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Optimization of Emergency Management System in a Construction Organization in India

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A B S T R A C T

It is not possible to eliminate the workplace emergencies but can be mitigated by effective planning. In all the construction organizations the possibility of facing emergencies is common. The objective of emergency management is to minimize losses that result out of emergencies. The employees in construction organizations are susceptible various workplace emergencies like fire, explosion, collapse of a structure/excavated side walls, scaffolding and tower cranes etc.. Site-specific emergency plan is to be prepared to prevent emergencies in construction organizations. The emergency preparedness plan must comprise of identifying probable emergencies and how to respond to emergency situation so as to minimize the total response time of employees to report to emergency assembly point. In most of the construction organizations in India are following conventional methods instead of implementing scientific techniques in emergency planning particularly while earmarking emergency assembling points and also allocation employees to assembly points resulting into wastage of time, damage to employees and property. A study was conducted in a construction organization involved in construction of 2*660MW thermal power plant in India by using combination of optimization techniques like shortest route algorithm for identifying optimal paths and depending on the capacities of assembly points ,the employees are allocated to different assembly points by using transportation model .In a case of a major emergency , the minimal spanning tree technique is used to identify the shortest route for a specific assembly point.

1. Introduction

In general, an emergency is a situation which harms (or threatens to harm) people, property or the environment. Therefore, each facility developing an emergency plan will need to define those circumstances that constitute an emergency for its specific operation and activities. This definition should also identify the types of incident or circumstance that do not constitute an emergency and the point at which an emergency ceases to be an emergency. It should be sufficiently comprehensive to cover the full range of activities at the facility (including non-routine activities such as maintenance or construction) that could result in an emergency situation; and should be relevant, realistic and sufficiently clear to be understood by all users and reviewers of the plan. Emergency planning seeks to minimize the effect of an

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accident inside and outside a facility and requires the timely application of defined procedures by personnel with adequate training and resources. Preparedness requires identifying what to prepare for and how to respond. It therefore involves accumulating knowledge and skills, disseminating information about the management of potential emergencies, and providing and allocating facility resources and personnel to deal with the emergencies identified.

Emergency management is commonly divided into four phases: mitigation, preparedness, response and recovery [1]. When an emergency situation occurs various societal resources become involved in the response. These resources can be found in an emergency response system [2].Several researchers suggest that an important part of emergency response management is to coordinate available resources [3-5]. Network and network theories could be used as central conceptions when theorizing emergency response and are also discussed [2,6,7,8], in reviewing literature concerned with emergent phenomena in a context such as the present one, conclude there to be ample evidence for emergent phenomena playing an important role during emergency response operations.

Emergency response management is a multi-dimensional subject area that continuously provides practitioners and researchers with challenges and scope for improvement. Successful emergency exercises can enhance perceptions of teamwork, training adequacy, response network effectiveness, job risk, and equipment adequacy [9].Organizing for emergency scenarios on construction sites aims to minimize the nature and extent of harm for the atmosphere that might ensue from an emergency scenario. The purpose of emergency preparedness is ensuring that emergency procedures actually work inside the event of an emergency. This requires testing emergency procedures for effectiveness, reviewing procedures after an emergency, training personnel in emergency response [10].

A risk assessment approach to planning for the unexpected--before it actually happens. Emergency planning is essential for all organizations. This applies whether you are a major manufacturer using large quantities of potentially hazardous materials or an organization that only employs office workers [11].Emergency management delves into the patterns of human disaster behavior, social psychology, and communication as well as the basics of generic protective actions, planning concepts, implementation, and action [12].

An employer shall ensure at a construction site of a building or other construction work that in case more than five hundred workers are employed ,emergency action plan is to be prepared to handle emergencies arise in construction sites[13].

2. Emergency response plan

The aim of an emergency plan should be expressed as a broad statement of planning intent. It should be based on the fundamental reasons for developing a plan. The objective is to provide a system and resources to deal with emergencies to protect people, property and the environment and to minimize adverse impacts on people, property and the environment. Emergencies in construction sites as per the Building and other construction workers - Regulation of employment and conditions of service, Act 1996 and rules, 1998 are fire and explosion, collapse of lifting appliances and transport equipment, collapse of building or structures, gas leakage or chemicals ,drowning of building workers.

