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Charging Station Location: Modelling and Solution

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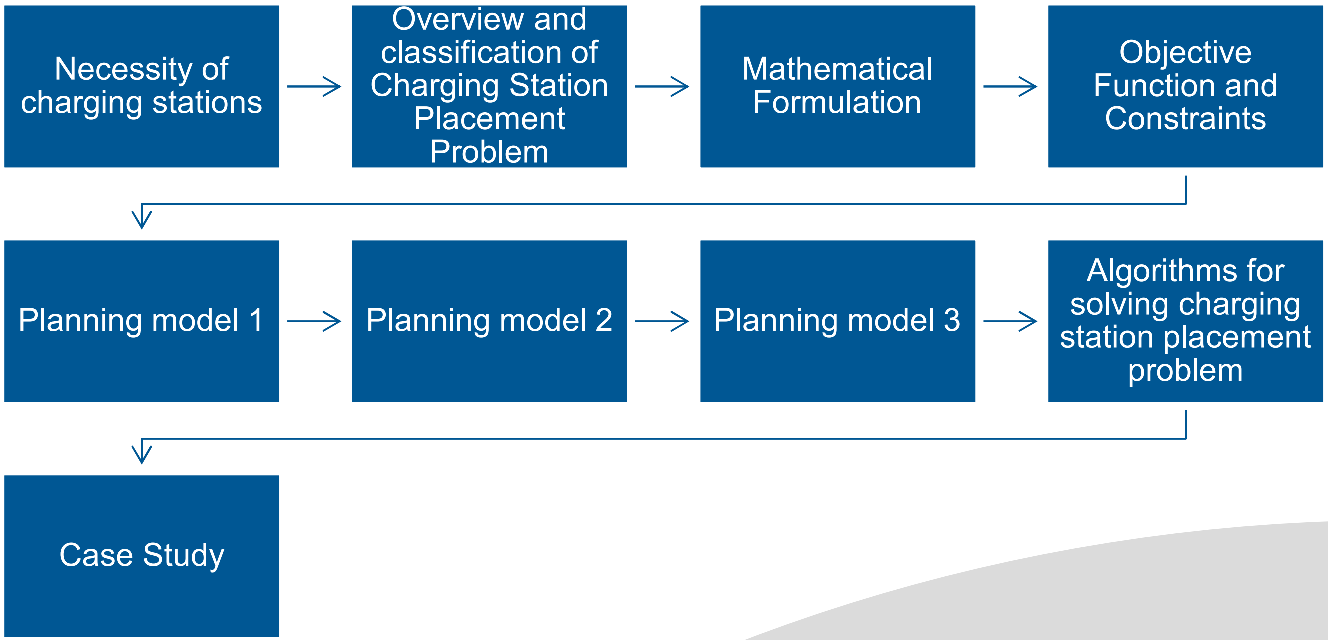
Outline


Necessity of charging stations
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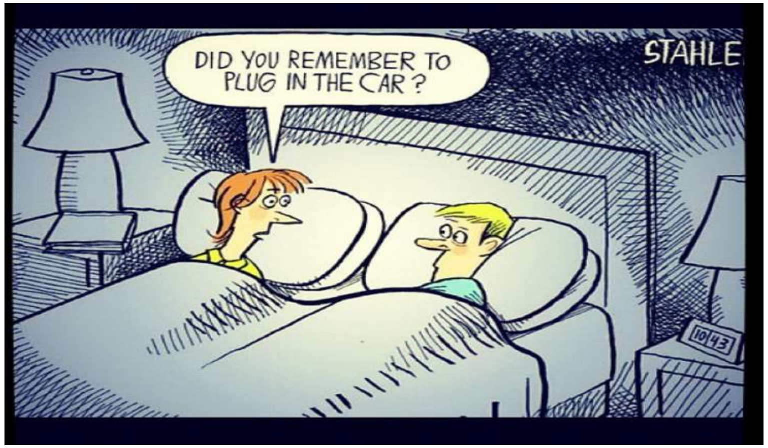
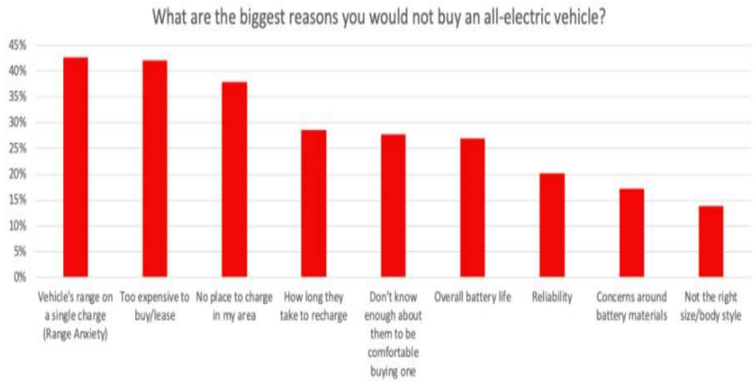
Case Study

