CHAPTER X

HISTORICAL RELIABILITY EVALUATION OF POWER DISTRIBUTION SYSTEMS BASED ON MONTE CARLO SIMULATION METHOD*

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1. INTRODUCTION

It is crucial to assess power systems' reliability to get the most accurate and appropriate planning, operation, and maintenance decisions. Historical assessment and predictive assessment are widely used methods to assess the reliability of a distribution network. Predictive reliability assessment is classified into two methods, analytical method and simulation method. Besides, analytical methods can be categorized into Markov modeling and network modeling groups (Koster et al., 1978). Simulation methods are considered the most flexible methods. However, it is computationally-burden. Since the historical reliability assessment based on actual data, which is exceptionally crucial in reliability analysis and can be a reference for comparison with other reliability assessment techniques (A. A. Chowdhury, 2005), it is preferable by most utilities rather than a predictive assessment. Thus, the utilities continually need to preserve and collect the data for plans and studies. The actual collected data would improve the system analyses in the future and the system's overall reliability. The significance of reliability studies for utility operators is crucial to determine the parts that are experiencing repeated failures, the areas of the highest amount of energy not supplied, and the areas of weak protection system (Wilson et al., 2006).

Many valuable works have been presented on historical reliability assessment (Allan, 1994)(Kim & Singh, 2010)(Baharum et al., 2013)(Abunima et al., 2018). Baharum et al. (Baharum et al., 2013), assessed the historical reliability based on the collected from an electricity distribution company in Baghdad, Iraq, and the two-parameter Weibull

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* Reliability Assessment of Closed Ring Power Distribution Systems

function. The statistical measures obtained by this analysis revealed the weakest parts such as transformers and circuit breakers. In (Feng, 2006), the actual data of 13 utilities in Canada are used to perform historical reliability analysis to determine the performance and assess the financial risk for their power distribution networks. Besides, it is established the regulations that are required to specify the reward/penalty levels. In (Wallnerström, 2008), the actual data for one Swedish power distribution network for three years (2004 -2006) are used to perform historical reliability analysis. The obtained result verified that the annual outage cost per customer was more than 500 €. In (A. A. Chowdhury, 2005), the actual data for two Canadian power distribution networks are utilized to improve the performance-based regulation in a deregulated environment to investigate the level of service reliability of these networks.

(Billinton & Pan, 2004) introduced a historical reliability assessment based on actual reliability data taken from the Canadian Electricity Association (CEA) service continuity reports. The study presented package of reward/penalty structure based on the historic reliability record could be integrated into a performance-based regulation plan. Historic reliability data are therefore, extremely crucial for distribution system risk assessment and remedial work in this new regime.

Monte Carlo Simulation (MCS) for reliability assessment in power systems also have been appeared in the literature (Thoemmes et al., 2010)(Schoemann et al., 2014)(Wijekularathna et al., 2019)(Godha et al., 2011)(Al-Wafi et al., 2016)(Bakkiyaraj & Kumarappan, 2010).

MCS techniques based on non-sequential state transition sampling reliability evaluation of power systems is proposed(Bakkiyaraj & Kumarappan, 2010). This method is applied to Roy Billinton Test System (RBTS) and verified its effectiveness compared with the sequential simulation. In (Godha et al., 2011) MCS to assess the costs due to electric supply interruptions in distribution power system. Feeder 1 of RBTS Bus-2 is utilized to carry out the simulation and to confirm the applicability of MCS.

The sequential time MCS is presented to assess distribution systems' reliability due to severe weather (Cadini et al., 2017). MCS in combining with stochastic models for describing uncertain weather conditions with a cascading failure model based on a DC approximation of the power flows and a proportional re-dispatch strategy is proposed. The sequential time MCS method was tested by IEEE14 reference power system. The obtained results show that rare, but highly severe (in terms of duration and intensity), weather events may have, in general, a significant impact on the distributions of the reliability performance indices of a power transmission grid.

Also, in (Silva et al., 2016), the Quasi-Sequential MCS is also used to assess the distributed generation's such as photovoltaic connection on the power quality indices of distribution networks impact on system reliability. The method was tested by a real distribution feeder with 1560 nodes. The obtained results show that PV penetration can cause about 31% of improvements in the voltage conformity indices, and increases the lifespan of the voltage regulators as a result of a reduction about 20% in the number of tap changes.

This Chapter introduces historical reliability analysis for a real 4-feeder power distribution network in Istanbul. Then, MCS is utilized to estimate its future reliability. The obtained results from historical and MCS are analyzed and compared.

In this Chapter, the following essential issues shall be discussed:

- The value of reliability assessment analyses in planning, design, and maintenance of power distribution networks;
- Evaluating the reliability of actual 4-feeder power distribution network in Istanbul via historical assessment;
- Evaluating the reliability based on the MCS method;
- Comparing the historical and MCS methods results;
- They are presenting several vital recommendations for power utilities and electric companies to improve their systems' reliability.

2. RELIABILITY CALCULATIONS

The components of any electric system are connected in two ways, series, and parallel. Similarly, power distribution networks’ components are connected in series, parallel, or combination of series and parallel. Calculation of load point (LP) indices, i.e., failure rate (λ), mean outage time (r), and the mean annual unavailability (U), is mandatory to calculate the system reliability indices. SAIFI that defined as the total number of customer interruptions by the total number of customers served, SAIDI defined as the total customer interruption duration by the total number of customers served, CAIDI that defined as the total customer interruption duration by the total number of customer interruptions, ASAI defined as the customer hours of available service by customer hours demand, expected energy not supplied (ENS) is defined as the product sum of average LP demand and the average outage time per year, and average expected energy not supplied (AENS) is defined as the expected ENS by the total number of customers served are the most crucial system reliability indices (Ali A. Chowdhury & Koval, 2009). Tables 1 and 2 present the formulas to calculate LP indices for series and parallel systems, respectively (Mohammed Wadi et al., 2017).