2.1.Key elements

Emergencies can happen at any time in any types of industry, The approach of the plan is to eliminate or reduce the risk of injury or harm that may occur during an evacuation by undertaking following steps:-

(a) Classification and identifying potentially hazardous situations;
(b) Assessment of the risks;
(c) Statutory requirements;
(d) Pre-emergency planning;
(e) Emergency mitigation measures;
(f) Emergency preparedness measures;
(g) Emergency response procedures and measures;
(h) Emergency organization and responsibilities;
(i) Infrastructure requirements;
(j) Procedures for declaration of on-site and off-site emergency;
(k) Resources for controlling emergency;
(l) Demographic information;
(m) Medical facilities;
(n) Evacuation;
(o) Public relations and information to public;
(p) Reporting of the incident;
(q) Emergency recovery procedures;

In all the construction organizations emergency response team is to be constituted and their roles and responsibilities in case of an emergency is to be defined clearly as shown in Figure 1.

1.1.Phases of emergency management

Emergency management involves a cyclic process of four phases, prevention, preparedness, response and recovery [1] as shown in Figure 2. Prevention is physical measures to prevent emergencies and mitigate their impact. Preparedness is arrangements to mobilize and deploy all necessary resources and services. Response is actions taken during and immediately after an emergency to minimize the impact and finally recovery deals with arrangements to restore the facility to normal as quickly as possible. Emergency planning plays a key role in the cycle of emergency management focusing primarily on the phases of preparedness and response.