Necessity of Charging Stations





Source: Electrek

Overview of Charging Station Placement Problem

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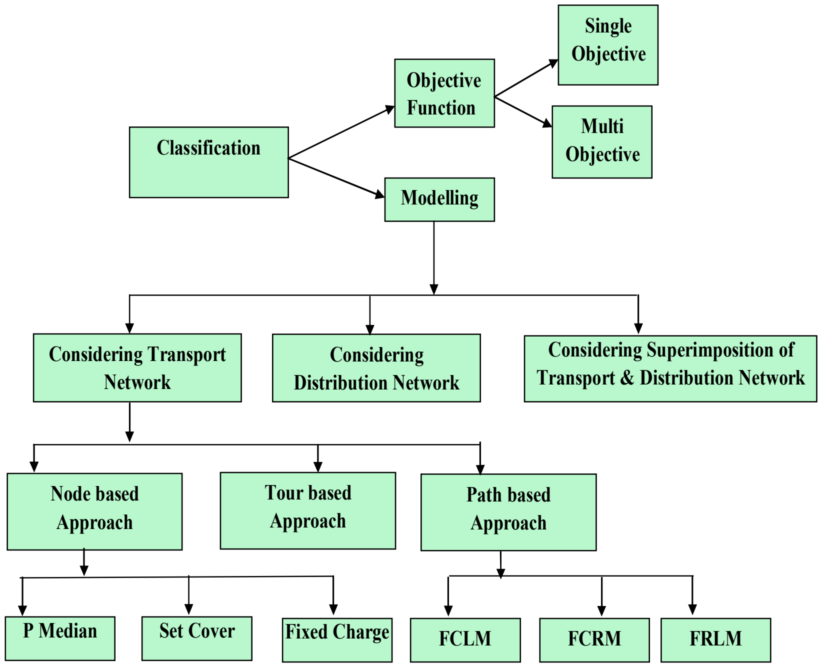
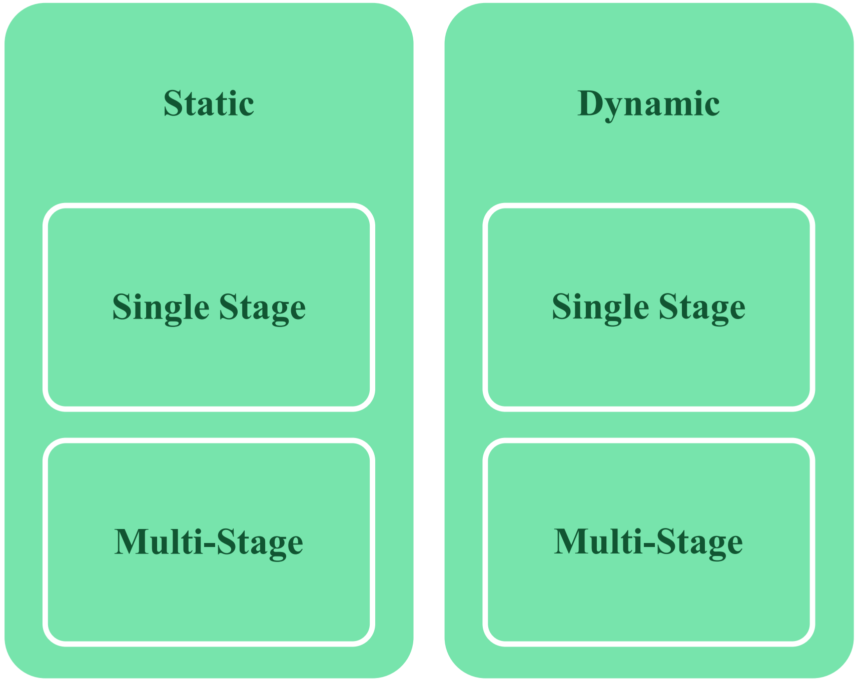
- Typical planning problem involving the following questions-
  - Where to place the charging stations?
  - What type of charging stations to be placed (slow/fast)?
  - How many charging stations to be placed?
  - What factors to be considered while solving the problem?

Classification of Charging Station Placement Problem





Source: Deb, S., Tammi, K., Kalita, K., & Mahanta, P. (2018). Review of recent trends in charging infrastructure planning for electric vehicles. *Wiley Interdisciplinary Reviews: Energy and Environment*, *7*(6), e306.

Mathematical Formulation

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$$Min(Z) = f(p, u_{fast}, u_{slow})$$

Subject to

$$u_{fast}^{min} \le u_{fast} \le u_{fast}^{max} \ \ and \ \ u_{slow}^{min} \le u_{slow} \le u_{slow}^{max}$$

$$g_j(p, u_{fast}, u_{slow}) = 0$$

j=1, 2...........m

$$h_k(p, u_{fast}, u_{slow}) \le 0$$

k=1, 2.............p

Decision variables can be
- ❖Nodes of distribution/ transport /superimposed transport and distribution network
- ❖Number of fast charging stations
- ❖Number of slow charging stations

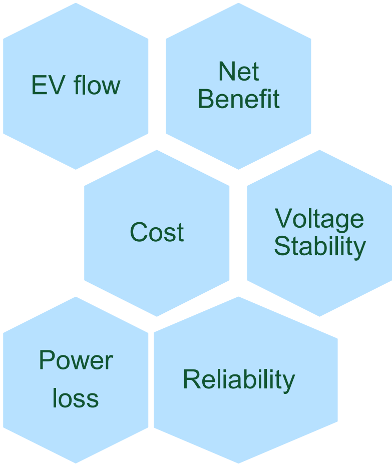
•Objective function Z can be
- ❖ Minimization of Cost
- ❖Maximization of Net Benefit
- ❖Maximization of EV flow
- ❖Minimization of impact of charging station placement on power grid

Equality constraint include
- ❖Power balance equation
- ❖Charging demand balance

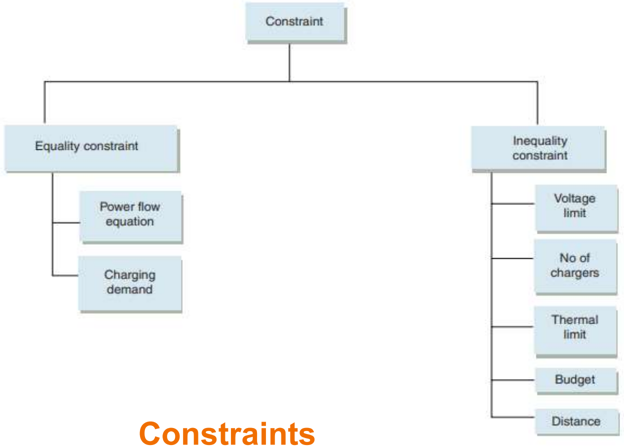
•First inequality constraint include
- ❖upper and lower limit of charging station to be placed

•Last inequality constraint include
- ❖Voltage limit
- ❖Current limit

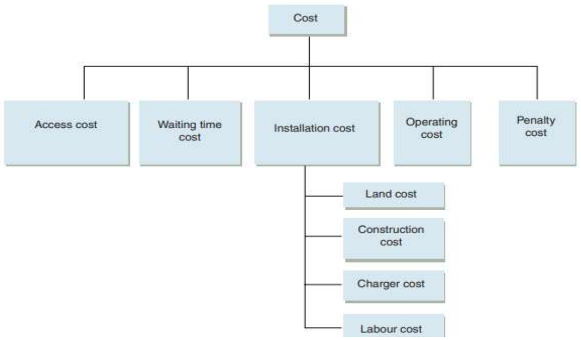
Objective Function and Constraints



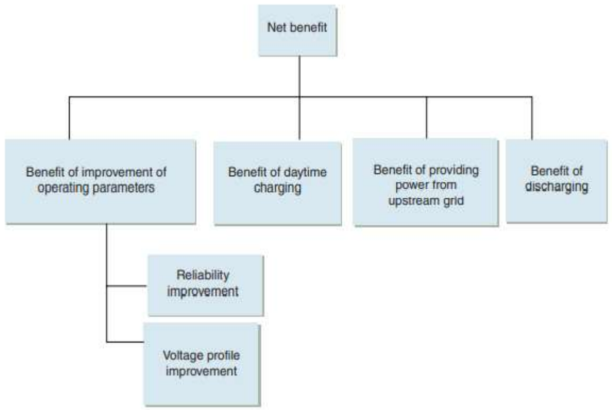
Objective Functions



Constraints



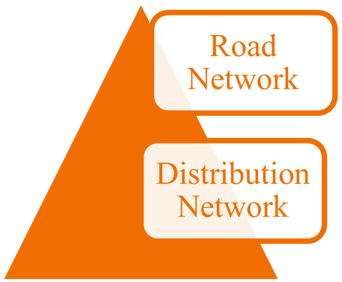
Cost Function



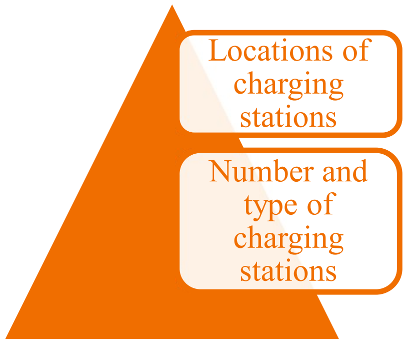
Net Benefit Function

Planning Model 1:Single-Objective Formulation of Charging Station Placement Problem

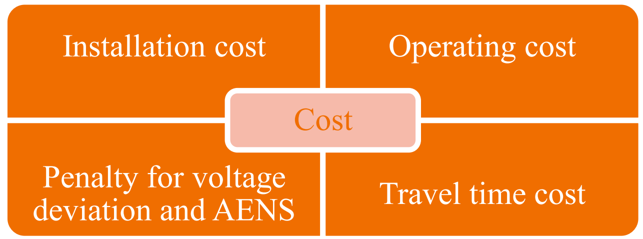
Test Network



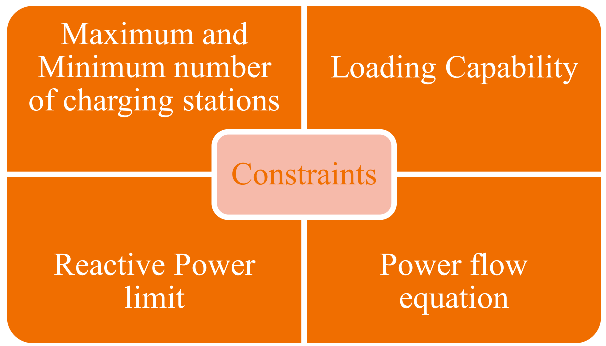
Decision variable



Objective Function



Constraints



Source: Deb, S., Gao, X. Z., Tammi, K., Kalita, K., & Mahanta, P. (2021). A novel chicken swarm and teaching learning based algorithm for electric vehicle charging station placement problem. *Energy*, *220*, 119645.

Planning Model 2: Multi-Objective Formulation of Charging Station Placement Problem

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Test Network

- Road Network
- Distribution Network

Objective Function

- Cost
- VRP index
- Accessibility index

Decision variable

- Locations of charging stations
- Number of charging stations

Constraints

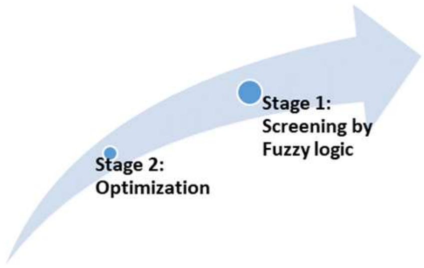
- Maximum and Minimum number of charging stations
- Loading Capability
- Reactive Power limit
- Power flow equation

Source: Deb, S., Tammi, K., Gao, X. Z., Kalita, K., & Mahanta, P. (2020). A hybrid multi-objective chicken swarm optimization and teaching learning based algorithm for charging station placement problem. *IEEE Access*, *8*, 92573-92590.

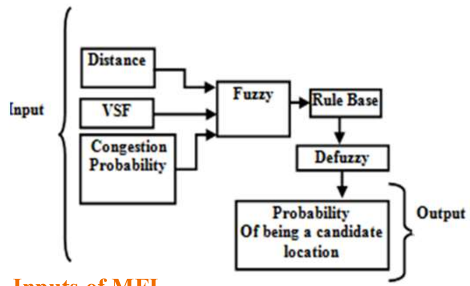
Planning Model 3: Robust two stage Planning Model

Key features

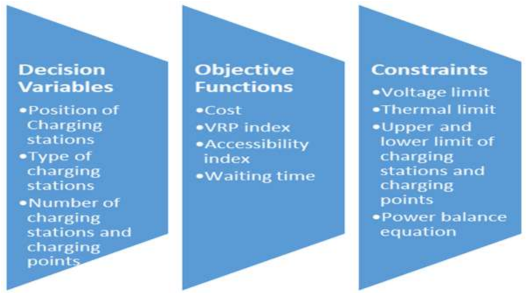
- Two stage model
- Considers economic factors, operating parameters of power grid as well as EV users convenience
- Considers reliability of distribution network while formulating the problem
- Considers uncertainty in road traffic



Stage 1



Stage 2



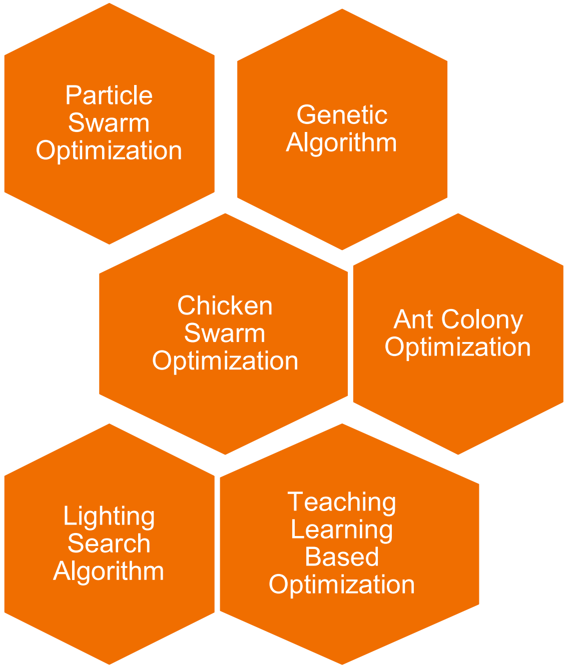
Inputs of MFI

Input	Significance	Linguistic variable associated
Distance	Represents graphical distance between node of the road network and bus of the distribution network	High, Low, Medium
Voltage Sensitivity factor	Represents the change in voltage with the change in active power	High, