Effect of Deploying Routing and Facility Location Methods on Power Transmission to Increase the Reliability of the Power Network and Minimize the Total Logistics Cost

Dr. Abdullah M. Alharbi
Assistant Professor
College of Engineering, Department of Industrial and Systems Engineering,
University of Jeddah
Jeddah, Saudi Arabia
amealharbi@uj.edu.sa

Abstract

Power generation, maintenance scheduling, and transmission have been a serious concern in the last few decades because of the high increase in power demand. Large electricity producing company is providing electricity to the most populated areas through both connected and non-connected power plants (PPs). This research discusses the most common issue of overhead power transmission lines in the western region. The main purpose of the study is to reduce the high-level power transmission cost by lessening the logistics expenses and by increasing the reliability of the power network. This problem is addressed by developing an algebraic framework for connecting different cities to a single loop having a minimum length between maintenance centers and setting up an appropriate number of teams. Furthermore, research also considers certain constraints for a more consistent and cost-effective transmission mechanism. For this purpose, western region cities are selected and the MLIP mechanism is used by feeding the MATLOG data for the current study. Research has contributed by proposing a certain number of maintenance centers and an appropriate number of teams by deploying an algorithmic solution for the data analysis and results. The study found some constraints that need to be further investigated in future studies for more reliable results.

Keywords
LRP, MLIP, MATLOG, SCP, and TSP.

1. Introduction
Power generation, maintenance scheduling, and consistent transmission is a very technical processes in nature. These three processes must be addressed professionally to provide the reliable and stable possible power services. This study particularly focuses on power transmission using overhead cable lines connected through towers. This process always needs a certain type of maintenance on regular basis as per the recommended schedule. The entire process cost is high and one of the main factors is logistics cost. Technical maintenance teams visit each tower one by one for inspecting the tower components and joints connected with overhead cables and submit a report to the immediate reporting office. This paper particularly addresses the issues of overhead transmission lines mechanism to make the power supply process consistent and most importantly cost-effective. One of the leading power generation companies in the Kingdom of Saudi Arabia provides power services. For this research western region, cities are selected as a pilot project. Electricity Company is providing regular electricity to the most populated areas in the western region through both connected and non-connected power plants (PPs).

The researcher has thoroughly investigated the entire power transmission process and visited some areas of the western region for collecting data from the concerned officials/technicians and other supporting staff. The researcher found that logistics cost is very high and it could be reduced by adopting certain important measures. For this purpose, following arrangements have been suggested to determine the minimum possible logistic cost referenced with each maintenance task.

2. Research Aim and Objectives
In view of the research domain, being in nature of operations management, cut down in logistic cost is the main aim of this study. Secondly, reducing the logistics cost is main objective of the study to ensure that reduction of logistic

cost must not affect the profit margin at all to make the transmission process stable and reliable. Logistic cost components and properties are considered as under:

1. Number of launching centers as per the network need,
2. Number of maintenance teams in each center, and
3. The coverage area for each team, and
4. Total length of lines to be covered by the maintenance team.

Several tasks are required to be completed:

1. To design a high voltage network by setting up a connection through overhead lines to the cities in a single loop.
2. To find the minimum length in the loop.
3. To set up the minimum number of maintenance centers.
4. To find the minimum number of maintenance teams.

Following are some of the important constraints considered as a benchmark for the study:

1. Distance between towers must be 0.25 miles (0.40 KM) from each other.
2. Each network point must be visited twice a year.
3. Maintenance center locations have to be limited within the cities or located along with the overhead transmission lines.
4. The maintenance team consists of at least four technicians to cover a maximum of eight towers per working day/time.
5. The maintenance team can travel only during a two-hour time window per day, and go back within the same window, with an approximate speed of 70 miles (112.6 KM) per hour.
6. Each team can cover a maximum of 10 towers per day aggregated as per every 2.5 miles (4.0 KM).
7. Maintenance teams have to submit an updated visit report to the maintenance center every day.