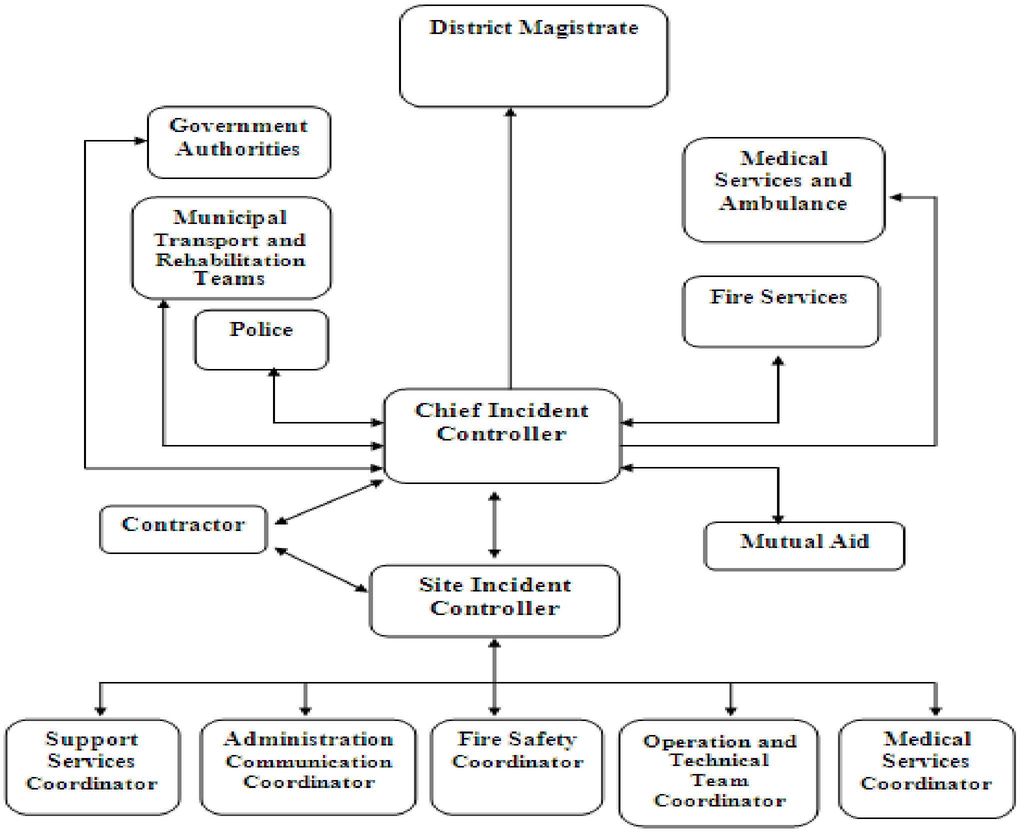

Figure 1.Emergency response Team

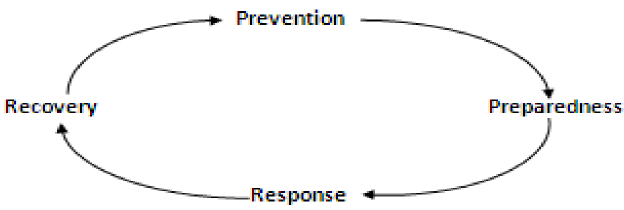

Figure 2. Emergency management cycle

2. Data collection

The study was conducted in a construction organization involved in construction of a coal fired thermal power project with two super critical units of 660 MW each located in western India .The data pertaining to site layout, strategic locations of work execution and the number of workers engaged at each location was collected from the safety department of the site. Much difficulty was faced to convince the management regarding the purpose of collection of data and explained about the importance of the study. The details of work locations, distances between locations; number of workers working at each location was shown in the form of a network in Figure 3.Totally there are nineteen work locations with three emergency assembly points. The assembly points are circumscribed with rectangle over circles at location 2, 13 and 16.The work locations are indicated by circles. The work locations include turbine generator I and II, electro static precipitators I and II, boilers I and II, cooling towers I and II, chimney, clarifiers, stores, fabrication yard, steel yard, batching plant, wagon tippler, pump house, switch yard, and office and canteen.

