]. Zhao vd. tarafından, deprem sonrası yangınların temel mekânsal ve zamansal özellikleri belirlenmiş ve 20. yüzyılda meydana gelen tarihi deprem sonrası yangın verileri toplanarak, deprem sonrası yangınlar regresyon analizi yöntemiyle modellenmiştir. Deprem sonrası yangınların mekansal ve zamansal olasılık dağılımını oluşturmak için bir rassal Poisson olayı ve Weibull dağılım modeli önerilmiş, meydana gelebilecek tutuşmaları tahmin etmek için Coğrafi Bilgi Sistemi tabanlı bir stokastik simülasyon şeması önerilmiştir [9]. Lee vd. tarafından, deprem sonrası yangının etkilerini tahmin etmek üzere geliştirilen mevcut tutuşma ve yayılma/bastırma modelleri incelenmiştir. Uygulanabilirlik açısından ampirik yayılma modelleri yerine fizik tabanlı yayılma modellerine ve farklı simülasyon teknikleri kullanılan modellere yönelik bir eğilime dikkat çekilmiştir. Bu modellerin eğim, bitki örtüsü ve bina hasarı, itfaiye teşkilatlarının söndürme çalışmalarının etkileri, su temini ve ulaşım sistemlerinin işleyişi açısından geliştirilebileceği belirtilmiştir [10]. Huang vd. tarafından yapılan çalışmada, Tayvan'da meydana gelen bir deprem Monte Carlo simülasyonu uygulanarak simüle edilmiş ve bu depremden sonra meydana gelen deprem sonrası yangın olaylarının sayısı belirlenerek şehrin farklı bölgelerinin deprem sonrası yangın riski tolerans olasılık seviyeleri analiz edilmiştir [11]. Zhao tarafından yapılan çalışmada, deprem sonrası yangın yayılımının karmaşık davranışını araştırmak ve yangının sebep olduğu kayıpları değerlendirmek amacıyla deprem sonrası yangınların dinamik simülasyonunu gerçekleştirmek üzere entegre bir yazılım sistemi geliştirilmiştir. Gelecek çalışmalarda yangın çıkışları ile sismik zamanlama arasındaki ilişkinin modellenmesi gerekeceği, yangının sıçrama yoluyla yayılmasının önemli bir faktör olarak ele alınması gerektiği ve su basıncının doğru tahmininin modelleme için yüksek öneme sahip olduğu belirtilmiştir [12]. Lee ve Davidson, deprem sonrasında kentsel yangınların nasıl yayıldığını modelleyen yeni bir simülasyon modeli sunmuştur. Yangının bir oda veya çatıdaki gelişimi, odadan odaya yangın yayılımı ve binadan binaya yangın yayılımı modellerini bünyesinde barındıran ve uyarlayan bu modelin, yangınların ne kadar, ne hızda, nerede ve nasıl yayılabileceğinin yanı sıra, bunda hangi unsurların en etkili olduğunun araştırılmasında da kullanılabileceği belirtilmiştir [13]. Lee ve Davidson tarafından diğer bir çalışmada, yangın yayılımının farklı biçimlerini içeren fizik tabanlı simülasyon modeline sahip bir vaka çalışması anlatılmış ve yangın yayılımının daha gerçekçi ve derinlemesine incelenmesine olanak sağlanmıştır. Aktif yangın söndürmenin entegre edilmesi ve su temini ile ulaşım hatları arasındaki etkileşimin dahil edilmesi yoluyla risk azaltma stratejilerinin değerlendirilebileceği belirtilmiştir [14]. Nishino vd., deprem sonrası yangınlarda kişilerin ve yapıların güvenliğini sağlamak amacıyla hava koşulları, yangın çıkışlarının sayısı ve yeri, ilk aşamadaki yangınla mücadele faaliyetleri, ilk tahliye edilenlerin yerleri, yolların tıkanması ve binalarda deprem kaynaklı oluşan hasar gibi yangının yayılması ve tahliyesine ilişkin belirsiz faktörleri ele alan bir risk değerlendirme yöntemi sunmayı amaçlamıştır. Risk, Monte Carlo simülasyonu ve fizik bazlı yangın yayılımı ve tahliyesi simülasyonlarının bir kombinasyonu ile hesaplanmıştır [15]. Himoto vd. tarafından yapılan çalışmada, yer hareketi nedeniyle binalarda meydana gelen yapısal hasarı ve yangının ısınması nedeniyle ilerlemesini dikkate alarak fizik-tabanlı bir deprem sonrası yangın yayılma modeli geliştirmiştir. Geliştirilen model, 1995 depremi sırasında Kobe şehir

bölgesindeki yangının yayılımının simülasyonu ile doğrulanmış ve yanan bina sayısına ilişkin beklenen değerler elde edilmiştir [16]. Omidvar vd., İran'ın Kirmanşah kenti altında gömülü olan yakıt boru hattı sistemleri, boru hattı arızaları ve deprem sonrası yangın açısından hasar analizine odaklanmıştır. Simülasyon metodolojileri ile deprem sonrasında yangına maruz kalacak alan, ev sayısı ve nüfus için olasılık dağılım fonksiyonu hesaplanmıştır ve yangın hasarını azaltmak için risk hafifletme seçenekleri değerlendirilmiştir [17]. Himoto ve Nakamura, Monte Carlo simülasyonu ve fizik tabanlı kentsel yangın yayılım modeli kullanarak Japonya'nın Kyoto kentindeki 2131 tarihi binanın deprem sonrası yangın güvenliği açısından değerlendirilmesine yönelik bir analiz yapmayı amaçlamıştır. Tarihi yapıların yakınında tutuşma, yangının ilk aşamasında yangınla mücadele faaliyetlerinin yetersizliği ve kentsel bölgelerde geniş alana yayılan yangınlar, tarihi yapıların yangına maruz kalmasına neden olan özel olaylar olarak ele alınmıştır. Yapıların ve çevrelerindeki kentsel alanların yangın güvenliği açısından iyileştirilmesinin, tarihi binaların yangın güvenliğini artıracağı belirtilmiştir [18]. Shang vd., Monte Carlo simülasyonu ile deprem sonrası yangınları simüle ederek Tayvan'ın Taipei şehrinin yangın kurtarma kapasitesini değerlendirmiştir. Çalışmada sunulan modelin, ilgili alandaki potansiyel afet kaynak planlama ihtiyaçlarını değerlendirmek üzere kullanılabileceği belirtilmiş ve elde edilen bulgulardan yola çıkılarak ilgili riski azaltmaya yönelik stratejiler önerilmiştir [19]. Himoto ve Suzuki, altı farklı yangın koruma ekipmanında meydana gelebilecek sismik hasarı ele alarak, orta yükseklikte ve çok katlı binalarda deprem sonrası yangın riskini tahmin etmek üzere bir model oluşturmuştur. Bu model, duman yayılmasına yönelik model, bina sakinlerinin yangınla mücadele faaliyetlerine yönelik model ve bina sakinlerinin tahliyesine yönelik model olmak üzere üç alt modelden oluşmaktadır. Uygulanan vaka çalışmasında deprem sonrası yangın riski Monte Carlo simülasyonu ile değerlendirilmiş ve yangın güvenliği ekipmanının bulunmamasının sonuç olarak insan kayıplarının kapsamını artırdığı belirlenmiştir [20]. Liu vd. tarafından yapılan çalışmada, sismik olarak zayıf bir kentsel bölgede deprem sonrası yangın etkisi altında yolların boşaltılması sorunu ele alınmış ve kalabalık akışı, tahliye alanı ve deprem sonrası yangın ilişkileri araştırılmıştır. Bina yüksekliği ve rüzgar hızı, simülasyon modelinde ele alınacak hassas faktörler olarak belirlenmiş ve bu faktörlerin farklı değerlerinin yangının yayılma hızını da farklı şekilde etkilediği belirlenmiştir [21]. Xu vd. tarafından yapılan çalışmada, yağmurlama sistemlerinin sismik hasarını dikkate alan ve bu hasarın neden olduğu yangın yayılımının etkisinin niceliksel olarak değerlendirilmesine yardımcı olan bir deprem sonrası yangın simülasyonu yöntemi önerilmiştir. Deprem sonrası yangının yayılma sürecinin simüle edildiği bir vaka çalışması sonucunda hasarlı bir yağmurlama sisteminin yatay ve düşey yönde daha ciddi yangın tehlikelerine neden olabileceği sonucuna varılmıştır [22]. Lu vd. tarafından, bina sismik hasarını dikkate alarak deprem sonrası yangın afetinin fizik tabanlı simülasyonu ve yüksek kaliteli görselleştirilmesi için bir çerçeve sunulmuştur. İncelenen bölgedeki binaların sismik hasarı simüle edilmiş ve yangın yayılımı ile duman etkilerini simüle etmeye yönelik bir görselleştirme yöntemi sunulmuştur. Farklı yer hareketleri ve bina sismik dirençlerinin tutuşma ve yangının yayılması üzerindeki etkisi dikkate alınarak deprem sonrası yangın olayının daha gerçekçi modellenebileceği belirtilmiştir [23]. Li vd. tarafından, sismik hasar ve deprem sonrası yangınların etkisi altında su dağıtım şebekelerinin hem yangınla mücadele akışını hem de orijinal talebi karşılamadaki afet sonrası performansını değerlendirmek amacıyla simülasyona dayalı bir model sunulmuştur. Hizmet verilebilirlikteki en önemli azalmanın deprem sonrası yangını takiben ilk birkaç saatte meydana gelen yoğun yangınla mücadele akışından kaynaklandığı ve yangınla mücadele için güvenilir bir ilave su kaynağının inşa edilmesinin yangın hasarını etkili bir şekilde azaltabileceği belirlenmiştir [24]. Nishino ve Hokugo, deprem sonrası yangın riskinin değerlendirilmesi amacıyla binalardaki deprem sonrası yangınların sayısının zaman serisi tahmini için stokastik bir model geliştirmiştir. Elektrik kaynaklarından meydana gelen tutuşmaların zamana bağlı oluşum modeli ile gaz, petrol veya diğer kaynaklardan meydana gelen tutuşmalar için zamandan bağımsız bir tutuşma modeli olmak üzere iki tür Poisson regresyon modeli kullanılmıştır. Önerilen modelin doğrulanması için 2011 Tohoku depremi tutuşma sayılarının zaman serisi tahmini Monte Carlo simülasyonu kullanılarak gerçekleştirilmiştir [25]. Rafi vd., yangının hem bina içerisindeki hem de binadan binaya yayılma mekanizmalarını dikkate alarak, yapı malzemelerine dayalı olarak yangının kitlesel yayılımının simülasyonu için bir model sunmuştur. Yapı bilgi verilerinin Coğrafi Bilgi Sistemi'ne entegrasyonu ve yangın yayılma mekaniğinin matematiksel formülasyonu ile uygulanan modelin, çalışmada ele alınan her iki modelleme mekanizması için de yangını yeterince simüle edebildiği ve literatürdeki diğer yöntemlere basit ve güvenilir bir alternatif olabileceği sonucuna