Table 1: LP reliability indices for series systems

# Series Component	$\boldsymbol{\lambda_s}$ **[failure/year]**	$\boldsymbol{r_s}$ **[hour]**	$\boldsymbol{U_s = \lambda_s r_s}$ **[hour /year]**
n Component	$\sum_i^n \lambda_i$	$\frac{\sum_i \lambda_i \ r_i}{\sum_i \lambda_i}$	$\sum_i \lambda_i \ r_i$

Table 2: LP reliability indices for parallel systems

$\boldsymbol{\lambda_p}$ **[failure/year]**	$\boldsymbol{r_p}$ **[hour]**	$\boldsymbol{U_p = \lambda_P r_P}$ **[hour /year]**
$\frac{\lambda_1\lambda_2(r_1+r_2)}{1+\lambda_1 r_1+\lambda_2 r_2}$ $\lambda_1\lambda_2(r_1+r_2)\ if\ \lambda_i r_i \ll 1$	$\frac{r_1 r_2}{r_1+r_2}$	$\lambda_1\lambda_2 r_1 r_2$
$\lambda_1\lambda_2\lambda_3(r_1r_2+r_2r_3+r_3r_1)$	$\frac{r_1r_2r_3}{(r_1r_2+r_2r_3+r_3r_1)}$	$\lambda_1\lambda_2\lambda_3 r_1r_2r_3$

3. DISTRIBUTION NETWORK STRUCTURE IN TURKEY

Generally, the topology of electric distribution systems is a radial configuration or mesh configuration, but radial-operated such as the distribution network given in Figure 1. Besides, a substantial part of Istanbul's local electric distribution company is also ring-designed but radial-operated, as shown in Figure 2. Power distribution utilities have been attempting to develop their networks by modifying them into closed-ring in lieu of radial networks based on state-of-the-art bidirectional protection, control, and communication devices (Suthapanun et al., 2015), (Xu & Zou, 2010). Likewise, automatic power electronic converter switches in lieu of manual-operated switches play a vital role in such networks (Pattabiraman et al., 2019).

There are many attempts from the Scientific and Technological Research Council of Turkey (TUBITAK) to modify the distribution system's automation and configuration in Turkey. TUBITAK-UZAY (Ozay et al., 1999) proposed new functions for fault detection and service restoration for BEDAS in Istanbul, known as the TUBITAK Distribution Automation System (TUDOSIS).

4. DESCRIPTION OF SYSTEM CONFIGURATION

The historical data for the 4-Feeder sector of the real power distribution network in Istanbul are utilized to evaluate its reliability. The 4-feeder system consists of four 34.5 kV distribution feeders, twenty-four buses, 40 distribution lines, 62301 customers, and a total load up to 200 MW, as shown in Figure 2.

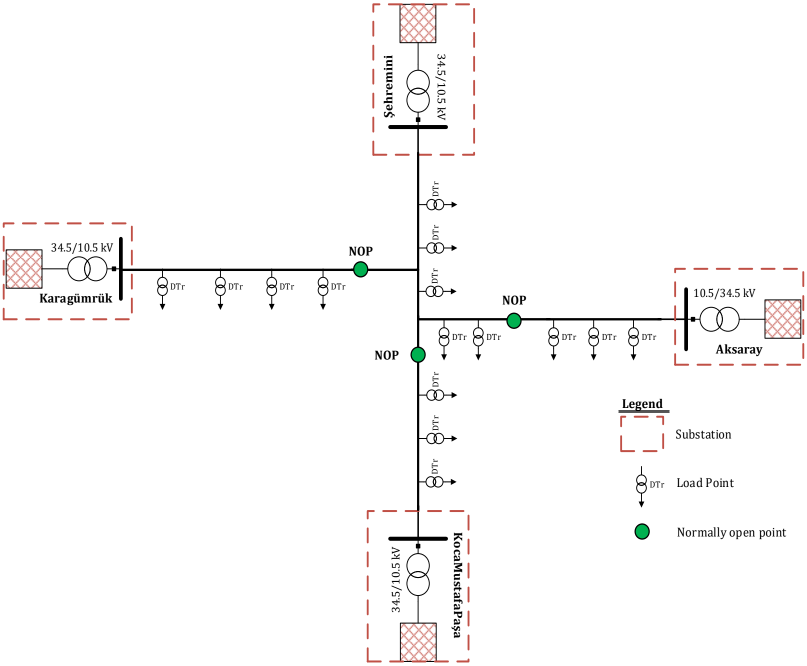

Figure 1. Electric distribution section meshed-designed radial-operated

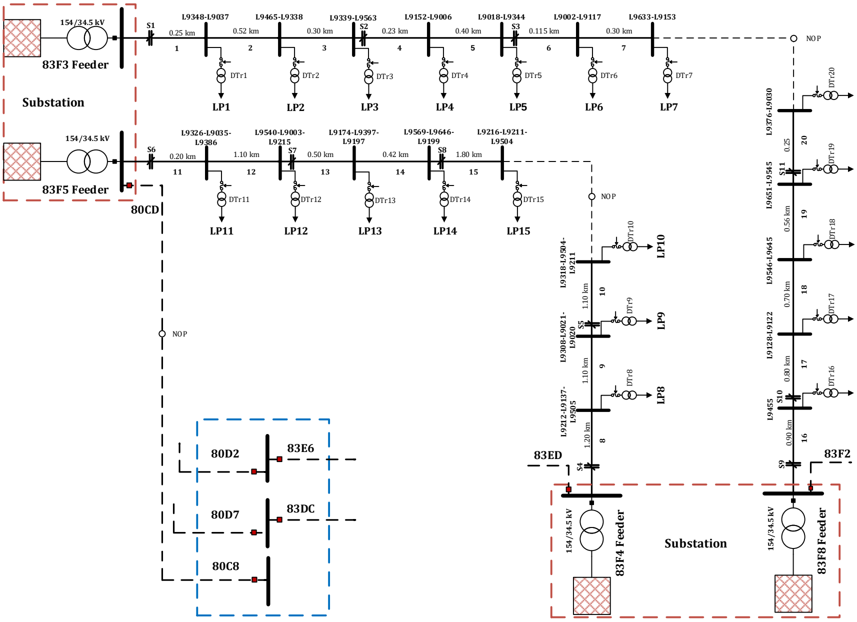

Figure 2. Single line diagram of the 4-Feeders distribution system

For the 4-feeder system depicted in Figure 2, the historical assessment reliability can be evaluated based on the following data (Wadi et al., 2020):

- The failure data of each component,
- The outage time and the switching time data for each component,
- Average load and peak load for each LP,
- The number of customers at each LP,
- The length of the feeder's sections and laterals,

These are collected from local power distribution utilities in Istanbul and organized as depicted in Tables 3-7.

Table 3: Feeder's sections and laterals length data in km

SN*	**F1⁺: 83F3**	**S. N**	**F2: 83F4**	**S. N**	**F3: 83F5**	**S. N**	**F4: 83F8**
1	0.25	8	1.20	11	0.20	16	0.90
2	0.52	9	1.10	12	1.10	17	0.80
3	0.30	10	1.10	13	0.50	18	0.70
4	0.23	28	0.595	14	0.42	19	0.56
5	0.40	29	0.313	15	1.80	20	0.25
6	0.115	30	0.331	31	0.086	36	0.316
7	0.30			32	0.272	37	0.127
21	0.11			33	0.222	38	0.335
22	0.252			34	0.156	39	0.208
23	0.181			35	0.397	40	0.221
24	0.152						
25	0.273						
26	0.10						
27	0.217						

*** SN:** Section Number, **⁺F_i:** Feeder Number

Table 4: 4-Feeder load points load in kW

Load Point	**Average Load/Customer**	**Peak load/ Customer**
1-7, 11-15	2.50	3.125
8-10, 16-20	3.00	3.750

5. HISTORICAL RELIABILITY ASSESSMENT OF 4-FEEDER SYSTEM

The reliability indices for any system are classified into two groups, LP indices such as λ, *r*, and U. Furthermore, system indices such as System SAIFI, SAIDI, CAIDI, ASAI, ENS, and AENS as given in (Wadi et al., 2018). The historical assessment results from 2012 to 2014 are summarized in Tables 7 and 8. Besides, Figures 3, 4, 5, and 6 graphically show the obtained results.