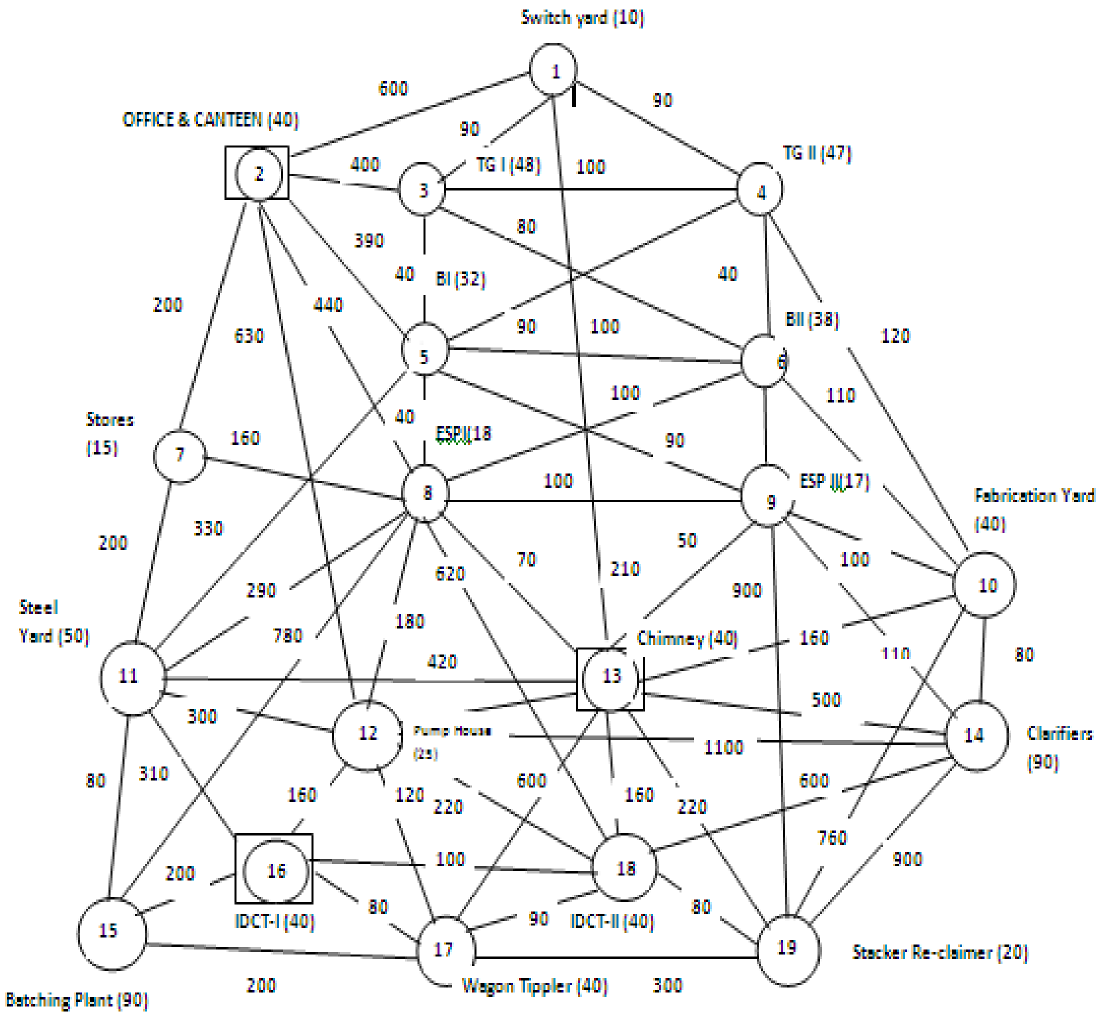

Figure 3. Work locations and distances

3. Methodology

The optimization techniques like shortest route algorithm, transportation model and minimal spanning tree are employed.

3.1.Shortest route algorithm

A typical problem in network analysis is finding the shortest path from one node to another through a network.

3.1.1. Dijkstra's Algorithm

Dijkstra's Algorithm is one of the most important and useful algorithms available for generating (exact) optimal solutions to a large class of shortest path problems. This algorithm is one attempt to find the shortest path from one node to all other nodes in the network. It assumes that the link lengths are always non-negative.
Let u_i be the shortest distance from node 1 to node I, and define $d_{ij}(\geq 0)$ as the length of arc (I,j),Then the algorithm defines the label for an immediately succeeding node j as $[u_j,i] = [u_i + d_{ij},i]$, $d_{ij} \geq 0$
The label for the starting node is [0,-], indicating that the node has no predecessor. The labels are of two types temporary and permanent. A temporary label is modified if a shorter route to a node can be found; the status of the temporary label is changed to permanent.
Step 0: Label the source node (node 1) with permanent label [0,-].Set i=1
Step I: (a) Compute the temporary labels $[u_i + d_{ij},i]$ for each node j that can be reached from node I, provided j is not permanently labeled. If node j is already labeled with $[u_j ,k]$ through another node k and if $u_i + d_{ij} < u_j$,replace $[u_j ,k]$ with $[u_i + d_{ij},i]$.

(b) If all the nodes have permanent labels,stop. Otherwise, select the label $[u_r ,s]$ having the shortest distance($=u_r$)among all the temporary labels. Set i= r and repeat step i.

3.2.Transportation model

The transportation model deals with a special class of linear programming problem in which the objective is to transport a homogeneous commodity from various origins to different destinations at a total minimum cost.

3.2.1. Mathematical formulation

Supposed a company has m warehouses and n retail outlets. A single product is to be shipped from the warehouses to the outlets. Each warehouse has a given level of supply, and each outlet has a given level of demand [14]. We are also given the transportation cost between every pair of warehouse and outlet, and these costs are assumed to be linear. More explicitly, the assumptions are:
The total supply of the products from warehouse $i = a_i$ where i= 1, 2, 3……m
The total Demand of the products at the outlet $j = b_j$, where j = 1, 2, 3…..n
The cost of sending one unit of the product from warehouse i to outlet j is equal to C_{ij}, where i= 1,2,3...*m* and j= 1,2,3,...*n* . The total cost of a shipment is linear in size of shipment.