varılmıştır [26]. Coar vd. su şebekesi tasarımı, sismik tehlike ve elektrik şebekesine bağımlılık senaryosu olmak üzere üç parametrenin yangın musluklarında deprem sonrası su mevcudiyeti üzerindeki etkilerini inceleyerek deprem sonrası yangın söndürme kapasitesini topluluk düzeyinde değerlendirmeyi amaçlamıştır. Şebeke davranışının gerçekçi temsili için su temin performansı ile topoloji bazlı ve enerji bazlı şebeke performans ölçümlerinin kullanılması gerektiği belirtilirken; su şebekesinin elektrik şebekesine açık bağımlılığının dikkate alınması tavsiye edilmiştir [27]. Himoto tarafından yapılan çalışmada, hiyerarşik Bayes yaklaşımı kullanılarak Japonya'da 1995-2016 yılları arasında meydana gelen beş büyük deprem sonrası yangın tutuşma olasılıklarının analizi sunulmuştur. Tutuşma nedenlerine yönelik parametrelerin hedef sonsal dağılımlarından örnekler alınabilmesi için simülasyon metodolojilerinden yararlanılmıştır. Hiyerarşik Bayes yaklaşımının, farklı bölgesel ve mevsimsel özellikleri modelleme sorununu çözmek için sistematik ve rasyonel bir çerçeve sağlayarak deprem sonrası tutuşma olasılıklarını tahmin etmede istatistiksel güvenilirliği artırdığı belirtilmiştir [28]. Lu vd. tarafından Yapı Bilgi Modellemesi ve sanal gerçekliğe dayalı iç mekan deprem sonrası yangın kurtarma senaryosunun simülasyonu için bir çalışma yürütülmüştür. Bina bileşenlerinin sismik hasarı ve duman yayılımının görselleştirilmesi ile bina içi yangın yayılımı ve kurtarma aşamaları analiz edilmiştir. Önerilen metodolojinin gerçekçi bir deprem sonrası yangın senaryosu oluşturulmasına bilimsel bir temel sağlayacağı belirtilmiştir [29]. Lotfi vd. tarafından, deprem sonrası yangın afeti sırasında yüksek katlı bir binada güvenli bir tahliye planının garanti edilip edilemeyeceğini değerlendirmek üzere bir çerçeve önerilmiştir. Bu amaçla; Yapı Bilgi Modellemesi'nden yararlanılarak çok katlı bir bina modellenmiş, yangın ve duman simülasyonları ile senaryo analizleri yapılmıştır. Doğru sonuçlar elde dilebilmesi için yangının tamamen simüle edilmesi ve binanın tüm katlarının dikkate alınması gerektiği belirtilmiştir [3]. Sarreshtehdari ve Elhami Khorasani, yangın söndürme sürecini ve itfaiye müdahalesini modelleyerek deprem sonrası yangınları simüle etmeye yönelik mevcut yöntemleri geliştirmeyi amaçlamıştır. Ulaşım ağı, su ve elektrik şebekeleri gibi altyapı sistemlerinin katmanları ile bina envanteri, depremin topluma verdiği hasarı karakterize edecek şekilde modellenmiştir. Yangın yayılımı ile yangını bastırma faaliyetleri de modellenerek tutuşma konumlarına itfaiye atamaları için bir karar verme algoritması uygulanmıştır [30]. Coar vd., art arda gelen deprem ve yangın felaketlerinin etkileri ile yapı envanteri, su şebekesi ve ulaşım ağı olmak üzere üç altyapı sisteminin zarar görebilirliğini, depremi takip eden 12 saat içerisinde itfaiyecilerin ve diğer acil durum hizmetlerinin ihtiyaçlarına özel olarak odaklanarak ele almıştır. Kentsel bir alan için topluluk ölçeğinde tahmin modelleri oluşturmak üzere bir çerçeve sunularak, mevcut veri deprem sonrası yangın hasarına en duyarlı bölgelerin belirlenmesinde kullanılmıştır [31]. Hou ve Li, sismik boru hattı hasarının ve deprem sonrası yangınların çoklu tutuşma etkileri altında, su dağıtım sisteminin yangınla mücadele kapasitesini değerlendirmek ve deprem sonrası yangınlar ile boru hattı hasarının mekansal dağılımlarını simüle etmek üzere entegre bir prosedür geliştirmiştir. Önerilen yöntemin olası uygulamaları için çoklu eş zamanlı su taleplerinin etkileri üzerine analizler yapılmış ve yangının tutuşma olasılığını azaltmanın deprem sonrası yangına direnme kapasitesini artırmada boru hattı sistemini güçlendirmeye göre daha etkili olduğu belirtilmiştir [32]. Scheele vd. tarafından yapılan çalışmada; aktif faylara yakınlık, yakın aralıklı ahşap kaplı binalar, zarar görebilirliği yüksek su ve gaz altyapısı, sık şiddetli rüzgarlar ve acil durum hizmetlerine erişimin zor olması gibi tutuşmaya ve yangının yayılmasına duyarlı birçok özelliğe sahip olan Yeni Zelanda'nın Wellington şehri ele alınmıştır. Yer hareketlerindeki belirsizlik, tutuşmaların sayısı ve lokasyonları, hava koşulları ve yangınla mücadele kapasitesi ele alınarak deprem sonrası yangının tutuşması, yayılması ve bastırılması modellenmiş ve riskli alanlar belirlenmiştir [33]. Tong ve Gernay, geçmişte meydana gelen bir deprem sonrasında yangın çıkma sayısını etkileyen değişkenleri analiz ederek, deprem sonrasında oluşabilecek yangın sayısını tahmin etmeyi amaçlamıştır. Önerilen modelin simülasyon uygulaması için varsayımsal bir vaka çalışması uygulanmıştır. Hiyerarşik Bayes modeliyle elde edilen tutuşma verilerinin, ele alınan geçmiş depremlerde yaşanan tutuşma sayılarıyla uyumlu olduğu, modelin gelecekteki sismik olaylarda tutuşmaları değerlendirmek üzere kullanılabileceği belirtilmiştir [34]. Wu vd. tarafından, deprem sonrası bina çökmelerini ve yangın nedeniyle yolların geçiş kabiliyetini dikkate alan bir deprem sonrası trafik simülasyon yöntemi önerilmiştir. Elde edilen sonuçların deprem sonrası trafik durumunun belirlenmesinde ve deprem sonrası tahliye ve kurtarma kararlarının alınmasında referans sağlayabileceği belirtilmiştir [35]. Nishino ise, bölgesel ölçekte yer sarsıntısı ve deprem sonrası yangınlara ilişkin çoklu tehlike riskini değerlendirmek üzere olasılıksal bir metodoloji sunmuştur. Kullanılan yangın modelleri; deprem sonrası yangın tutuşma

modelleri, hava durumu modeli, fizik-tabanlı kentsel yangın yayılma modeli ve itfaiye müdahale modellerini içermektedir. Belirsiz faktörlerin değerlendirmelere dahil edilmesini sağlayan entegre modelleme metodolojisinin, mevcut riskin anlaşılmasında ve risk azaltmaya yönelik karar verme aşamalarında kullanışlı olacağı belirtilmiştir [36].

4. Sonuç ve Çıkarımlar

Deprem sonrası yangınlar, birçok belirsiz risk faktörü barındırmaları sebebiyle ikincil afetlerin en tehlikelilerinden biri olarak tanımlanmaktadır ve tarihi olaylara dair veriler de bunu doğrulamaktadır. Bu afetler, sismik hasarın daha ileri boyutlara ulaşmasına sebebiyet verebilmektedir.

Bu çalışmada, deprem sonrası yangın afetinde simülasyon metodolojileri üzerine kavramsal bir bakış açısı sunmak amacıyla literatür araştırması ve bibliyografik analiz yaklaşımlarından yararlanılmıştır. Bu amaçla bibliyografik veri analizi ve görselleştirmesinde yaygın olarak yararlanılan Bibliometrix ve VosViewer araçları kullanılmıştır.

Literatürdeki çalışmalar; deprem sonrası yangınların belirli bina tipleri üzerindeki etkilerinin araştırılması, deprem sonrası yangının su hattı, ulaşım ağı veya sismik hasara uğramış yangınla mücadele ekipmanları gibi spesifik faktörler açısından ele alınması, yangını bastırma, yangınla mücadele ve tahliye faaliyetlerinin analizi, risk değerlendirmesi ve kayıp tahmini gibi çeşitli alanlardadır. Simülasyon metodolojileri; deprem sonrası yangının tutuşma aşamasında tutuşmalarının sayısının, yerlerinin ve zamanlarının belirlenmesi, yangından etkilenebilecek binaların ve toplam nüfusun belirlenmesi, belirli bina tiplerinin güvenilirliğinin analiz edilmesi, potansiyel toplam yanan alanın belirlenmesi ve itfaiyecilerin öncelikli olarak çalışması gerekecek olan yangına eğilimli alanların belirlenmesi için kullanılabilmektedir. Yangının yayılma aşamasında yangının nereye, ne şekilde ve ne hızda yayıldığının incelenmesi, yangının gelişiminin modellenmesi, farklı zaman aralıklarında yapıların durumlarının analizi ile zaman içerisinde yangına maruz kalan yapı sayısı ve toplam nüfusun belirlenmesi, belirli yangınla mücadele ekipmanlarının sismik hasarı ele alınarak yangın yayılımının değerlendirilmesi ve duman yayılımının incelenmesi amacıyla simülasyon metodolojilerinden yararlanılmaktadır. Bastırma ve tahliye aşamasında ise yangının sürme zamanının belirlenmesi, su şebekesi vb. altyapı unsurlarının sismik hasarı dikkate alınarak yangınla mücadele faaliyetlerinin değerlendirilmesi, tahliye planları ve kurtarma faaliyetlerinin değerlendirilmesi, tahsis edilmesi gereken itfaiye araçlarının sayısının belirlenmesi ve tahliye süresinin belirlenmesi için trafik simülasyonu gibi çeşitli alanlarda simülasyon yer almaktadır.

Simülasyon modellerinde kullanılan veriler çalışmanın kapsamına ve ele alınan bölgeye göre çeşitlilik göstermektedir. Tutuşma modellemelerinde genellikle tepe yer ivmesi, sismik yoğunluk ve tutuşma kaynaklarının durumu gibi girdiler dikkate alınmaktadır. Yayılma ve bastırma modellerinde ise bina özelliklerine, imar planına ve çevre koşullarına ilişkin çeşitli faktörler analize dahil edilmektedir. Bina yüksekliği, binalar arası alan, bina çeşitleri ve bina şekilleri, ahşap bina yüzdesi, bina hasar durumu, eğim ve bitki örtüsü gibi faktörler bunlara örnek olarak sıralanabilir. Hava durumuna ilişkin hava sıcaklığı, nem, yağış, rüzgar hızı ile rüzgar yönü gibi faktörler de bu modellerde içerilen değişkenler arasında yer almaktadır. Bastırma modellerinde ayrıca yangını söndürmek üzere mevcut su kaynakları ve su şebekesinin durumu, gerekli su miktarı ve trafik ağı gibi faktörler de ele alınmaktadır. Sismik yoğunluğun ölçümündeki potansiyel belirsizlikler ve hatalar, geçmiş depremlere ilişkin farklı kaynaklardan elde edilen verilerde tekrar, çelişki ve sapmalar ile veri eksikliği nedeniyle deprem sonrası yangında etkili olan birçok farklı faktör arasındaki niceliksel ilişkilerin belirsizliği gibi durumlar modellemeyi güçleştiren faktörler arasında yer almaktadır.

Simülasyon metodolojileri ile entegre olarak, tutuşma alanlarına itfaiye araçlarının atanması gibi problemler için çok kriterli karar verme algoritmaları, yapıların ve binalardaki oda konfigürasyonunun detaylı incelemesi için Coğrafi Bilgi Sistemi, bina içi faktörlerin değerlendirmelere dahil edilmesi için Yapı Bilgi Modellemesi ve yer hareketi tahmini gibi deprem sonrası yangın çerçevesinde yer alan bazı faktörlerin ele alınması için çeşitli olasılıksal ve istatiksel yaklaşımlar kullanılmaktadır.

Genel olarak modellerin tutuşma, yayılma ve tahliye faaliyetlerini bütünsel olarak ele alarak daha detaylı bir analiz sunulması önerilmektedir. Deprem kaynaklı bina, söndürme ekipmanı, gaz sistemi ve elektrik

ağı hasarı, yangınla mücadele çalışmaları, su temin ağı, ulaşım hatları, yangın yayılımının çeşitli mekanizmaları, iklimsel ve mevsimsel faktörler, depremin zamanlaması, bitki örtüsü, bölgesel jeoloji, tektonik çerçeve ve depremsellik gibi faktörlerin mevcut modellere entegre edilmesiyle daha etkili analizler yürütülebileceği belirtilmektedir. Mevcut modellerin uyarlanabilirliklerinin genişletilebileceği, duyarlılık analizi gibi çeşitli analizler ek doğrulamalar yapılabileceği, daha rasyonel verilerin kullanımı ile analizlerin geliştirilebileceği ve yangından korunma planlaması ile yangınla mücadele faaliyetleri kapsamında karar vericilerin ilgili afeti yorumlama kabiliyetlerinin geliştirilmesi için deprem sonrası yangın afetinin yüksek kalitede görselleştirilmesi ile karar verme süreçlerinin desteklenebileceği belirtilmektedir.

Deprem sonrası yangında simülasyon metodolojilerine kavramsal bir bakış açısının sunulduğu bu çalışmanın temel kısıtları olarak iki akademik veri tabanı ile belirli anahtar kelimeler ve filtreleme kriterlerinin kullanılmış olması sıralanabilir. Farklı akademik veri tabanlarının da araştırmaya dahil edilmesi ve çeşitlendirilmiş anahtar kelimeler ile ele alınan konuya dair daha detaylı bir analiz sağlanabilir.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

Referanslar

[1] A. Coburn & R Spence, "*Earthquake protection"*, John Wiley & Sons, 2002.

[2] B. Behnam, "*Post-earthquake fire analysis in urban structures: Risk management strategies"*, CRC Press, 2017.

[3] N. Lotfi, B. Behnam & F. Peyman, "A BIM-based framework for evacuation assessment of high-rise buildings under post-earthquake fires", *Journal of Building Engineering*, *43*, 102559, 2021. DOI: 10.1016/j.jobe.2021.102559

[4] N. Elhami Khorasani & M. E. Garlock, "Overview of fire following earthquake: Historical events and community responses", *International Journal of Disaster Resilience in the Built Environment*, *8*(02), 158-174, 2017. DOI: 10.1108/IJDRBE-02-2015-0005

[5] C. Scawthorn, J. M. Eidinger & A. Schiff, (Eds.), "*Fire following earthquake",* Vol. 26, ASCE Publications, 2005.

[6] M. Aria & C. Cuccurullo, "bibliometrix: An R-tool for comprehensive science mapping analysis", *Journal of Informetrics*, 11(4), 959-975, 2017.

[7] N. Van Eck & L. Waltman, "Software survey: VOSviewer, a computer program for bibliometric mapping", *scientometrics*, *84*(2), 523-538, 2010.

[8] A. Z. Ren & X. Y. Xie, "The simulation of post-earthquake fire-prone area based on GIS", *Journal of fire sciences*, *22*(5), 421-439, 2004. DOI: 10.1177/0734904104042440

[9] S. J. Zhao, L. Y. Xiong & A. Z. Ren, "A spatial–temporal stochastic simulation of fire outbreaks following earthquake based on GIS", *Journal of Fire Sciences*, *24*(4), 313-339, 2006. DOI: 10.1177/0734904106060786

[10] S. Lee, R. Davidson, N. Ohnishi & C. Scawthorn, "Fire following earthquake—Reviewing the state-of-the-art of modeling", *Earthquake spectra*, *24*(4), 933-967, 2008. DOI: 10.1193/1.2977493

[11] C. J. Huang, Y. S. Wu, K. Y. Chang & C. H. Chang, "Reliability analysis of rescue capabilities of fire-fighting units after earthquake", *Journal of Applied Fire Science*, *18*(2), 143-154, 2008. DOI: 10.2190/AF.18.2.c

[12] S. Zhao, "GisFFE—an integrated software system for the dynamic simulation of fires following an earthquake based on GIS", *Fire Safety Journal*, *45*(2), 83-97, 2010. DOI: 10.1016/j.firesaf.2009.11.001

[13] S. W. Lee & R. A. Davidson, "Physics-based simulation model of post-earthquake fire spread", *Journal of Earthquake Engineering*, *14*(5), 670-687, 2010. DOI: 10.1080/13632460903336928

[14] S. W. Lee & R. A. Davidson, "Application of a physics-based simulation model to examine post-earthquake fire spread", *Journal of Earthquake Engineering*, *14*(5), 688-705, 2010. DOI: 10.1080/13632460903336936

[15] T. Nishino, T. Tanaka & A. Hokugo, "An evaluation method for the urban post-earthquake fire risk considering multiple scenarios of fire spread and evacuation", *Fire safety journal*, *54*, 167-180, 2012. DOI: 10.1016/j.firesaf.2012.06.002

[16] K. Himoto, K. Mukaibo, Y. Akimoto, R. Kuroda, A. Hokugo & T. Tanaka, "A physics-based model for post-earthquake fire spread considering damage to building components caused by seismic motion and heating by fire", *Earthquake*

spectra, *29*(3), 793-816, 2013. DOI: 10.1193/1.4000154

[17] B. Omidvar, M. Eskandari & E. Peyghaleh, "Seismic damage to urban areas due to failed buried fuel pipelines case study: fire following earthquake in the city of Kermanshah, Iran", *Natural hazards*, *67*, 169-192, 2013. DOI: 10.1007/s11069-013-0554-9

[18] K. Himoto & T. Nakamura, "An Analysis of the post-earthquake fire safety of historic buildings in Kyoto, Japan", *Fire Technology*, *50*, 1107-1125, 2014. DOI: 10.1007/s10694-013-0330-0

[19] S. Shang, C. Su, C. Huang, S. Kao, Y. Wu & C. Lin, "The evaluation of fire rescue capability from post-earthquake fires in Taipei, Taiwan", *Journal of Earthquake and Tsunami*, *8*(05), 1450014, 2014. DOI: 10.1142/S1793431114500146

[20] K. Himoto & K. Suzuki, "Probabilistic fire risk assessment of a mid-rise or high-rise building with fire safety equipment systems damaged by seismic shaking", *Journal of Environmental Engineering (Japan)*, 81(728), 855-863, 2016. DOI: 10.3130/aije.81.855

[21] X. Liu, W. Wang, T. Dong & Z. Yang, "Dynamic evaluation on road's evacuation capability under the influence of post-earthquake fire in urban seismic weak area", Disaster Advances, 11 (1), 57-65, 2018.

[22] Z. Xu, Z. Zhang, X. Lu, X. Zeng & H. Guan, "Post-earthquake fire simulation considering overall seismic damage of sprinkler systems based on BIM and FEMA P-58", *Automation in Construction*, *90*, 9-22, 2018. DOI: 10.1016/j.autcon.2018.02.015

[23] X. Lu, X. Zeng, Z. Xu & H. Guan, "Physics-based simulation and high-fidelity visualization of fire following earthquake considering building seismic damage", *Journal of earthquake Engineering*, *23*(7), 1173-1193, 2019. DOI: 10.1080/13632469.2017.1351409

[24] Y. Li, J. Gao, H. Zhang, L. Deng & P. Xin, "Reliability assessment model of water distribution networks against fire following earthquake (FFE)", *Water*, *11*(12), 2536, 2019. DOI: 10.3390/w11122536

[25] T. Nishino & A. Hokugo, "A stochastic model for time series prediction of the number of post-earthquake fire ignitions in buildings based on the ignition record for the 2011 Tohoku Earthquake", *Earthquake spectra*, *36*(1), 232-249, 2020. DOI: 10.1177/8755293019878184

[26] M. M. Rafi, T. Aziz & S. H. Lodi, "A suggested model for mass fire spread", *Sustainable and Resilient Infrastructure*, *5*(4), 214-231, 2020. DOI: 10.1080/23789689.2018.1519308

[27] M. Coar, M. Garlock & N. Elhami Khorasani, "Effects of water network dependency on the electric network for post-earthquake fire suppression", *Sustainable and Resilient Infrastructure*, *5*(5), 269-288, 2020. DOI: 10.1080/23789689.2018.1563408

[28] K. Himoto, "Hierarchical Bayesian modeling of post-earthquake ignition probabilities considering inter-earthquake heterogeneity", *Risk Analysis*, *40*(6), 1124-1138, 2020. DOI: 10.1111/risa.13455

[29] X. Lu, Z. Yang, Z. Xu & C. Xiong, "Scenario simulation of indoor post-earthquake fire rescue based on building information model and virtual reality", *Advances in Engineering Software*, *143*, 102792, 2020. DOI: 10.1016/j.advengsoft.2020.102792

[30] A. Sarreshtehdari & N. E. Khorasani, "Integrating the fire department response within a fire following earthquake framework for application in urban areas", *Fire safety journal*, *124*, 103397, 2021. DOI: 10.1016/j.firesaf.2021.103397

[31] M. Coar, A. Sarreshtehdari, M. Garlock & N. Elhami Khorasani, "Methodology and challenges of fire following earthquake analysis: an urban community study considering water and transportation networks", *Natural hazards*, *109*(1), 1-31, 2021. DOI: 10.1007/s11069-021-04795-6

[32] G. Hou & Q. Li, "Firefighting capacity evaluation of water distribution system subjected to multi-ignitions of post-earthquake fires", *Structural safety*, *88*, 102035, 2021. DOI: 10.1016/j.strusafe.2020.102035

[33] F. Scheele, B. Lukovic, J. Moratalla, A. Dunant & N. Horspool, "Estimating fire following earthquake risk for Wellington City, New Zealand", *Bulletin of the New Zealand Society for Earthquake Engineering*, *55*(4), 241-256, 2022. DOI: 10.5459/BNZSEE.55.4.241-256

[34] Q. Tong & T. Gernay, "A hierarchical Bayesian model for predicting fire ignitions after an earthquake with application to California", *Natural Hazards*, 1-24, 2022. DOI: 10.1007/s11069-021-05109-6

[35] Y. Wu, Z. Xu, C. Liang & R. Song, "Post-earthquake traffic simulation considering road traversability", *Sustainability*, *14*(18), 11145, 2022. DOI: 10.3390/su141811145

[36] T. Nishino, "Probabilistic urban cascading multi-hazard risk assessment methodology for ground shaking and post-earthquake fires", *Natural Hazards*, *116*(3), 3165-3200, 2023. DOI: 10.1007/s11069-022-05802-0

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Parametric and Non-Parametric Reliability Analysis of The Propeller Unit of an Aircraft Fleet

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Abstract

Preventive maintenance is performed to sustain the safe and reliable operation of industrial equipments. In order to plan preventive maintenance or evaluate the existing maintenance plan, the failure behavior of the system must be modeled. The failure behavior of a repairable system is modeled utilizing counting processes. In this study failure behavior of propellers belonging to a small aircraft fleet is modeled. First non-parametric estimate of population mean cumulative function (MCF) is obtained. MCF helps discovering the special features of the maintenance data. The parametric model selection depends on the result of the trend analysis of the time between failures. In the second part of the study trend analysis is performed on propeller maintenance data. Based on the trend analysis two prospect parametric models are selected. Reliability measures are estimated using both models and results are compared to evaluate the existing preventive maintenance plan.

Keywords: repairable system reliability, MCF, counting process, reliability metrics

1. Introduction and Background

Increasingly complex systems are being produced to meet today's technological needs. For these systems to fulfill their functions, all the parts, devices, and components that make up the system must work properly. The loss of function of even a small part of the system can have a negative impact on the operation of the entire system. However, as systems are used, the components that make up the systems wear out over time. This reduces the efficiency of the systems and leads to their failure after a certain period.

Maintenance is an important element in ensuring the reliable working of systems throughout their life cycle. Maintenance schedules and types are determined by the system's needs, equipment's nature and condition, and other factors. Insufficient, excessive, or incorrect maintenance can cause malfunctions, which affects the usability of the systems and causes the system to lose performance. System repair costs may increase significantly due to possible secondary failures. An effective maintenance plan must be developed and implemented to keep a system in good working condition. In addition, existing maintenance data should be analyzed over time and the existing maintenance plan should be updated to meet the system's needs. Maintenance data are classified as recurring event data. These data are analyzed using counting processes from stochastic models. Counting processes are models of the occurrence of events over time and are used in systems with recurring events [1, 2].

In the literature, Ye, et al. [3] developed the reliability evaluation framework for hard disk drive (HDD) based on the non-homogeneous Poisson process (NHPP) and illustrated the framework on real data from the HDD tests. Traditional methods for accelerated life test (ALT) data analysis cannot fit the time-to-failure data well. A multi-country production system operational status can be characterized using a task reliability model based on product quality status, as proposed by Yang, et al. [4]. Majumdar [5] proposed a failure model for a repairable hydraulic excavator system, which is modeled by a NHPP with a time-dependent log-linear hazard rate function, and the failure modes of the system, which are at very high risk, are identified by failure mode and effect analysis (FMEA) and appropriate corrective measures are

discussed. Huang, et al. [6] proposed the NHPP to model the degradation in the system. The proposed model considers the virtual age concept and uses the production yield rate as a condition variable for the optimal preventive maintenance (PM) framework, then three different case-based PM strategies are proposed for the system. Ali [7] developed intuitive, practically interpreted, and adapted process monitoring strategies to monitor time-between-events (TBE) online and used a power-law NHPP model to develop TBE schedules. Cahoon, et al. [8] discussed the background of reliability growth models. They presented two models based on the Poisson process and competing risks. They discussed how these models can be extended to a Bayesian framework. Li, et al. [9] developed an improved four-parameter NHPP model and presented a meta-action reliability model for machine tools. Said and Taghipour [10] developed the likelihood function corresponding to the failures and preventive maintenance of a fleet of trucks in the mining industry and optimized the parameters of the failure process with some meta-heuristics. The Kijima virtual age models [11] discussed by Jack [12] and the failure density adjustment model for NC machine tools were used by Guo, et al. [13] as part of their imperfect PM model. Van and Bérenguer [14] assumed that deterioration behavior is a Gamma stochastic process and proposed a state-based maintenance policy for deteriorating production systems. Kahle [15] discussed the Kijima models [11] applied to system virtual age and deterioration.

Preventive maintenance is performed to sustain the safe and reliable operation of industrial equipment. To plan preventive maintenance or evaluate the existing maintenance plan, the failure behavior of the system must be modeled. The failure behavior of a repairable system is modeled utilizing counting processes. In this paper, the failure behavior of propellers belonging to a small aircraft fleet is modeled. First, the non-parametric estimate of population mean cumulative function (MCF) is obtained. MCF helps to discover the special features of the maintenance data. The parametric model selection depends on the result of the trend analysis of the time between failures. In the second part of the study trend analysis is performed on propeller maintenance data. Based on the trend analysis NHPP and Kijima II models are selected as prospect models. Reliability measures are estimated using both models and results are compared to evaluate the existing preventive maintenance plan.

The remainder of this paper is structured as follows: Section 2 reviews NHPP and Kijima II models. The problem and data definitions are given in Section 3. Reliability analysis of propellers is performed in Section 4. In section 5, results of the proposed models are presented. Finally, the conclusion is given in Section 6.

2. Methodology

Counting processes are stochastic models, defined as the occurrence of events over time. These events are thought of as points on the time axis, usually the time between events is neither independent nor identically distributed [16, 17]. When events are failures of a system, counting processes can be categorized based on the quality of repairs as homogeneous Poisson processes (HPP), renewal processes (RP), non-homogeneous Poisson processes (NHPP), and imperfect repair processes (IRP). The classification of the counting processes according to repair type is shown in Figure 1.

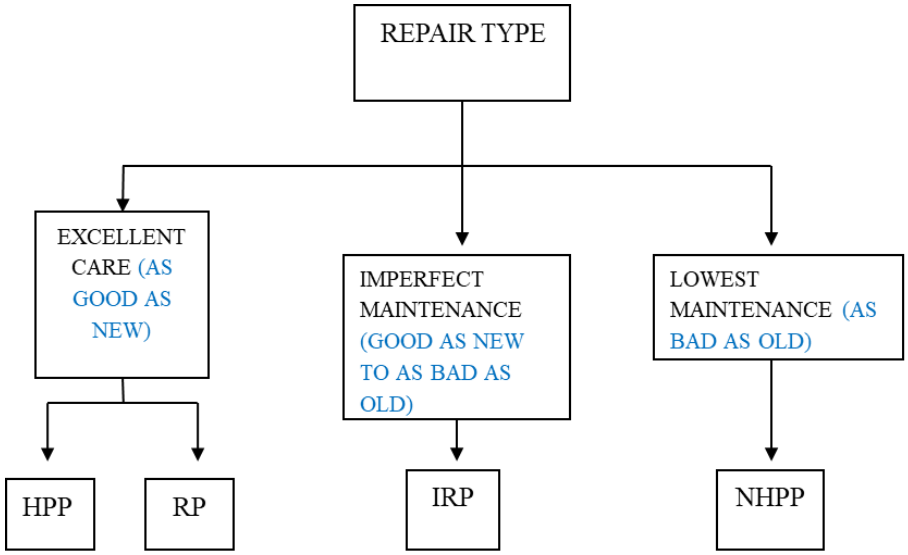

Figure 1: The classification of the counting process [18].

In this study, NHPP and IRP models are used. The NHPP is also called a non-stationary Poisson process [19]. The basic assumption of the NHPP model is that in the event of a failure, the system is repaired to the state it was in immediately before the failure, i.e. the minimal repair or as-bad-as-olds [18, 20]. This assumption is justifiable for repairable systems, such as an engine, since typically only a few components of the system is repaired at a time, restoring it to its pre-failure state [21].

Some applications of the NHPP model in reliability; trend analysis based on failure occurrence, optimal replacement analysis, statistical warranty claim prediction. As an example of these studies; in the study conducted by Rausand and Hoyland [18], Asfaw and Lindqvist [22], Nelson [23], Tang, et al. [24], the NHPP model was used in the problem of trend analysis based on fault occurrences. Sheu, et al. [25], Srivastava and Mondal [26] discussed the NHPP model optimal replacement problems. Kaminskiy and Krivtsov [27], Majeske [28] used the model to analyze the statistical warranty claim prediction.

For the counting process $N_i(t), t \geq 0$ to be NHPP with the rate function $w_i(t)$, must satisfy the following conditions; $N_i(0) = 0$, $N_i(t), t \geq 0$ is an independent increment and it is not possible for more than 1 failure to occur in at the same time. For the NHPP, the probability mass function of the number of events occurring at time $(0, t]$ for subpopulation i is according to a Poisson distribution.

$$P(N_i(t) = n) = \frac{W_i(t)^n e^{-W_i(t)}}{n!} \tag{1}$$

In Equation 1, $N_i(t)$ is the random variable representing the number of events at time $(0, t]$ for subpopulation i. $W_i(t)$; is the expected value known as the mean cumulative function (MCF) for subpopulation i at time $(0, t]$ expressed in Equation 2.

$$E[N_i(t)] = W_i(T) = \int_0^T w_i(t)\, dt, \tag{2}$$

where $w_i(t)$ is rate of occurrence of failures (ROCOF) at time t for unit i.

In order to calculate the ROCOF for the NHPP model, a parametric model is needed. The power-law was first discussed by Duane [29], and later broadened by Crow [30].The power–law NHPP is used to model failure times that occur at an increasing, decreasing and constant rate. When the rate constant NHPP becomes HPP. It is often used for the reliability of repairable systems or complex systems.

$$W_i(T) = \int_0^T \left(\frac{1}{\lambda_i}\right)^{\beta_i} t^{\beta_i - 1} dt = \left(\frac{T}{\lambda_i}\right)^{\beta_i}, \tag{3}$$

where β_i is the shape parameter and λ_i is scale parameter. The power-law NHPP model is highly sensitive to β_i. Accurate calculation of β_i is crucial. This calculation is challenging for noisy data sets and/or subpopulations with few data points. Therefore, in such cases, a power law NHPP model with a common shape parameter is proposed [20]. According to the value of β_i, the following situations are observed; if $0 < \beta_i < 1$, the time between failures increases, if $\beta_i = 1$, the NHPP model is reduced to the HPP model, and if $\beta_i > 1$, the time between failures decreases.

The general renewal process (GRP) is an IRP model. In particular, GRP models model the failure behavior of a given system and enable an understanding of the effects of repairs on the age of the system. The GRP is an appropriate model when the state of the system after repair is between "as good as new" and "as bad as new". In the study by Crocker [31], the failures were analyzed by special forms of GRP Kijima model I and Kijima model II. It was revealed that the system would not be as good as new after repair. The models developed in Kijima [11] study proposed these two models, which deal with a general assumption regarding the repair situation of the GRP [32].

Kijima model I assumes that the repair after system failure is based only on the removal of the last damage, while Kijima model II assumes that the repair after failure removes the damage accumulated up to the present time and all wear and tear.

$$R(x) = P(X > x), \tag{4}$$

where $R(x)$ is the reliability or survivor function, distribution function $F(x) = 1 - R(x)$, densitiy function $f(x) = -dR(x)/dx$.

$$r(x) = f(x)/R(x), \tag{5}$$

where r(x) is the hazard rate and $H(x) = \int_0^x r(u)du$ is the cumulative hazard function. In the event of a system failure, a repair is performed, and the time between the $(i-1)$th failure and the (i)th failure is the system uptime, expressed as X_i, and the distribution of X_i depends on the value of V_{i-1}, which is the virtual age of the system after the $(i-1)$th repair [33].

$$P(X_i \geq x \setminus V_{i-1} = v) = \frac{R(x+v)}{R(x)}, \tag{5}$$

$$V_i = \gamma(V_{i-1}, X_i), \qquad i \geq 0, V_0 = 0 \tag{6}$$

where γ is the repair function. Situations by virtual age can be summarized as follows: if $V_i = 0,\ i \geq 0$, replacement ("as good as new") for The RP or HPP, if $V_i = V_{i-1} + X_i,\ i \geq 0$, minimal repair ("as bad as old") for The NHPP, if $V_i = V_{i-1} + \alpha_i X_i,\ i \geq 0$ where α_i is a random variable and $0 \leq \alpha_i \leq 1$, Kijima model I, and $V_i = \alpha_i(V_{i-1} + X_i),\ i \geq 0$ and $0 \leq \alpha_i \leq 1$, Kijima model II. Maintenance models are constrained by the fact that repairs are either "good as new" or "minimum repair", so the general repair models Kijima model 1 and Kijima model 2 are more suitable as they provide flexibility in modeling the degree of repair between the two extremes of repair [33]. When the virtual age V_i is increased considerably, it will have an infinite failure rate and the uptimes will stochastically decrease towards a boundary value of zero. For this reason, Kijima model I cannot be used in a repair strategy that aims to maintain a constant long-term expected time between failures in the system, instead Kijima model II is a more appropriate approach.

3. Description of the Problem

Propellers are the parts that use the energy generated by the engines to accelerate the air mass so that the aircraft can move through the air. Propeller maintenance data for a fleet of aircraft is analyzed using counting processes and suitable reliability measures are estimated to evaluate the existing maintenance plan. The fleet consists of 34 aircraft and the failed propeller is removed from the aircraft and replaced with another propeller from the stock. The repaired propeller is sent to stock room. The propellers are regularly checked and overhauled as part of preventive maintenance. The propeller is tracked in the

system using the serial number. We have maintenance data for a total of 72 propellers. The maintenance data used in the study was compiled from various sources. An example of the data can be found in Table 1. The table shows the accumulated flight hours between removals of the propeller *P01*. From this data the accumulated flight hours between failures are calculated for the reliability analysis.

Table 1: Maintenance data

Serial Number	Reason	Flight Time Between Disassemblies
P01	Overhaul	1118.0
P01	Failure	1909.7
P01	Failure	2422.2
P01	Failure	2481.3

Propellers suffered different numbers of failures. This information is summarized in Table 2. For example, 22 propellers had no failures and 25 had only one failure. The total number of failures for the whole population of propellers is 96 failures.

Table 2: The Number of Propellers that have Suffered a Given Number of Failures

Number of Failures	Propeller Units
0	22
1	25
2	13
3	7
4	1

All propellers are from the same manufacturer, and their ages and operating conditions are the same, forming a homogeneous population. Therefore, maintenance data of all propellers are polled. Reliability analysis is performed on the pooled data and reliability metrics are calculated for the fleet.

4. Methodology and Case Study

Two modeling approaches are proposed to analyze the propeller unit data and the systems are modeled separately for each modeling approach. The propeller units are not considered as good as new after overhauls so the cumulative flight hours between failures are taken as a basis. Figure 2 below presents the event plot of propeller units. Cross marks indicate the accumulated flight hours that failures took place.

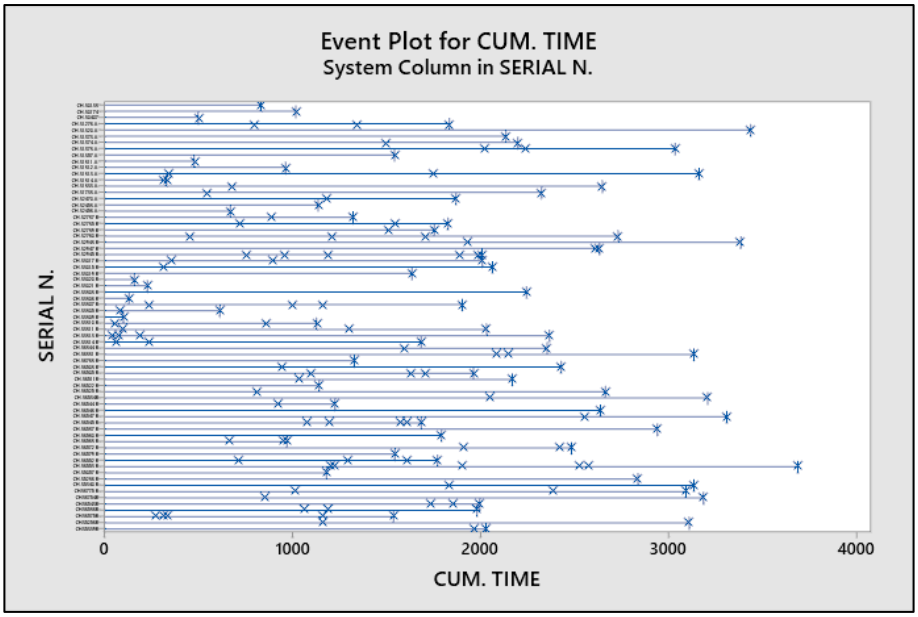

Figure 2: Event Plot for Cumulative Time

4.1. Trend Test

The general trend of the data was first determined using a non-parametric model. In the non-parametric model, the MCF is estimated over time from the data without assuming a model. MCF is a plot of the average cumulative number of failures per unit, over time. The MCF is estimated for each time point at which a failure occurs and averaged over the number of units observed at that time point (number of units at risk) [23].

The shape of the MCF gives information on the shape of the ROCOF. If MCF is linear, ROCOF is constant in time and there is no trend in the time between failures. If MCF is convex, ROCOF is an increasing function in time and the time between failures decreases with time. If MCF is concave, ROCOF is a decreasing function in time and the time between failures increases over time. In these two cases, ROCOF has a monotonic increase or decrease. When the MCF changes shape, the ROCOF is also not monotonic. The MCF plot for propeller units is given in Figure 3 below. The slight convex nature of the figure shows that the propeller deteriorates more often as it ages. This is an expected result as the propeller is a mechanical system [34].

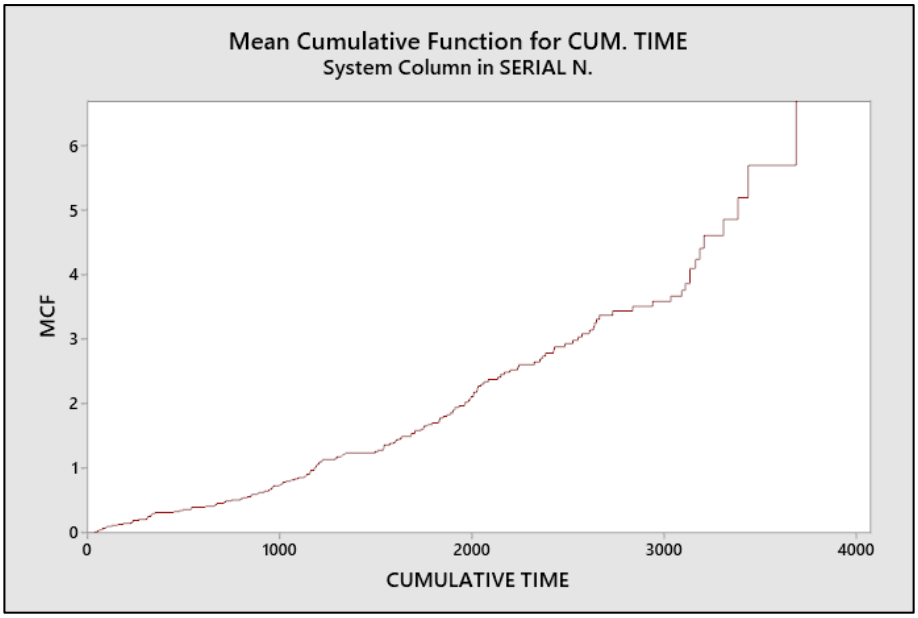

Figure 3: Mean Cumulative Function for Propeller Units

MCF values for some flight hours are given in Table 3. As an example, the third row of the table can be explained as follows. It is estimated that an average of 2.032 failures per unit will occur in 2133.2 flight hours. The standard error of this prediction is 0.225 and the 95% confidence interval (CI) is calculated as 1.635-2.525.

Table 3: Estimation of MCF

Time	**MCF**	**Std. Error**	**95% Normal CI limit**		**Serial Number**
			Upper	**Lower**	
32	0.014	0.014	0.099	0.002	*P59*
1190.5	1.008	0.135	0.312	0.775	*P11*
2133.2	2.032	0.225	2.525	1.635	*P35*

After determining the general trend of the data with the nonparametric model, a trend test was applied to the time between failures of the propeller units to determine the appropriate parametric model and the trend test results are given in the Table 4.

Table 4: Trend Test Results for Propeller Units

	MIL-Hdbk-189		**Laplace's**		
	TTT-based	**Pooled**	**TTT-based**	**Pooled**	**Anderson-Darling**
Test Statistic	190.83	157.27	1.96	1.59	3.01
P-value	0.036	0.100	0.050	0.112	0.027

DF	234	188

Since the units are homogeneous, the test results based on the total-time-on-test statistic are analyzed. The test results are evaluated for 0,05 significance level. Since the P-values are less than or equal to 0.05, there is a trend. Based on the trend test results and the nonparametric model results a nonstationary counting process model is suitable for modeling the reliability of the propellers. Power law model and Kjima model II are chosen as prospect models.

4.2. Proposed Modeling Approach 1

Parameters of the power law model are estimated by maximum likelihood method. The parameter estimates of the power law model are given in the Table 5. From the table, the shape parameter ($\boldsymbol{\beta}$) is estimated as 1.11 and the scale ($\boldsymbol{\theta}$) parameter is estimated as 1447.51. Although the 95% confidence interval contains values less than 1, the trend test results, and the non-parametric MCF model results support the trend in the time between failures as the propeller unit ages.

Table 5: Estimation of Power Law Model Parameters

Parameter	**Estimate**	**Std. Error**	**95% Normal CI Limit**	
			Lower	**Upper**
Shape ($\boldsymbol{\beta}$)	1.11	0.089	0.952	1.303
Scale ($\boldsymbol{\theta}$)	1447.51	143.707	1191.56	1758.44

The average cumulative number of failures predicted from the model is given in Figure 4. The blue dots in the figure represent the data and the solid line represents the values predicted from the model, thus the figure shows that the model predictions are close to the actual data.

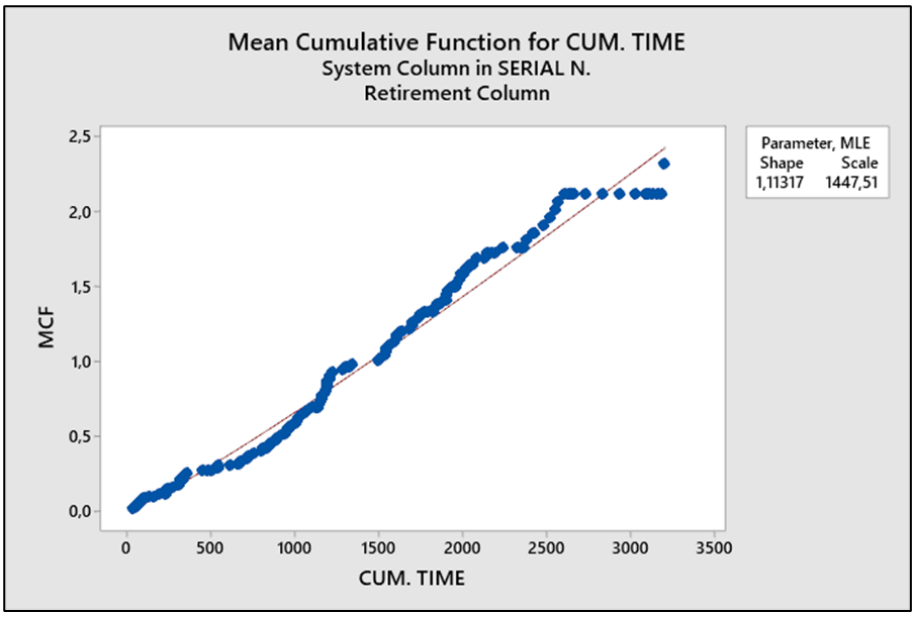

Figure 4: MCF for Cumulative Time

The values of the ROCOF for the power law model at some time points are given in the Table 6. For example, a propeller that has completed 1000 hours of flight time will fail on average $\mathbf{7.38 \times 10^{-4}}$ times in an hour flight. This is a very low failure density. As can be seen from the values in the table, ROCOF increases slowly over time.

Table 6: Proposed Model 1 Density Function Values

Time (t) (flight hour)	**Density function, $\lambda(t)$ (failure/flight hour)**
1000	0.000738
2000	0.000798
3000	0.000835
4000	0.000863

Estimates of the values of the mean time between failures at some time points and the 95% confidence intervals of the estimates are given in the Table 7. For example, for a small-time interval dt starting with 1000 flight hours, the mean time between failures (MTBF) is approximately 1356 hours. As the ROCOF increases over time, MTBF decreases over time as shown in the table.

Table 7: Proposed Model 1 MTBF Values

Time	**MTBF (flight hour)**	**95% Normal CI**
1000	1355.93	1109-1657
2000	1253.62	970-1619
3000	1197.40	874.84-1638.90

4.3. Proposed Modeling Approach 2

When the Kijima II model is applied for all data, the model parameters are estimated by maximum likelihood method and given in the Table 8. The value of the parameter $\boldsymbol{q}$, which indicates the repair quality, is approximately zero. This indicates that the repair quality is very good. After repair, the systems are almost as good as new. This also supports the fact that the confidence interval for $\boldsymbol{\beta}$ parameter of NHPP includes also 1. Therefore, Kijima model is more appropriate for modelling propellers failure behavior.

Table 8: Kijima II Model Parameters

Parameter	**Estimate**
β	0.900173
λ	0.001473
q	0.000015

For the Kijima II model, the values of ROCOF at some time points are given in the Table 9. For example, a propeller that has completed 1000 flight hours will fail an average of $\mathbf{6.87 \times 10^{-4}}$ times in a hour flight. This is a very low failure density.

Table 9: Proposed Model 2 Density Function Values

Time (t) (flight hour)	**Density function, λ (t) (failure/flight hour)**
1000	0.000687
2000	0.000659
3000	0.000844

The values of the mean time between failures at some time points are given in the Table 10. The mean time between failures in 1000 flight hours is 1456.43 hours. A propeller unit with 1000 flight hours (which may have failed and been repaired) has a 0.41 probability of flying for another 1000 hours without failure.

Table 10: Proposed Model 2 MTBF Values

Time (flight hour)	**MTBF (flight hour)**	**95% Normal CI Limit**
1000	1456.43	1156.15-1888.38
2000	1517.47	1177.55-2025.30

The values of the average number of failures per propeller and the average number of propeller unit failures for the fleet at some time points are given in the Table 11. For example, the mean number of failures per propeller unit between 1500-2000 flight hours is 0.315. Since there are 34 aircraft in the fleet and each aircraft has one propeller unit, the average number of propeller unit failures for the fleet between 1500-2000 flight hours is $\mathbf{34 \times 0.315 = 10.71}$.

Table 11: Mean Number of Failures for the Kijima II Model

Time (flight hour)	**Mean Failure ($E[N(t)]$)**	**Mean Number of Failures for the Fleet**
0-1000	0.396	13.464
1000-2000	0.343	11.662
1000-1500	0.326	11.084
1500-2000	0.315	10.71
2000-2500	0.307	10.438

5. Conclusions

In this paper, the maintenance data of propellers are analyzed using parametric and non-parametric models. Analysis results showed that the Kjima II model more appropriate to model the failure behavior of propellers.

The Kjima II model used in the proposed modeling approach 2 suggests that the repair quality is almost as good as new. This shows that the current preventive maintenance plan is effective and the quality of the corrective maintenance is satisfactory.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] P. K. Andersen, O. Borgan, R. D. Gill, and N. Keiding, *Statistical models based on counting processes*. Springer Science & Business Media, 2012.

[2] S. E. Rigdon and A. P. Basu, "Statistical methods for the reliability of repairable systems," *(No Title),* 2000.

[3] Z.-S. Ye, M. Xie, and L.-C. Tang, "Reliability evaluation of hard disk drive failures based on counting processes," *Reliability Engineering & System Safety,* vol. 109, pp. 110-118, 2013.

[4] X. Yang, Y. He, R. Liao, Y. Cai, and W. Dai, "Mission reliability-centered opportunistic maintenance approach for multistate manufacturing systems," *Reliability Engineering & System Safety,* vol. 241, p. 109693, 2024.

[5] S. Majumdar, "Study on reliability modelling of a hydraulic excavator system," *Quality and Reliability Engineering International,* vol. 11, no. 1, pp. 49-63, 1995.

[6] Y. S. Huang, C. C. Fang, and S. Wijaya, "Condition-based preventive maintenance with a yield rate threshold for deteriorating repairable systems," *Quality and Reliability Engineering International,* vol. 38, no. 8, pp. 4122-4140, 2022.

[7] S. Ali, "Time-between-events monitoring using nonhomogeneous Poisson process with power law intensity," *Quality and Reliability Engineering International,* vol. 37, no. 8, pp. 3157-3178, 2021.

[8] J. Cahoon, K. Sanborn, and A. Wilson, "Practical reliability growth modeling," *Quality and Reliability Engineering International,* vol. 37, no. 7, pp. 3108-3124, 2021.

[9] Y. Li, X. Zhang, Y. Ran, and G. Zhang, "Reliability modeling and analysis for CNC machine tool based on meta-action," *Quality and Reliability Engineering International,* vol. 37, no. 4, pp. 1451-1467, 2021.

[10] U. Said and S. Taghipour, "Modeling failure process and quantifying the effects of multiple types of preventive maintenance for a repairable system," *Quality and Reliability Engineering International,* vol. 33, no. 5, pp. 1149-1161, 2017.

[11] M. Kijima, "Some results for repairable systems with general repair," *Journal of Applied probability,* vol. 26, no. 1, pp. 89-102, 1989.

[12] N. Jack, "Analysing event data from a repairable machine subject to imperfect preventive maintenance," *Quality and Reliability Engineering International,* vol. 13, no. 4, pp. 183-186, 1997.

[13] J.-f. Guo, Z.-y. Rui, R.-c. Feng, and X.-c. Wei, "Imperfect preventive maintenance for numerical control machine tools with log-linear virtual age process," *Journal of Central South University,* vol. 21, no. 12, pp. 4497-4502, 2014.

[14] P. D. Van and C. Bérenguer, "Condition-based maintenance with imperfect preventive repairs for a deteriorating production system," *Quality and Reliability Engineering International,* vol. 28, no. 6, pp. 624-633, 2012.

[15] W. Kahle, "Imperfect repair in degradation processes: A Kijima-type approach," *Applied Stochastic Models in Business and Industry,* vol. 35, no. 2, pp. 211-220, 2019.

[16] R. de Queiroz Souza and A. J. Álvares, "FMEA and FTA analysis for application of the reliability centered maintenance methodology: Case study on hydraulic turbines," in *ABCM Symposium Series in Mechatronics*, 2008, vol. 3, pp. 803-812.

[17] T. R. Fleming and D. P. Harrington, *Counting processes and survival analysis*. John Wiley & Sons, 2013.

[18] M. Rausand and A. Hoyland, *System reliability theory: models, statistical methods, and applications*. John Wiley & Sons, 2003.

[19] W. Kuo and M. J. Zuo, *Optimal reliability modeling: principles and applications*. John Wiley & Sons, 2003.

[20] A. Chehade, Z. Shi, and V. Krivtsov, "Power–law nonhomogeneous Poisson process with a mixture of latent common shape parameters," *Reliability Engineering & System Safety,* vol. 203, p. 107097, 2020.

[21] V. V. Krivtsov, "Practical extensions to NHPP application in repairable system reliability analysis," *Reliability Engineering & System Safety,* vol. 92, no. 5, pp. 560-562, 2007.

[22] Z. G. Asfaw and B. H. Lindqvist, "Unobserved heterogeneity in the power law nonhomogeneous Poisson process," *Reliability Engineering & System Safety,* vol. 134, pp. 59-65, 2015.

[23] W. B. Nelson, *Recurrent events data analysis for product repairs, disease recurrences, and other applications*. SIAM, 2003.

[24] Y. Tang, J. Fu, W. Liu, and A. Xu, "Bayesian analysis of repairable systems with modulated power law process," *Applied Mathematical Modelling,* vol. 44, pp. 357-373, 2017.

[25] S.-H. Sheu, T.-H. Liu, Z. G. Zhang, and Y.-H. Chien, "Extended optimal replacement policy for a two-unit system with shock damage interaction," *IEEE Transactions on reliability,* vol. 64, no. 3, pp. 998-1014, 2015.

[26] N. K. Srivastava and S. Mondal, "Development of predictive maintenance model for N-component repairable system using NHPP models and system availability concept," *Global Business Review,* vol. 17, no. 1, pp. 105-115, 2016.

[27] M. P. Kaminskiy and V. V. Krivtsov, "G-renewal process as a model for statistical warranty claim prediction," in *Annual reliability and maintainability symposium. 2000 Proceedings. International symposium on product quality and integrity (Cat. No. 00CH37055)*, 2000, pp. 276-280: IEEE.

[28] K. D. Majeske, "A non-homogeneous Poisson process predictive model for automobile warranty claims," *Reliability Engineering & System Safety,* vol. 92, no. 2, pp. 243-251, 2007.

[29] J. Duane, "Learning curve approach to reliability monitoring," *IEEE transactions on Aerospace,* vol. 2, no. 2, pp. 563-566, 1964.

[30] L. H. Crow, "An extended reliability growth model for managing and assessing corrective actions," in *Annual Symposium Reliability and Maintainability, 2004-RAMS*, 2004, pp. 73-80: IEEE.

[31] J. Crocker, "Effectiveness of maintenance," *Journal of Quality in Maintenance Engineering,* vol. 5, no. 4, pp. 307-314, 1999.

[32] A. Mettas and W. Zhao, "Modeling and analysis of repairable systems with general repair," in *Annual Reliability and Maintainability Symposium, 2005. Proceedings.*, 2005, pp. 176-182: IEEE.

[33] J. Dagpunar, "Some properties and computational results for a general repair process," *Naval Research Logistics (NRL),* vol. 45, no. 4, pp. 391-405, 1998.

[34] W. Q. Meeker, L. A. Escobar, and F. G. Pascual, *Statistical methods for reliability data*. John Wiley & Sons, 2022.