3. Research Problem

The main purpose of the study is to reduce the high-level power transmission cost mainly by lessening the logistics expenses and by increasing the reliability of the power network. Furthermore, research also considers certain constraints for a more consistent and cost-effective transmission mechanism by reducing the logistic expenses. This is considered in terms of increasing reliability at some PPs to enhance power production by feeding to the less capacity PPs. The study also addresses the power generating cost by reducing the team visit to each PP as high power generating PPs cost is high and it affects the other PP module's expected regular service output in the long run (Cai *et al.*, 2020). This problem is addressed by developing an algebraic framework for connecting different cities in the western region to a single loop having a minimum length between maintenance centers and setting up an appropriate number of teams for reliable and stable power supplies (Prukpanit et al. 2021).

In this regard, power transmission using overhead cable lines and towers needs a certain type of regular maintenance. Maintenance teams have to visit each tower, one by one, and perform this periodic maintenance for the other tower components and the joints connecting the overhead cables. Their transportation goes through roads already constructed along with the network itself. After that, each team goes back to its reporting center to do reporting procedures. The overall western region with tower and overhead cables is depicted in the figure given below in Figure 1:

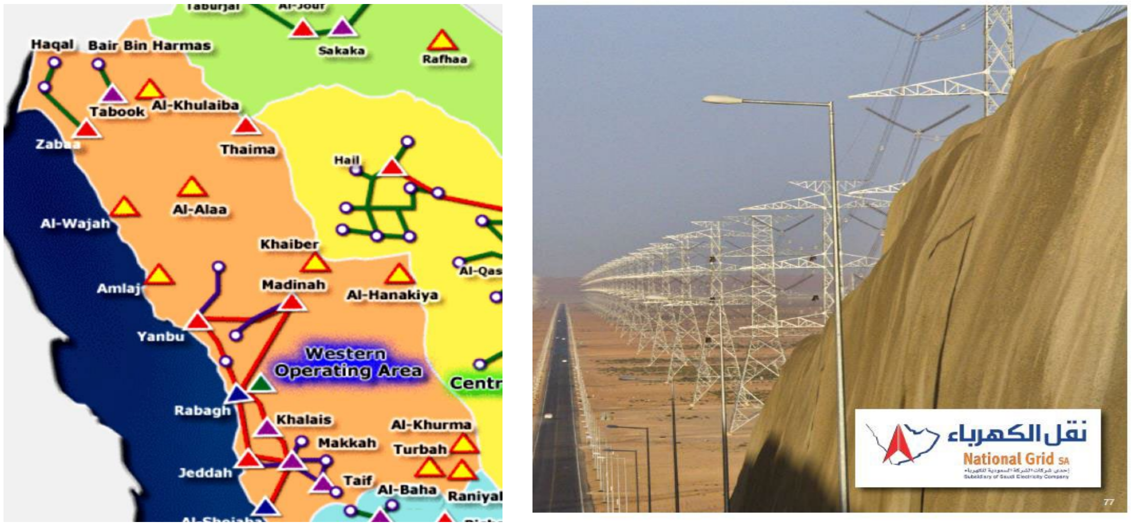

Figure 1. Western Region Cities Connectivity with Overhead Transmission Lines

4. Literature Review

Researchers have given due course of attention to power generation, transmission and maintenance process as mentioned in the problem statement. In this domain of locational analysis, Location-Routing Problems (LRP) is a mathematical optimization of problems considering the vehicle routing along with the facility location for better and stable power supply and maintenance issues. This method consists of number; size and location of facilities and allocation of demand points to facilities in the combination of the design of routes combines into LRPs. Routing decisions are not performed implicitly rather both decisions are performed inter-dependently (Ouhader and El kyal, 2017). Saudi Arabian authorities have also keen interest in building a logistics competitive advantage by introducing the regulations as per the international standards as suggested by World Bank's Doing Business 2020 report ('Saudi Arabia Logistics Industry Report 2021', 2021). Saudi Arabia ranked among top ten most improved global business climates in year 2019. This has been achieved by making series of reforms and digital transformation initiatives across the country, especially in logistics for improving the ease of transport of goods within the kingdom and outside the kingdom (Alanazi et al. 2022). Increasing logistic cost is one of the key problem in the recent years and worldwide people are working on it to somehow deploy an appropriate routing and facility location methods to reduce the overall cost. Power transmission is also one of the area that is affected by the increasing cost in logistics domain, producer adds burden to overall production cost, and hence it affects the end user (Veenstra *et al.*, 2018).