Table 5: 4-Feeder customer data

Load Point	No. of Customers	Load Point	No. of Customers
1	3305	11	3281
2	1447	12	3571
3	866	13	4742
4	2378	14	6335
5	640	15	8023
6	209	16	2611
7	549	17	2866
8	5439	18	2103
9	5216	19	663
10	7322	20	735

Table 6: 4-Feeder switches locations

Feeder	Section No.
F1	*S (1,1), S (2,4), S (3,6)
F2	S (4,8), S (5,10)
F3	S (6,11), S (7,13), S (8,15)
F4	S (9,16), S (10,17), S (11,20)

*S (x, y): Switch location, where x is the number of switches, while y the number of sections

Examining Figure 3 shows that Feeder F4-83F8 has the smallest SAIFI, 0.0305, and 0.0611 interruption /customer for the years 2012-2013 and 2013-2014, respectively. Therefore, this feeder can be considered the most reliable feeder, and its customers encounter the least occurrence of sustained interruptions among all the feeders. On the other hand, the Feeder F3-83F5 has the highest SAIFI, 0.4679, and 0.2366 for 2012-2013 and 2013-2014.

Table 7: Feeders and system indices for the period 2012-2013

Feeders/Indices	SAIFI	SAIDI	CAIDI	ASAI	AENS
F1-83F3	0.1825	0.3499	1.9178	0.99996006	0.87
F2-83F4	0.0797	0.0964	1.2105	0.99998899	0.24
F3-83F5	0.4679	0.4952	1.0582	0.99994347	1.24
F4-83F8	0.0305	0.0285	0.9333	0.99999675	0.07
System-Average	0.1901	0.2425	1.2754	0.99988927	0.61

Table 8: Feeders and system indices for the period 2013-2014

Feeders/Indices	SAIFI	SAIDI	CAIDI	ASAI	AENS
F1-83F3	0.1245	0.0692	0.5557	0.99999210	0.17
F2-83F4	0.1408	0.1286	0.9133	0.99998532	0.32
F3-83F5	0.2366	0.1458	0.6162	0.99998336	0.36
F4-83F8	0.0611	0.0326	0.5333	0.99999628	0.08
System-Average	0.1408	0.0940	0.6681	0.99995706	0.24

Based on the 4-Feeder distribution power systems, the average failure and repair data for each component can be extracted by historical assessment. These data are indispensable to predict the system's reliability at any time using simulation assessment methods such as MCS. This analysis noticed that most failures were with the lines, and the most occurred faults are the earth fault and the phase-to-ground fault. Circuit breakers rarely experience faults, and the only failure with CB was taken place at 9540 current transformer (CT) related to the feeder F1-83F3 due to the explosion of CB. Likewise, the failure of transformers also rarely occurred, for this system at 34.5/0.4 kV 9569 CT related to the feeder F3-83F5 registered one failure due to rats. Table 9 summarizes the reliability data. In this historical reliability analysis, only the distribution transformers, CBs, and distribution lines components are considered. The other components, such as relays, sectionalizers, and buses, are considered 100% reliable.

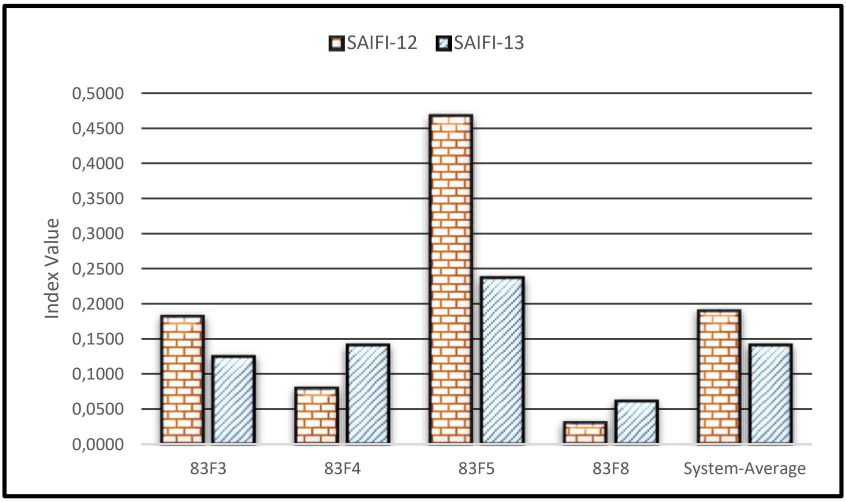

Figure 3. Feeder s and system SAIFI index for the period 2012-2014

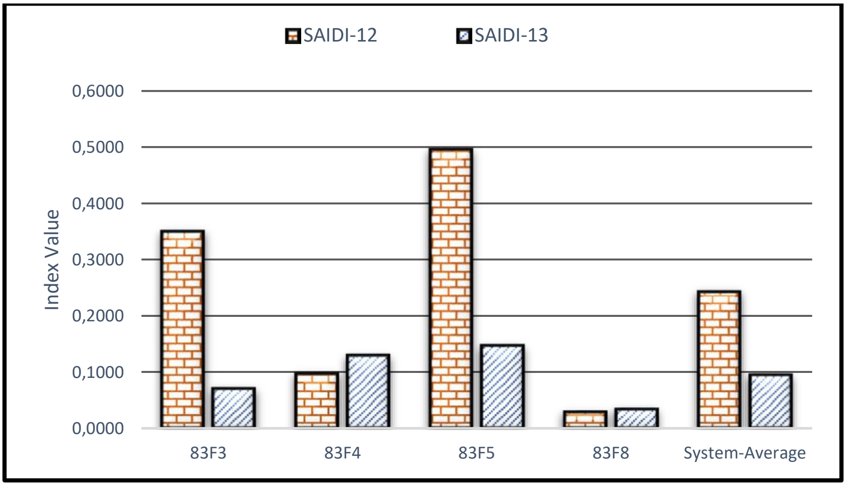

Figure 4. Feeders and system SAIDI index for the period 2012-2014

In the same manner, the feeder F4-83F8 has the least interruption duration with 0.0285 and 0.0326 *SAIDI* index for the years 2012-2013 and 2013-2014, respectively, as given in Figure 4. However, the feeder F3-

83F5 has the highest interruption duration with 0.4952 and 0.1458 SAIDI index for the years 2012-2013 and 2013-2014, respectively. Figure 5 provides a whole picture of the system by showing each feeder's reliability compared to others. It can be noticed that the feeder F4-83F8 has the highest reliability value, of 0.99988927 and 0.99995706 for the years 2012-2013 and 2013-2014, respectively.