3.2.2. The Objective function

The objective function contains costs associated with each of the variables. It is a minimization problem. Consider the shipment from warehouse i to outlet j. For any i and j, the transportation cost per unit C_{ij} and the size of the shipment is X_{ij}. Since we assume that the total cost function is linear, the total cost of this shipment is given by c_{ij} x_{ij} [15].The objective function is as shown in Equation (1).

$$Minimize \sum_{i=1}^{m} \sum_{j=1}^{n} X_{ij} C_{ij} \tag{1}$$

3.2.2.1.The Constraints

The constraints are the conditions that force supply and demand needs to be satisfied. In a Transportation Problem, there is one constraint for each node. Let a_1 denote a source capacity and b_1 denote destination needs

i)The supply at each source must be used as shown in Equation (2).

$$Minimize \sum_{i=1}^{m} X_{ij} = a_i \,, \quad i = 1,2,...,m \tag{2}$$

ii) The demand at each destination must be met as shown in Equation (3).

$$Minimize \sum_{i=1}^{n} X_{ij} = b_j \,, \quad j = 1,2,...,n \tag{3}$$

(iii) Nonnegativity: $X_{ij} \geq 0$ for i and j.

The transportation model will then become, minimizing the transportation cost as shown in Equations (4-6).

$$Minimize \sum_{i=1}^{m} \sum_{j=1}^{n} X_{ij} C_{ij} \tag{4}$$

$$\sum_{i=1}^{m} X_{ij} \leq a_i \,, \quad i = 1,2,...,m \tag{5}$$

$$\sum_{j=1}^{n} X_{ij} \geq b_j \,, \quad j = 1,2,...,n \tag{6}$$

$$X_{ij} \geq 0 \quad for \quad i \quad and \quad j$$

3.3.Minimal spanning tree

The minimal spanning tree algorithm deals with linking the nodes of a network, directly or indirectly, using the shortest total length of connecting branches [16]. The steps of procedure are given as follows: Let N= {1, 2…n} set of nodes of the network and define

C_k= set of nodes that have been permanently connected at iteration *k*.

$\overline{C}_k$= set of nodes as yet to be connected permanently after iteration *k*.

Step 0: Set $C_0 = ø$ and $\overline{C}_0 = N$

Step 1: Start with any node *i* in the unconnected set $\overline{C}_0$ and set $C_1 = \{i\}$, which renders $\overline{C}_1 = N - \{i\}$. Set $k = 2$.

General step k: Select a node, *j**, in unconnected set $\overline{C}_{k-1}$ that yield in shortest arcs to a node in the connected set C_{k-1}. Link *j** permanently to C_{k-1} and remove it from $\overline{C}_{k-1}$; that is,

$$C_k = C_{k-1} + \{j^*\},\ \overline{C}_k = \overline{C}_{k-1} - \{j^*\}$$

If the set of unconnected nodes, $\overline{C}_k$, is empty stop. Otherwise, set $k = k + 1$ and repeat the step.

4. Results

In the construction organization under study, the 19 work locations are identified as sources and 3 assembly points are the destination points. The details about connected nodes and its distances were shown in Table 1. In order to select optimum route from each source to destination, shortest route algorithm of network is adopted. Input parameters are source nodes that are work locations and destinations are assembly points. The distances between various sources and destinations and labeling of different sources is shown in Table 1.The shortest distances between work locations and assembly points are calculated by using Dijkstra's algorithm with help of TORA software is shown in Table 2.

The transportation model was applied with an objective to determine the number of employees from each work location to each assembly point that minimize the total response time while satisfying the both supply limits and demand requirements. Once the shortest between from each work location to assembly point is identified, the allocation of work locations to each assembly point was done by using transportation model. In order to minimize the response time, the time taken from each work location to assembly point was estimated based on the distance among work locations assuming that the time to reach a particular assembly point is directly proportional to distance. The initial basic feasible solution and minimum time is calculated by using TORA software. The transportation problem is unbalanced and a dummy assembly point is to be identified to meet the rim requirements with a capacity of assembly point as 140.