This problem has also been addressed in recent past and there are different solutions proposed by the researchers for reducing the overall cost. Power transmission and maintenance is one of the most important phase of GMS, if the logistics cost goes high, it affects the profit margin in both regulated and unregulated environments (Jelti *et al.*, 2021). There are certain ways recommended to reduce the overall cost as recommended by the professionals. Transmission and maintenance sector is one of the area, which could be further studied, explored, and can be considered to cut to logistic cost without affecting the profit margin of producer (Jelti *et al.*, 2021). This could be achieved by improving the coordination procedure with the suppliers to enhance the supply chain process in terms of managing fuel consumption at lower cost (Alanazi, Al-Ghahtani and Alsugair, 2022). Best approach is to setup a maintenance mechanism in a win-win cost savings program without compromising the quality of transmission (Veenstra *et al.*, 2018). Literature showed that cutting down logistics cost can be obtained by deploying an appropriate methodology for evaluating the distances between cities and the number of teams for maintenance to server the purpose (Singh *et al.*, 2021) ('Saudi Arabia Logistics Industry Report 2021', 2021). Researcher found that, literature has showed a narrow gap of managing and handling the logistic support services in power transmission. Hence, logistics support needs to be addressed in terms of putting a cut down on the unnecessary and avoidable expenses without increasing the profit margin of the producer (Mo, 2020). This paper addresses the research gap found in the literature to further extend the issue and lessen the gap by proposing a more practical approach in the western region of Saudi Arabia. Study will deploy two algorithms i.e. Travelling Salesman Problem (TSP) (Sorma *et al.*, 2020) and Set Cover Problem (SCP) (Rosenbauer *et al.*, 2020) to observe the current situation of power transmission mechanism, number of maintenance teams and number of members in each team. Furthermore, study will look into the areas where overall expenses can be cut down without increasing the profit margin.

5. Research Methodology

Power transmission is a critical and technical process in nature and needs in-depth clear and justified understanding for the research study. This paper is planned to address the core issue of lessening the logistics expenses with reliable power transmission in the western region of the Kingdom of Saudi Arabia. For this purpose, western region cities are selected for clear observation, supported by the well-organized and justified data based on the distance between cities to be used for study analysis and reliable results. The research concept in nature is operations management in the power industry; hence, Machine Learning Interatomic Potentials (MLIP) mechanism is deployed as recommended by the professionals (Gubaev, 2018). It is used in large-scale atomistic computer simulations of materials relying on the interatomic potentials providing computationally efficient predictions of energy and other forces (Mortazavi *et al.*, 2020). Traditionally MLIP potentials have served in this capacity for over three decades and proved to be one of the best ways of dealing the critical problems. Furthermore, MLIP data is used in the Material Logcat (MATLOG) platform for further data analysis and to produce accurate and precise results, which could help the industry with sustainable planning for their short-term and long-term projects. MATLOG is also strongly recommended by professionals to be deployed in these kinds of research domains (Huang, 2016).

6. Data Collection

The researcher collected the data from the most authentic official resources available at (https://www.latlong.net) for city coordinates of the western region to further use in the research process. The data given below is representing both distribution centers and PPs, which are located among some of these cities for the current study. It has been confirmed by the researcher that the given data is accurate and confirmed for each city regarding both Longitude and Latitude as illustrated in the table given below in Table 1:

Table 1. Cities Detail with Longitude and Latitude

ID	City	Longitude	Latitude
1	Tabuk	36.503152	28.455813
2	Tayma	38.533366	27.615669
3	Ula	37.915728	26.630595
4	Khaybar	39.286272	25.703737
5	Medina	39.610992	24.481326
6	Henakiyah	40.490971	24.870412
7	Mahd	40.871813	23.501338
8	Khurma	42.031246	21.946127
9	Ranyah	42.860714	21.246399
10	Turbah	41.643978	21.187509
11	Lith	40.261974	20.185644
12	Taif	40.412372	21.268435
13	Hada	40.283303	21.371253
14	Huwaya	40.489812	21.43678
15	Sail	40.422525	21.625303
16	Mecca	39.80729	21.424094
17	Jumum	39.693475	21.62744
18	Bahrah	39.451089	21.407696
19	Jeddah	39.184213	21.486997
20	Asfan	39.380708	21.872659
21	Khulais	39.306893	22.135268
22	Thuwal	39.100213	22.286564
23	Rabigh	39.032805	22.797696

24	Mastorah	38.850389	23.11543
25	Badr	38.77161	23.784261
26	Musayjid	39.101071	24.08221
27	Saddarah	39.206815	24.13799
28	Furaysh	39.278226	24.225685
29	Asuwayq	38.449401	24.375612
30	Alfera	38.062924	24.982963
31	Ais	38.111675	25.057006
32	Umluj	37.247983	25.058924
33	Wajh	36.462461	26.227594
34	Duba	35.688238	27.35735
35	Almuwaylih	35.480284	27.691927
36	Bad'a	35.010345	28.468584
37	Haql	34.936874	29.290485

7. Research Analysis and Results

Power transmission using overhead cable lines and towers needs a well-organized mechanism of periodic maintenance for stable, reliable, and cost-effective power transmission to the cities of western. In this regard, it is important to estimate the total number of launching centers in the given network with a minimum number of maintenance teams in each control center. Furthermore, the estimation of the coverage area for each team and the total length of lines to be managed by the maintenance team is also important to be assessed. This process must be supported by a well-studied network design, setting up a proper connection by using the overhead lines in a single loop. Additionally, it is important to find the minimum loop length, the minimum number of maintenance centers, and the number of maintenance teams. Maintenance teams are performing the tasks on day-to-day basis activity. The study needs to look for a well-organized plan used for the maintenance teams to visit each tower and the network connection joints hooked up with the overhead cables and follow up with each launching team center for daily/monthly reporting procedures. For this purpose, the following solution steps are proposed to overcome the existing logistics support system concerns to further reduce the logistics cost by improving the transmission mechanism for the study analysis and results:

7.1 **Feeding data in MATLOG:** The first step is to feed the MATLOG data, which is collected and available in excel format as detailed in the above table 0.0. Data is loaded showing Longitude at X-axis and Latitude at Y-axis by using the following code:

```
%% Collecting Primary Data

clear all

S = xls2struct('Cities_Data.xlsx','Data'); City_Name
=[S.City]';

XY  =[S.Longitude_X; S.Latitude_Y]';

C = dists(XY,XY,'mi')
```