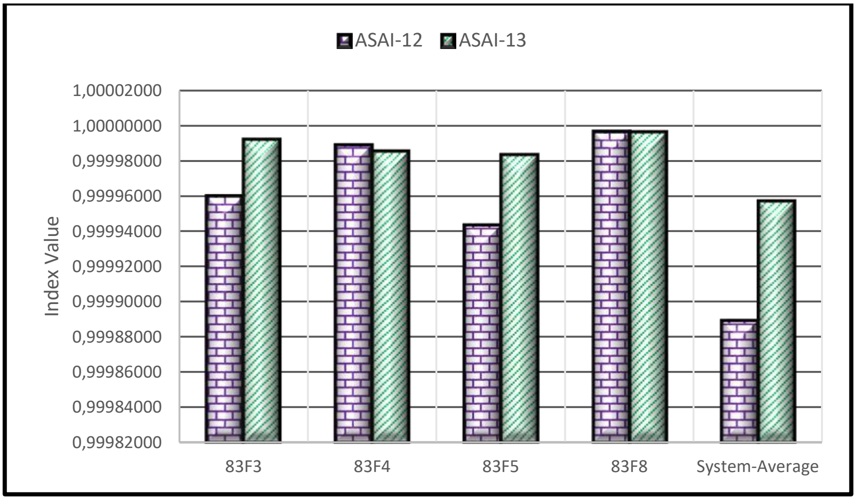

Figure 5. Feeders and system ASAI index for the period 2012-2014

Table 9: System reliability data for the period 2012-2014

Component	λ	r
34.5/0.40 kV Transformer	0.025	3.0
34.5/0.4 kV Circuit Breakers	0.025	2.0
34.5 kV Lines	0.050	1.5
0.4 kV Lines	0.125	1.0

It is crucial to calculate the ENS and AENS indices of different customers to estimate the interruptions costs. Figure 6 explains the AENS for the 4-Feeder distribution power system, and it is found that the feeder F3-83F8 is achieving the least AENS, i.e., 0.61 and 0.24 kWh/year/customer for the years 2012-2013 and 2013-2014, respectively.

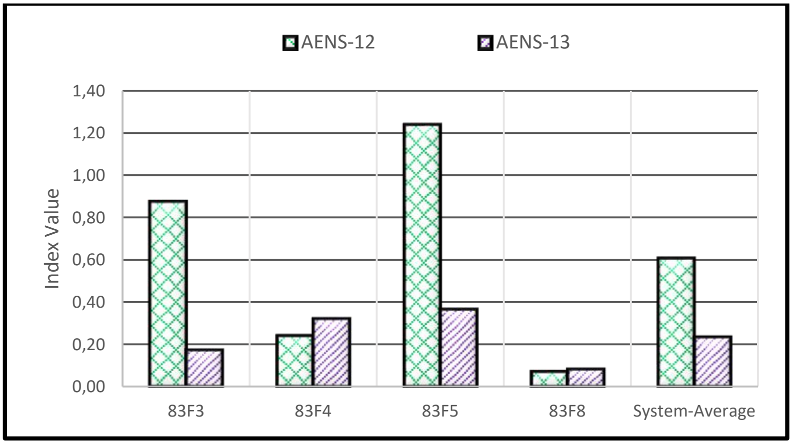

Figure 6. Feeders and system AENS index for the period 2012-2014

6. RELIABILITY ASSESSMENT VIA MONTE CARLO SIMULATION

Monte Carlo simulation method occupies a distinctive standing in a lot areas, such as nonlinear mathematical problems, stochastic simulation, medical diagnostic, engineering system analysis, and reliability assessment (Wadi et al., 2020). MCS introduces a powerful approach to evaluate the reliability of any system (Zhang et al., 2011). MCS's primary task to assess power systems' reliability is to generate an artificial history of faults for each component in the power system, i.e., lines, transformers, and circuit breakers. The failure process was frequently modeled using Weibull or Exponential distribution, while Lognormal or Exponential distribution for modeling repair process (Martinez-Velasco & Guerra, 2016). In this analysis, Exponential distribution is used for modeling both Time-to-Failure (TTF) and repair to time (TTR) as in equation (1) (Haroonabadi & Haghifam, 2011)

$$TTF = -\frac{1}{\lambda}\ln(n), \quad TTR = -\frac{1}{\mu}\ln(n) \tag{1}$$

where: *n* is a random number between 0 and 1

MCS is used to generate the TTF and TTR for each component based on random numbers and usually uniform random numbers (Wadi et al., 2018) (M. Wadi et al., 2017) (Wadi & Baysal, 2017). It is crucial to expand the simulation time to be tens or hundreds of thousands of years to obtain accurate and robust results.

In distribution power systems, MCS is used to generate random samples of λ and μ of each component, such as transformers, lines, circuit breakers, and relays. Upon the two parameters, TTF and TTR are calculated. Then, reliability indices such as SAIFI, SAIDI, and others can be calculated. Hence, these reliability indices are aggregated to generate the probability distributions for each component. These probability distributions provide an essential tool to expect the reliability of any component at any time. Besides, the process of the MCS method in power distribution systems as given in Figure 7 (Shobole et al., 2017) (Guo et al., 2016), and can be described as follows:

1. Start with the first sample year,
2. Randomly an artificial hourly history of faults is generated for each component to calculate TTF and TTR based on their formulas as depicted in Eqn. (3). In this paper, two states for each component energized and de-energized are considered,
3. Start at time one (first hour), determine the fault locations,
4. Identify interrupted customers (i.e., LPs) and their TTR values,
5. Return to step 2 until each hour in a year has been examined,
6. Carry out a counter to obtain the total interrupted customer-numbers and total interrupted customer-hours,
7. Calculate SAIFI and SAIDI for this sample year,
8. Return to step 1 until predetermined stopping condition (i.e., number of iterations 10000 times) is fulfilled,
9. Aggregate calculated reliability indices to generate probability distributions,
10. Repeat steps 2-9 for the following sample year until a predetermined number of sample years (i.e., 100 years) is fulfilled.

In this analysis, the following operating conditions are considered;

- All feeder sections and lateral distributors' failures are included.
- All protection devices and sectionalizers are assumed to be 100% reliable.
- Not all the feeder sections have sectionalizer, while all laterals have fuses at the lateral point.
- All customers are residential.
- All 34.5 kV feeders’ sections and 0.4 kV lateral distributors are overhead lines.
- The average time for repair is 2 hours.
- The average failure rate for 34.5 kV lines is 0.05 failure/year, while 0.4 kV lines is 0.125 failure/year.

Table 10 draws the obtained results of MCS reliability assessment and comparison with average system reliability indices based on historical reliability assessment. Figure 8 graphically explains the difference in system reliability indices between both methods.