Table1. Distances between nodes and destinations

LABEL NO.	CONNECTED NODE AND DISTANCE								
1	2(490)	3(90)	4(90)	13(210)					
2	1(490)	3(400)	5(390)	8(360)	7(200)	12(610)			
3	1(90)	2(400)	4(100)	5(40)	6(80)				
4	1(90)	3(100)	5(90)	6(40)	10(120)				
5	2(390)	3(40)	4(90)	6(100)	8(40)	9(90)	11(330)		
6	3(80)	4(40)	8(100)	9(40)	10(110)	5(100)			
7	2(200)	8(160)	11(200)						
8	2(360)	5(40)	6(100)	7(160)	9(100)	11(290)	12(170)	13(70)	15(370)	18(230)
9	5(90)	6(40)	8(100)	10(100)	13(50)	14(110)	19(270)		
10	4(120)	6(110)	9(100)	13(150)	19(370)	14(80)			
11	7(200)	5(330)	8(290)	12(300)	16(280)	15(80)	13(360)		
12	2(610)	8(170)	11(300)	13(100)	18(210)	17(120)	16(160)	14(260)	
13	1(210)	8(70)	9(50)	10(150)	12(100)	14(160)	18(160)	19(220)	11(360)	17(220)
14	9(110)	10(80)	12(260)	13(160)	18(320)	19(380)			
15	8(370)	11(80)	16(200)	17(200)					
16	11(280)	12(160)	15(200)	17(80)	18(100)				
17	12(120)	13(220)	15(200)	16(80)	18(90)	19(170)			
18	8(230)	12(210)	13(160)	14(320)	16(100)	17(90)	19(80)		
19	9(270)	10(370)	14(380)	17(170)	18(80)	13(220)			

Table 2. Shortest distances from work locations to assembly points and capacities

NODE	EMERGENCY ASSEMBLY POINTS					No. OF WORKERS
	E1	E2	E3	E4(11)	E4(8)	
1	490	210	470	460	170	10
2	0	430	680	400	360	40
3	400	150	410	370	80	48
4	480	130	390	420	130	47
5	390	110	370	330	40	32
6	480	90	350	390	100	38
7	200	230	480	200	160	15
8	360	70	330	290	0	18
9	460	50	310	390	100	17
10	560	150	420	490	200	40
11	400	360	280	0	290	50
12	610	100	160	300	170	25
13	430	0	260	360	70	40
14	570	160	420	520	210	90
15	480	460	200	80	370	90
16	680	260	0	280	330	40
17	680	220	80	280	290	40
18	770	160	100	370	230	40
19	850	220	180	450	290	20

The allocation of employees to various assembly points in case of emergency is shown in Table 3.The location of dummy assembly point is also analyzed by considering node 11 and 8.The transportation model was repeated for both these locations and found that the time is minimum when assembly point is at 11 instead of 8.

Table 3. Allocation of employees to assembly points

NODE	EMERGENCY ASSEMBLY POINTS					No. OF WORKERS
	E1	E2	E3	E4(11)		
1				460(10)		10
2	0(40)					40
3	400(48)					48
4		130(47)				47
5	390(32)					32
6		90(38)				38
7	200(15)					15
8	360(15)	70(3)				18
9		50(17)				17
10		150(40)				40
11	400(50)					50
12		100(25)				25
13		0(40)				40
14		160(70)		520(20)		90
15				80(90)		90
16			0(40)			40
17			80(40)			40
18		160(20)	100(20)			40
19				450(20)		20

In case of major emergency in the site, all the employees are to be moved to one assembly point instead of allocated assembly points as per transportation model. The Figure 4, 5, and 6 shows the shortest path from work locations in the site in order to move the employees to specific assembly points located at 2, 13, and 16 respectively. The length of minimal spanning tree for all the three assembly points located at 2, 13, and 16 is 1660mts.