a. **Building the Shortest Possible Network:** The second step is to read data and manipulate it for building the shortest path network by using traditional Travelling Salesman Problem (TSP) algorithm construction (Cai *et al.*, 2020). TSP was formulated in the 19th century by William Rowan Hamilton and Thomas Kirkman and found a strong evidence-based method to solve distance-related problems using graph algorithms (Al-Furhud and Ahmed, 2020). The main purpose of this algorithm was to observe the non-optimality of the nearest neighbor heuristic (Sorma *et al.*, 2020). Based on the strong literature evidence TSP was adopted for the current study and it was deployed to store the available clusters to classify data or build case-based classification on similarity measures (Sorma *et al.*, 2020). Industry professionals for data classification based on neighbors' classification mostly consider this phenomenon. Below is the code given for deploying the TSP algorithm:

```
Percentage Building the Shortest Network

% TSP Construction: Nearest neighbor algorithm
help tspnneighbor
```

```
makemap(XY)
h = pplot(XY,'r.');
pplot(XY,num2cell(1:size(XY,1))) [loc,TC] = tspnneighbor(C,1,h);
TC[loc,TC,bestvtx] = spnneighbor(C,[],h);
TC[loc,TC] = tsp2opt(loc,C,[],[],[],h); TC
```

The above-mentioned code is deployed to build the shortest possible network based on the given data and plot the diagram given hereunder in a clearly defined geographical representation. This process will make the further analysis process easier to develop and design an algorithmic data representation for the current study. All 37 cities have been processed through the given data and they are plotted in the diagram given below in Figure 2, identifying and representing the location of each city on the X-axis and Y-axis location showing the sequence improvement data, where TC=1991.25966

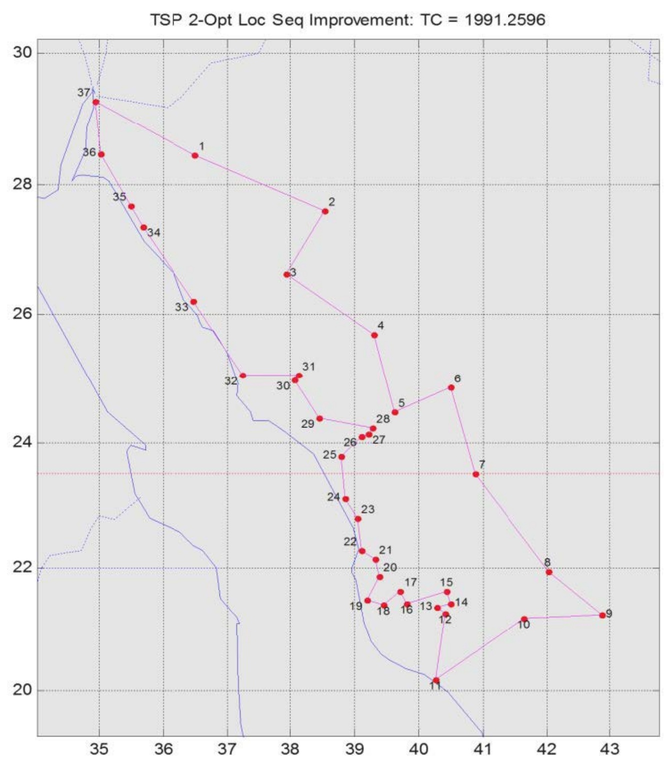

Figure 2. LOC Sequence Improvement

8. Network Segmentation

Furthermore, the overall network needs to be segmented based on the candidate points to address the core study problem. In order to solve this problem, the distances between the cities have been divided into multiple segments by assessing and evaluating the distance between cities, where each segment represents the team capable of handling 10 towers per day. Therefore, the total number of segments is about 796 segments and for developing a qualitative and flexible solution, cities and PPs are interpreted as nodes and indices. Below is given the code performing this step:

```
% Constructing Inter Location Distance Matrix
Last = C(37,1); C(:,1)=[]; C(37,:)=[]; d = diag(C)
Inter_Dis = [d;Last]

% Number of Inter Location Group of Towers
N = round(Inter_Dis/2.5);
% Changed Location Index
```

```
    New_Nodes = [1;cumsum(N(1:36))]

    % Finding the distance matrix
    D = zeros(796,796);
    for i = 1:(size(New_Nodes,1))
       for j = 1:398
       if (New_Nodes(i)+j)<=796
          D(New_Nodes(i),New_Nodes(i)+j) = D(New_Nodes(i),New_Nodes(i)+j-1)+2.5;
          else
             D(New_Nodes(i),New_Nodes(i)+j-796) =
             D(New_Nodes(i),New_Nodes(i))+(j)*2.5;
          end
       end
end
    for i = 1:(size(New_Nodes,1))
       for j = 1:398
       if (New_Nodes(i)-j)>=1
          D(New_Nodes(i),New_Nodes(i)-j)=D(New_Nodes(i),New_Nodes(i)-j+1)+2.5;
         else
         D(New_Nodes(i),New_Nodes(i)-j+796)=(New_Nodes(i),New_Nodes(i))+(j)*2.5;
         end
      end
end
    % Extracting New_Nodes rows from D
    Grand_Dis = [D([New_Nodes],:)];
```

Based on the above code, the output shown in Table 2 is showing the detail after adding the new nodes:

Table 2. Updated table after adding new nodes

idx	City	idx	City
1	Tabuk	481	Asfan
55	Tayma	488	Khulais
86	Ula	495	Thuwal
129	Khaybar	509	Rabigh
164	Medina	519	Mastorah
189	Henakiyah	538	Badr
228	Mahd	550	Musayjid
280	Khurma	553	Saddarah
309	Ranyah	556	Furaysh
340	Turbah	577	Asuwayq
385	Lith	596	Alfera
415	Taif	598	Ais
419	Hada	620	Umluj
425	Huwaya	658	Wajh
430	Sail	695	Duba
447	Mecca	706	Almuwaylih
453	Jumum	730	Bad'a
462	Bahrah	753	Haql
469	Jeddah		

9. Finding the minimum number of control centers

Finding the minimum number of control centers needed to build an algorithmic solution to be more precise and accurate. For this purpose, the researcher observed some of the known algorithms and found Set Cover Problem algorithm could be one of the better choices in dealing with this kind of problem as recommended by the experts (Akhter, 2015). The Set Cover Problem is a classical way of dealing in multiple environments like combinatorics, computer science, operations management, and complexity theory as one of Karp's 21 NP-complete problems shown to be NP-complete in the year 1972 (Sheng *et al.*, 2020). The researcher deployed this algorithm at MATLOG to find out the minimum number of control centers (Alanazi, Al-Gahtani and Alsugair, 2022). The MILP mechanism is used after formulating the problem, and the six cities shown in the "idx" below represent the nodes on the pre-defined network segment described earlier in step 3.

```
%% Set Cover Problem
A = false(size(Grand_Dis));
A(Grand_Dis<140) = true;
mp = Milp('Set Cover') mp.addobj('min',ones(1,size(A,2)))
mp.addcstr(A,'>=',1) mp.addctype('B')
mp.dispmodel;
%% Using Cplex
cp = Cplex;
cp.Model = mp.Model;
cp.solve
x = cp.Solution.x;
%makemap(XY)
%pplot(XY,'r.')

idx =
38
173
330
464
575
707
```

10. Defining the nodes, and locating their coordinates

In this step, the index of every Maintenance Center has been translated into the coordinates of the X-axis and Y-axis, and then plotted on the map. The map below shown in figure 3, displays the six proposed centers in black dots and circles among the network, as shown in Figure 3:

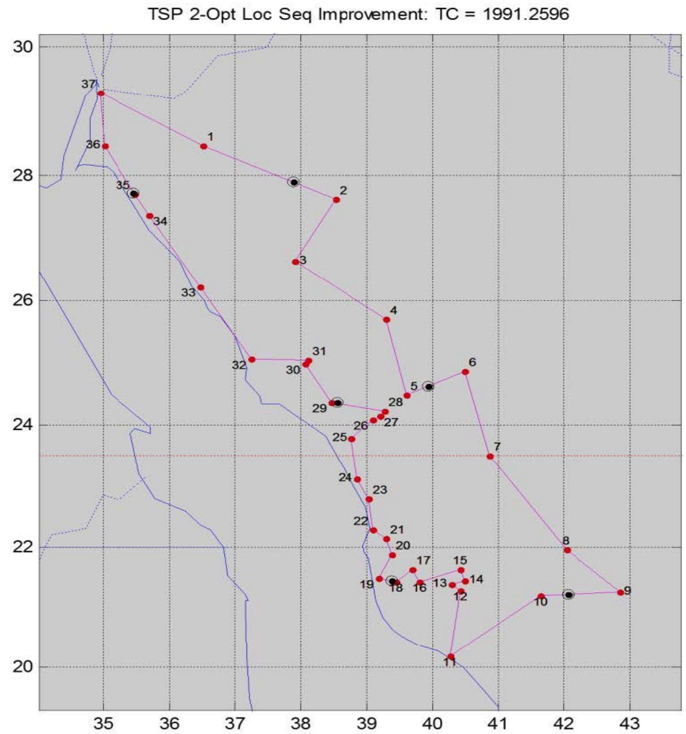

Figure 3. LOC Sequencing Improvement

Below is the code for solving this core problem.

```
%% Locating and Plotting the Maintenance Centers final Locations
Centers = idx
Cities = New_Nodes
for i=1: size (Centers,1)
   for j=1: size (Cities,1)
   if Centers(i)> Cities(j) & Centers(i)< Cities(j+1)
      Center_Dist = (idx(i)-Cities(j))*2.5;
      Perc_dist= Center_Dist/ Inter_Dis(j);
      Centers_XY(i,:)=[(XY(j+1,1)-XY((j),1)),(XY(j+1,2)-
      XY((j),2))]*Perc_dist + XY(j,:);
   end
end
end
disp('The Final Locations for the centers are:')
Centers_XY
pplot(Centers_XY,'k.')
pplot(Centers_XY,'ko')
```

The final locations for the centers are given hereunder:

```
Centers_XY =
  37.8771   27.8873
  39.9333   24.6238
  42.0467   21.2070
  39.3770   21.4297
  38.5382   24.3596
  35.4610   27.7239
```

11. Conclusion

The main purpose of the study was to reduce the logistics cost by improving the power transmission in the western region of Saudi Arabia. The study has collected important data on city coordinates and deployed the most suitable and appropriate methods like MLIP and MATLOG as a tool for digging out important results. Study results have proved that reducing the logistics cost without affecting sustainable power transmission is cost-effective support to the power producer. Study results have recommended a minimum of six control centers, which can efficiently perform the maintenance as per the network demand in a given time. Secondly, a minimum number of teams as per the proposed solution methodology are going to be the same for every center. In other words, the problem is solved to divide the workload by the given number of centers equally. This process will help the management to perform an algebraic algorithm according to any specific labor constraints at any later stage to determine the number of teams and number of people in each team etc. The Total logistic cost here is proportional to the distances covered by each team in each control center. This process can be economic and cost-effective if it is deployed as per the research recommendations.

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Biography

1. **ABDULLAH M. ALHARBI**, Ph.D., is an Assistant Professor in the Industrial and System Engineering Department at Faculty of Engineering, University of Jeddah. Currently, he is the University-VP's Assistant for Projects and Facilities Sector. Dr. Abdullah earned his Ph.D. in Industrial Engineering from North Carolina State University, USA. His research interests include scheduling, production planning, logistics, power generation management, project engineering, engineering management, renewable energy and system dynamics. Dr. Abdullah can be contacted on amealharbi@uj.edu.sa

2. **NOTE**

This research makes a strong base for deploying routing and facility location methods on power transmission to increase the performance based reliability of the power network for minimizing the logistic cost. Hence, routing and facility location methods helped the power transmission system to increase the reliability of the power network to minimize the total logistics cost, research focuses on transmission system reliability. Machine Learning Interatomic Potentials (MLIP) mechanism is used by feeding the data to Material Logcat (MATLOG) for the current study.