Table 10: Comparison between historical and MCS assessments

Indices	Historical Assessment	MCS Assessment
SAIFI	0.165	0.1163
SAIDI	0.168	0.4382
CAIDI	1.017	3.767
ASAI	0.99992316	0.99956999
AENS	0.42	0.25

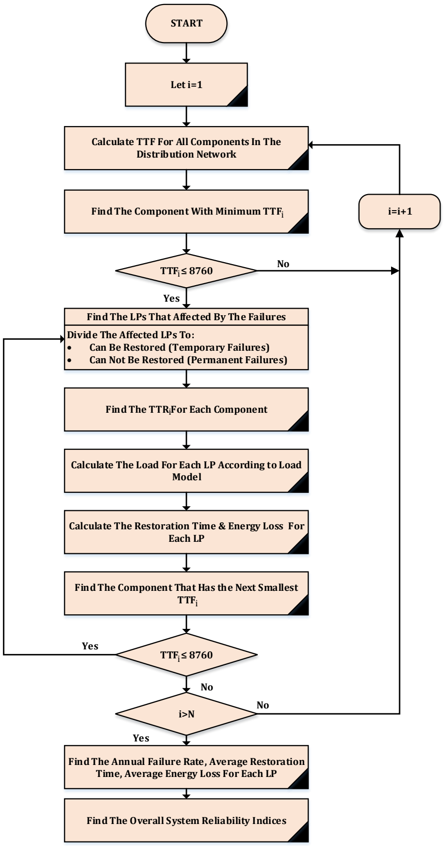

Figure 7. MCS flowchart for reliability assessment in distribution power systems

Table 10 shows that there is, to some extent, a difference between the results of historical reliability analysis and MCS analysis. This difference is because of the historical reliability assessment based only on three years of data. The simulation in this study depends on the average values of failure and repair rates to construct the artificial history for distribution transformers and lines. Three years, i.e., 2012 – 2014, are used to create the TTF and TTR probability distribution function. The minimum advised period for suitable reliability assessment is five years of reliability data, while ten years is the best for accurate reliability assessment and expectation (Shobole et al., 2017a) (Chojnacki, 2012) (Guo et al., 2016). Moreover, it is necessary to notice that the maximum difference was in CAIDI, which can be explained due to the sensitivity of this index to SAIFI and SAIDI. In other words, any change in SAIFI, SAIDI, or both causes dramatically change in CAIDI (Arya et al., 2012) (Moazzami et al., 2013).

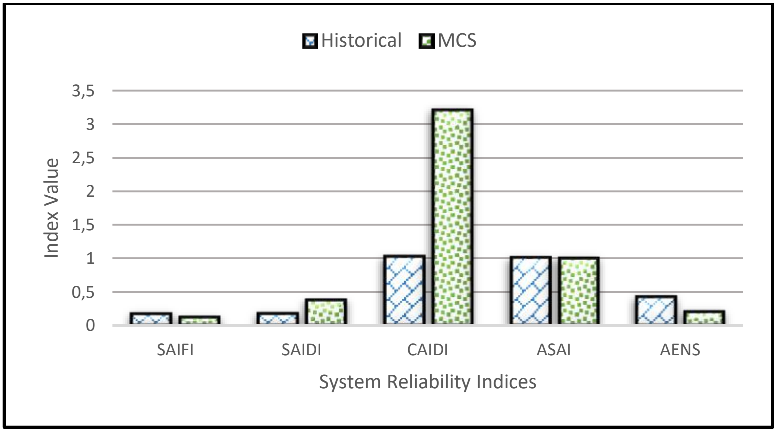

Figure 8. Comparison between historical and MCS reliability assessment

7. CONCLUSION

Collecting reliability data in databases is crucial for energy utilities to conduct reliability assessment whenever the need arises. Historical reliability assessment also can be taken as a reference for other reliability assessment methods. Besides, it is a crucial tool in the planning, design, and maintenance processes of power systems. In this Chapter, the historical reliability assessment for the 4-Feeder power distribution system is assessed and analyzed. MCS reliability analysis is performed based on the average reliability values extracted from the historical reliability assessment. The comparison results verify that MCS is a powerful tool to assess the reliability of power systems. This study found that the feeder F3-83F5 experiences the most significant frequency and duration of interruption with 0.4679 and 0.2366 for the SAIFI index.

Similarly, 0.4952 and 0.1458 the SAIDI index for the years 2012-2013 and 2013-2014, respectively. On the contrary, the feeder F4-83F8 experiences the least frequency and duration of interruption with 0.0305 and 0.0611 for the SAIFI index and 0.0285 and 0.0326 for the SAIDI index for the years 2012-2013 and 2013-2014, respectively. Ultimately, the reliability assessment is a powerful tool to define the power system's weakness and then decide the relevant remedial actions needed to achieve the required service reliability levels. Generally, power utilities and electric companies can consider the following recommendations to improve their systems' reliability;

- Continuous and accurate registration of different failures and interruptions by preparing certain forms, including all data required for reliability assessment.

- Training the crew of maintenance to fill out the forms of reliability on time, the date of fault, the cause of failure, and the exact period for repair and restoration.

- Preparing a smart mobile application instead of filling out forms; to increase registration speed and the accuracy of the collected data.

- Organizing the collected data into databases to simplify future reliability studies.

- Increase the number of sectionalizers at feeder sections to reduce the number of customers being interrupted.

- Replacing manual sectionalizers with automated ones to reduce the time of restoration.

- Installing insulators and anti-bird cones on the top of poles impede birds from access to distribution transformers and connections.

- To ward off the rodents, it is essential to use tightly sealed cabinets, poison materials, or ultrasonic devices.

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APPENDIX

$$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customers\ Served} = \frac{\sum_i \lambda_i\ N_i}{\sum_i N_i}$$

$$SAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ Number\ of\ Customers\ Served} = \frac{\sum_i U_i\ N_i}{\sum_i N_i}$$

$$CAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ Number\ of\ Customer\ Interruptions} = \frac{\sum_i U_i\ N_i}{\sum_i \lambda_i\ N_i}$$

$$ASAI = \frac{Customer\ Hours\ of\ Available\ Service}{Customer\ Hours\ Demanded} = \frac{\sum_i\ N_i \times 8760 - \sum_i U_i\ N_i}{\sum_i\ N_i \times 8760}$$

$$ENS = \text{Total Energy not Supplied by the System} = \sum_i L_i\, U_i$$

$$AENS = \frac{\text{Total Energy not Supplied}}{Total\ Number\ of\ Customers\ Served} = \frac{\sum_i L_i\, U_i}{\sum_i N_i}$$

where:
N_i: is the number of customers of load point i
8760: is the number of hours in a calendar year
L_i: is the average load connected to load point i

NOMENCLATURE

AENS:	Average Energy Not Supplied (kWh/customer/year)
ASAI:	Average System Availability Index
BEDAS:	Bosporus Electric Distribution LTD Company
CAIDI:	Customer Average Interruption Duration Index (hour/failure)
CEA:	Canadian Electrical Association
CT:	Central Transformer
DTr:	Distribution Transformer
ENS:	Energy Not Supplied (MWh /year)
LP:	Load Point
MC:	Monte Carlo
MCS	Monte Carlo Simulation
RBTS	Roy Billinton Test System
S:	Switch
SAIFI:	System Average Interruption Frequency Index (interruption/customer)
SAIDI:	System Average Interruption Duration Index (hour/interruption)
S. N.	Section Number
TTF:	Time to Failure
TTR:	Time to Repair
TUBITAK:	The Scientific and Technological Research Council of Turkey
TUDOSIS:	TUBITAK Distribution Automation System
U:	Average Annual Outage (hour/year)
λ:	Average Failure Rate (failure/year) for lines and cables (failure/year.km)
μ	Average Repair Rate (hour/year)

CHAPTER XI

NETWORK DISTANCE COEFFICIENT EFFECT ON DETERMINING TRANSPORTATION FACILITY LOCATION

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1. INTRODUCTION

Design in engineering can be identified as a decision-making procedure to make solutions satisfying some specific needs. Most of the engineering design problems contain multipart objective functions along with several decision variables. Feasible solutions must be found for every kind of designs characterized by potential decision variables of design parameters. At this point, optimization becomes a great option to discover the most appropriate solution among the solutions of the problem under specific conditions. For such purposes, an optimization technique tries to find the most suitable solution among all available feasible solutions. Traditional search methods have been used for a long time for getting solutions of engineering design problems. However, in real design problems, there can be a lot of decision variables effecting on objective function which those can make the problem very complicated. Therefore, there is a strong requirement to apply operative optimization approaches (Parkinson et al. 2013; Aydogdu 2017). One kind of such effective optimization methods is implementing a metaheuristic algorithm. Metaheuristic algorithms are prescribed as advanced and global search operators (Yang 2010). Many methods possess results through trial and error which can be titled as a standard search engine. A standard search engine finds numerous possibilities for the final solution. However, metaheuristic algorithm can greatly reduce the number of possibilities of a standard search engine. This provides convenience and reliability to many researchers. A couple of examples of well-known metaheuristic algorithms are particle swarm optimization (PSO) based on social behavior of bird flocking and fish schooling, firefly algorithm (FA), harmony search algorithm (HSA) based on music improvisation process.

Engineering designs and decision-making procedures are commonly encountered in transportation, especially in the aviation sector. It continues to develop rapidly in Turkey as in the whole world. The demand for aviation, which is of great importance in freight and passenger transportation, is increasing day by day. According to the General Directorate of Civil Aviation, the fact that more passengers are carried than in the past shows that almost everyone in Turkey has started to become accessible to aviation (SHGM 2020). As a result of the increasing demand, the opportunities in the aviation sector increases. In addition, the number of aircrafts using the airports in Turkey or landing and taking off at the airports in the country increases day by day. Civil aviation in Turkey has made great strides in aviation infrastructure in recent years. As new airports were put into service, the number of domestic and international flights increased rapidly. Although the rules in aviation are very strict, there may be crashes or accidents of various sizes due to running into some setbacks (Uslu and Dönmez 2017). Although these crashes or accidents occurring in the chain of faults are tried to be minimized, loss of life and property during the accident is at a high level. In such cases, emergency intervention aims at minimizing financial losses, and most importantly, minimizing injuries and fatality rates. One of the ways to minimize losses in airline accidents is rapid interventions during or after the accident. When health, rescue or engineering service is provided quickly, the time lost will be minimized and thus losses and expenses will be reduced. When it comes to emergency response, airline transportation and the properties of the airports in our country have an important place.

Location analysis can be performed to minimize losses. As an example, Demir and Kockal (2019) determined the location of a facility that is planned to serve the entire transportation network in order to minimize financial losses. In another study (Demir 2018a), analyses were made to select the airport with the most suitable location that can be used within the borders of the country. The traffic rates of the airports were taken into account using the Weizsfeld algorithm (WA) in line with the Weber problem (WP). Then, Istanbul Sabiha Gokcen Airport was proposed as the airport that can provide service to all airports in Turkey. However, in this research, the following novelties are introduced. 1) Crow search algorithm (CSA) has never been used for evaluating an optimum facility location for the airports in a country. Therefore, the evaluation of finding an optimum facility location for the airports in Turkey will be held by using CSA. 2) Although other algorithms such as WA have been used for evaluating a facility location for the airports (Demir 2018b) and for a cement plant (Demir and Kockal 2019); network distance matrix and network distance coefficient were not included. Euclidean distance matrix between the nodes were used as inputs rather than highway network distance matrix depicting the costs between the nodes of a particular network. In this study, however, highway network distance matrix indicates the transportation costs between the nodes of the airports network in the country. It is thought that the use of up-to-date optimization opportunities together with up-to-date data will contribute to the national development by making the supply or transportation needs faster in emergency situations.

This text is planned as follows. In the second part, the method to be used is explained. Data collection and the attributes are introduced in the third section. Also a design example is submitted in the same section to demonstrate the analysis. Next, the findings that are encountered in line with the analyses and discussion are presented. In the last part, a general evaluation is made within the framework of the results.

2. METHODOLOGY

The problem of this study comes from finding the most convenient aid facility location considering the travel matrix between the airports in the country. Therefore, the objective with the parameters are described as follows (2.1, 2.2).

$$\text{Min}\sum_{i=1}^{n} k * a_i * \sqrt{\left|X_i - X_f\right|^2 + \left|Y_i - Y_f\right|^2} \qquad (2.1)$$

$$k = {d_{i,j}} \Big/ {\sqrt{\left|X_i - X_j\right|^2 + \left|Y_i - Y_j\right|^2}} \qquad (2.2)$$

where;

i, j : node i and node j respectively

k : coefficient for distance cost

a_i : weight coefficient of node i

X_i : x coordinate for node i

Y_i : y coordinate for node j

X_f : x coordinate of the final node

Y_f : y coordinate of the final node

$d_{i,j}$: network distance between node i and node j

When i and j are equal to one another, k can be accepted as 1 which is a non-factor in formula (2.1). In this study, the CSA created by observing the behavior of crows is used for optimization of a facility location. Crows are members of smart bird species. Observations suggest that crow flocks' behaviors have several similarities with optimization parameters. According to a behavior type of crows, they follow the other birds and steal their food, thus they find food sources. Moreover, crows hide their food to protect them and try to fool other bird species. In this case, one can say that crows are researchers, the environment is search area, positions of crow show a possible solution, and quality of food source can be convenience function. Using this behavioral similarity, CSA tries to simulate the crow's smart behavior to find solutions for optimization problems. Considering all such behaviors, a population-based metaheuristic algorithm is created. In this way, basic CSA principles can be described as follows: crows live in flocks, they memorize locational positions of places used for hiding objects, they follow birds to steal their belongings, and they shelter their cache from theft (Askarzadeh 2016).

A d-dimensional environment with an input of a number of crows is assumed in CSA. The number of crows which is flock size is N and the position of crow i during iteration in search space is specified by a vector $x^{i,iter}(i = 1,2,\dots,N;\ iter = 1,2,\dots,iter_{max})$ where $x^{i,iter} = \left[x_1^{i,iter}, x_2^{i,iter}, \dots, x_d^{i,iter}\right]$. Here $iter_{max}$ is the maximum number of iterations. Crows have memory to find the location of its hiding place. The location of hiding place of the crow i is shown by $m^{i,iter}$. In fact, each crow memorizes that the location of its best experience. Crows move around in the neighborhood to find a better food source (i.e. hiding places of food). One can assume that crow j wants to go to its hiding place $m^{j,iter}$ during the iteration. In iteration, crow i decides to follow crow j to find the hiding place of crow j. In this situation, the following two cases may be seen.

Case-1: As crow i follows crow j, crow j does not notice this move. Therefore, crow i can merge to the hiding location of crow j. For case-1, crow i gains a new position which is obtained as using the following equation (2.3).

$$x^{i,iter+1} = x^{i,iter} + r_i * fl^{i,iter} * \left(m^{j,iter} - x^{i,iter}\right) \qquad (2.3)$$

where r_i is a randomly chosen number using a uniform distribution between 0 and 1. $fl^{i,iter}$ shows the flight length of crow i at iteration $iter$.

Case-2: Crow j knows that it is followed by crow i. Therefore, crow j wants to cheat crow i by heading to another location of the search field to prevent the cache. Case-1 and Case-2 can be combined as in (2.4).

$$x^{i,iter+1} = \begin{cases} x^{i,iter} + r_i * fl^{i,iter} * \left(m^{i,iter} - x^{i,iter}\right) & r_j \geq AP^{j,iter} \\ a\ random\ position & otherwise \end{cases} \qquad (2.4)$$

where r_j is a number chosen randomly with a uniform distribution between 0 and 1. $AP^{j,iter}$represents awareness probability of crow j at iteration $iter$. Generally, metaheuristic algorithms contain two main components which are intensification and diversification. Intensification is basically concentrating on searching in a local area by being aware of there is a good solution available in that particular region. Diversification is to creating a wide variety of solutions to explore a global scale search area. When discovering the best solutions in metaheuristic algorithms, the right balance must be constructed between intensification and diversification. In the case of CSA, the algorithm is mainly controlled by and awareness probability (AP) when considering the balance between intensification and diversification. Low values for AP increases intensification. In addition to this, an increased AP value decreases the probability of searching good solutions in the neighborhood. Also the search is continued on a global scale. In other words, letting large AP values in CSA increases diversity of solutions. Given an AP value, general steps of CSA are as follows.

Firstly, in step-1, problem and parameters are initialized. Optimization problem, decision variables and constraints are defined. Adjustable parameters of CSA such as flock size (N), flight length (fl) awareness probability (AP), and maximum number of iterations ($itermax$), are submitted.

Secondly, step-2 initializes location of crow and memory of a crow. A number of crows such as N crows which are the members of the flock, are randomly placed in a d-dimensional search area. Each crow indicates a possible solution of the problem and d is inserted as the number of decision variables. When a memory is assigned to a crow, that crow has no experience at the first. That means it does not remember an experience from its previous moves. Moreover, it is assumed that crows hide their food at their starting positions.

Thirdly, step-3 evaluates fitness function. By adding the decision variable values into the objective function, quality value of the locations of crows are computed. Later step-4 generates new position. As a crow would like to discover a new location, it randomly selects on of the flocks such as crow j. The crow follows crow j to reveal a new food location (m^j) hidden by the crow j. This process repeats for all crows. Accordingly, checking the applicability of new positions takes place in step-5. That means after new positions are produced for each crow, the validity of them is inspected. If the position is feasible, the crow position is updated. Otherwise, the position of crow cannot be updated and thus it remains in the same position as it stands before the move.

After deciding on the applicability of new positions, fitness function for new positions is evaluated as step-6. In this step, the fitness function values are computed for new positions of each crow. Then the memory should be updated as changes happened in step-7. Using the equation (2.5) where f () indicates the objective function value, the crows update their memories. When the fitness function value of the crow's new position is more appropriate than the fitness function value of the memorized position, the memory of the crow is updated in accordance with the new location.

$$m^{i,iter+1} = \begin{cases} x^{i,iter+1} & f(x^{i,iter+1}) \text{ is better than } f(m^{i,iter}) \\ m^{i,iter} & \text{otherwise} \end{cases} \tag{2.5}$$

Last but not least, the ending process criterion should be checked as step-8. In this manner, step-4 and step-7 are repeated until $iter_{max}$ is attained. When the ending criterion or the finish criterion is met, the most convenient position in objective function value is reported. Thus, this is the solution of the optimization problem.

3. THE CASE STUDY

In this section, the data will be processed under two main headings. The first is the preparation of geographic data and the second is the preparation of transport data. Then, by using such processed data, the procedures and methods in this study are applied.

3.1. LOCATION DATA

Location information is very important in the analysis of location optimization problems. In this study, location data is carefully collected. The costs such as distances between the airports are one of the main variables to be used in the optimization method in this study. In that respect, geographical coordinate information of fifty-five airports actively used in civil aviation in Turkey has been of interest. The State Airports Authority (DHMİ) website shares many information about the airports of the country. The website offers location information in degrees, minutes, seconds for latitudes and longitudes which is a common global geographic positioning system (DHMİ 2020). However, because the optimization method used in this research will operate on a plane-based system, it has become necessary to establish a plane coordinate system. For this reason, projection changes were made in order to transfer the coordinates of all airports to a horizontal plane. Mercator projection which can be used worldwide in plane-based maps was preferred to be used in optimization processes. It is not completely possible to geometrically position the latitude and longitude coordinates in the Mercator projection, since there is a special shape of our planet called geoid. Although the Earth is flattened from the top and bulged from the sides and this makes challenging positioning problems, the Mercator projection is one of the best projections for conversions. Therefore, Snyder (2012), Demir (2018b), Demir and Kockal (2019) used such practices in their studies.

3.2. TRANSPORTATION DATA

Transportation network data is one of the most important elements of this study. Moreover, traffic data related to the network data is very crucial for the analysis. Traffic data were obtained thanks to the DHMİ website, which regularly stores data on the number of aircraft using the airports on a monthly basis and presents them for research (DHMİ 2020). The most up-to-date traffic data can be collected through the website. The following time period of the traffic data is examined: From the full service time of Istanbul Airport (i.e. from May 2019) to the measures taken by the Ministry of Interior against the Coronavirus disease (COVID-19) pandemic. In short, the ten-month time period from May 2019 to February 2020 is under the scope of evaluation. It is assumed that the services provided at the fifty-five airports within the scope of the assessment were performed under normal conditions in this ten-month period. The traffic data during this period were included in the analysis. Traffic data of a particular airport will demonstrate the weight coefficient of the airport which is a kind of importance factor. The total traffic data of ten months for a particular airport are recorded to form the specific weight coefficient of that airport. Thus, the weight coefficients to be used in the problem were provided. For example, Table-1 shows the aircraft traffic data of six airports as a sample in the six-month period between September 2019 and February 2020. In the analysis, ten-month period of data from May 2019 to February 2020 were investigated. Such data is very crutial to possess the information of a_i (i.e. weight coefficient of node i) in network.