1. Conclusions

Basing on the study the following conclusions are drawn. Optimum paths developed in a network model are useful in reducing the response time and also effective way of reporting at assembly points. Transportation models are useful for developing strategies for effective way of reporting at respective assembly points and also for developing a strategy to establish new assembly points. In the present study the transportation model is unbalanced, it is necessary to increase the capacities of assembly points to balance the rim requirements or a new emergency assembly point has to be established either at node 11 or 8.The two alternatives of establishing emergency assembly point at node 11 or 8 was analyzed by using transportation model and the result is to establish at node 11, in which case the total response time is minimum instead of at node 8.

Minimal spanning tree results are vital to move all the employees to a specific assembly point in case of major emergency where there is possibility of effecting the all the employees in the site. The existing assembly points are to be restructured to increase the capacities to accommodate total number of employees working in the site. In the organization under study, sufficient space is available to increase the capacities of assembly points. The models are practicable to implement in all the construction sites where space is not a constraint. The employees are to be trained regarding the application of these models, allocation of employees to a particular assembly point and also importance of spanning tree model is reporting to a specific assembly point.

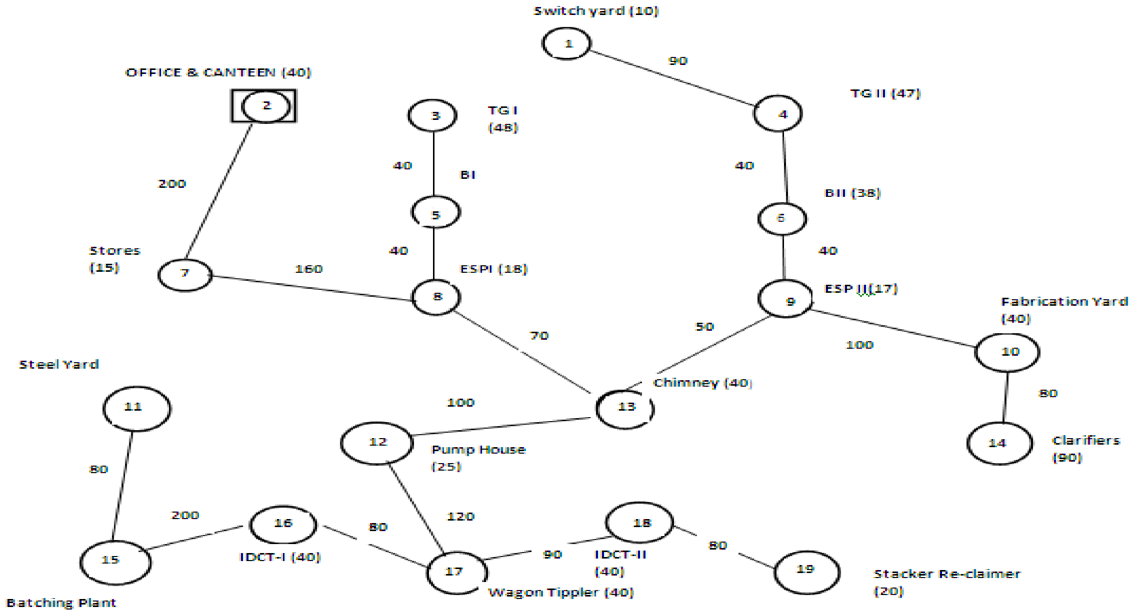

Figure 4. Minimal spanning tree for assembly point 2

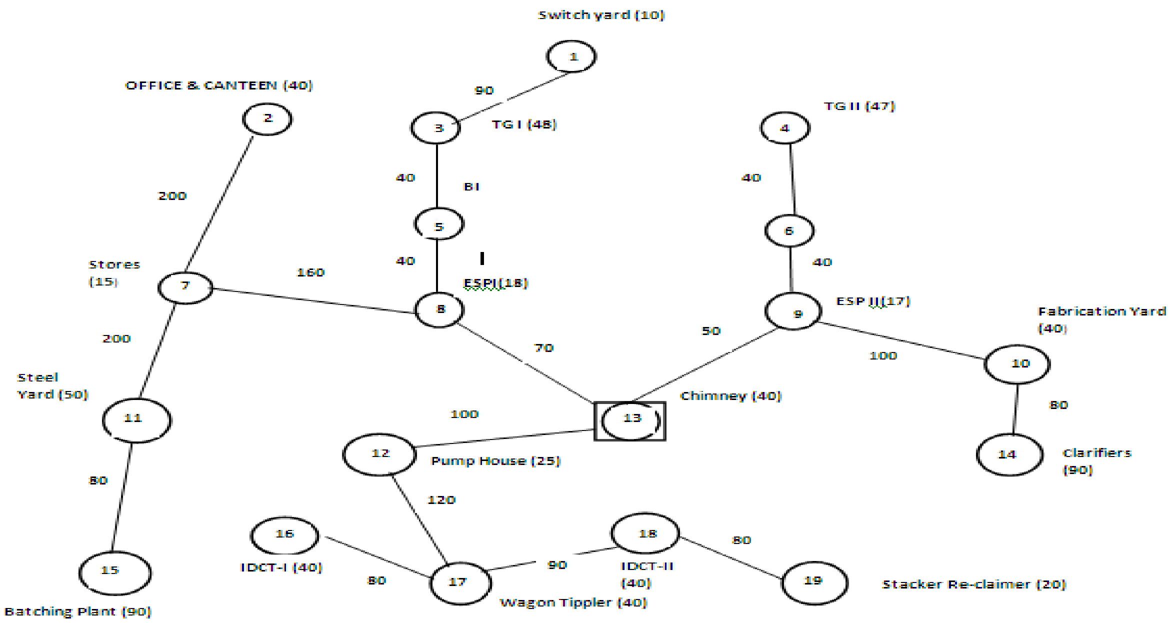

Figure 5. Minimal spanning tree for assembly point 13

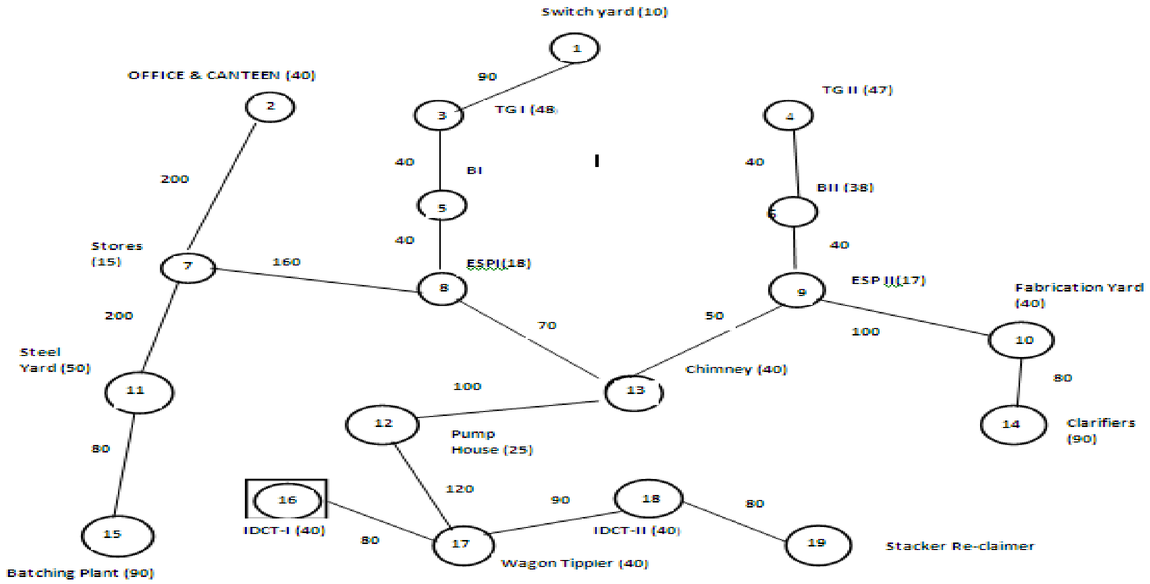

Figure 6.Minimal spanning tree for assembly point 16

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