Table-1. Monthly aircraft traffic data of six airports as a sample (DHMİ 2020)

Airport	**Data Period**						**Ten months total**
	09/19	**10/19**	**11/19**	**12/19**	**01/20**	**02/20**	
Erzurum	5,455	6,023	6,623	7,047	444	850	42,509
Gaziantep	14,574	16,263	17,993	19,573	1,714	3,341	115,265
Adiyaman	1,372	1,534	1,708	1,850	139	275	10,674
Agri	1,774	1,972	2,152	2,320	174	346	13,746
Amasya	969	1,074	1,171	1,273	98	196	7,740
Balikesir	16,921	18,925	20,661	22,165	1,762	3,481	127,931

Network distance matrix data is also constituted by the data depicting the relationship between the nodes in network. That type of data represents the costs between the nodes in terms of distance values. Distance values between the nodes provides a detailed information about the positions of the airports in the network. Such information has been recorded by measuring the highway distances between each airport in the country. As a sample, Table-2 demonstrates a part of the whole distance matrix, which consists the distances in kilometers between five randomly chosen airports. Such information is very essential in order to decide on the coefficient k (i.e. the coefficient for distance cost).

Table-2. Distances between five airports in kilometers.

Airport	**Antalya**	**Adana**	**Trabzon**	**Diyarbakir**	**Zonguldak**
Antalya	–	599	1223	1115	703
Adana	599	–	843	524	742
Trabzon	1223	843	–	574	817
Diyarbakir	1115	524	574	–	1142
Zonguldak	703	742	817	1142	–

4. RESULTS AND DISCUSSION

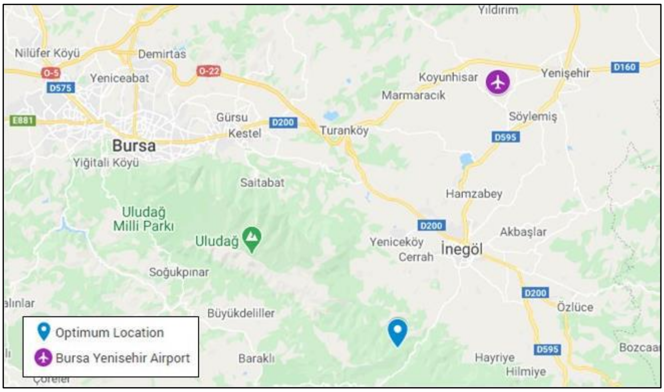
Data collection, transfers and data processing were performed on a computer with an Intel® Core ™ i5-2410M CPU @ 2.30GHz, 6GB of installed memory, and a 64-bit operating system. The optimization process based on the transportation data and the weight coefficients of the transportation network nodes was calculated with CSA method. The coding in which the algorithm is reflected was run. Thus the values under the “optimum location” heading in Table-3 were obtained. These values indicate the latitude and longitude indicators of the optimum location respectively. They are found in degrees but that can be turned into other measurement types. The values point at the vicinity of Inegol in Bursa region where the terrain is relatively suitable for a possible construction. If another option is thought, the nearest airport facility can be offered as the ideal airport (Table-3). With the assistance of the assessment made in congruity with the optimum location appeared in Table-3, it is found that there is no air terminal office at the optimum location. In any case, a thick street network as of now exists, which depicts that the landscape is generally appropriate for a potential development. In this way, a facility can be situated at the optimum location. Another alternative could be allocating the optimum location to the closest air terminal office which is now being used. In accordance with this, it is assessed that the nearest air terminal, Bursa Yenisehir Airport, can offer support to all air terminals if there should arise an occurrence of crises regarding access distance or actual distance to optimum location coordinates.

Table-3. Optimum location and the nearest ideal airport

	Optimum Location	**Ideal Airport**
Latitude (λ°)	39.97647	40.25583
Longitude (Φ°)	29.41965	29.56194
Place	Vicinity of Inegol, Bursa	Bursa Yenisehir Airport

Underpinned the available traffic data of the airports and geographical location data, in line with all these analyses, the ideal airport place is recommended for positioning the necessary equipment and personnel. In addition, the geographical location of the ideal location which is recommended to provide service in emergency situations and the ideal airport are shown visually on the map in Figure-1.

Figure-1. The optimum location and the ideal airport according to CSA. (Note: This figure has been mapped with the help of Google Maps.)



5. CONCLUSION

It is crucial to reduce the loss of life and reduce the costs in emergency by urgently intervening. Recently, Istanbul Airport as a new large airport started to serve the region. Therefore, the traffic data have been collected for a while by observing the new situation. Up-to-date data should be evaluated by considering up-to-date optimization method. In addition to the new airline traffic data, the highway network distances between the airports in use in the country play a key role in the analysis. The network distance matrix is introduced for the optimization process. Moreover, the weight coefficients of the airports based on traffic data greatly contributed to detect the outputs. If the center of gravity of the network nodes had been found only, the specific importance of airports with heavy air traffic would have been ignored. Since the network distance matrix and the weight coefficients of the airports were taken into consideration, the analysis provided the most convenient and ideal results to be applied to reality. Considering the optimum location coordinates found in this study and presented in Table-3, there are currently no airport facilities that these coordinates point at. Therefore, the closest airport in terms of access distance or physical distance to these coordinates was determined by finding the shortest network distance between two points. With the help of the evaluation made in conformity with the optimum location value shown in Table-3, it is discovered that there is no airport facility at the optimum location. However, a dense road network already exists, which describes that the terrain is relatively suitable for a possible construction. Therefore, a facility can be located at the optimum location. Another option could be assigning the optimum location to the nearest airport facility which is already in use. In line with this, it is evaluated that the closest airport to the optimum location computed, Bursa Yenisehir Airport, can provide service to all airports in case of emergencies. Thus, it is evaluated that the airport closest to the optimum location can serve the airports within the country in case of emergency.

In this study, as a result of the analysis made considering the traffic data and location data collected, Bursa Yenisehir Airport was proposed for the positioning of the equipment and personnel that may be needed for emergency response. It is considered that assigning this airport, where aid facilities can be established, aims at minimizing the loss of life during or after disasters such as any natural disaster or accident. As a result of this study and in line with the recommendations of the research, it is expected that progress will be made in minimizing the loss of life and reducing time and expense loss. Thus, a significant contribution is expected to result in regional and countrywide development.

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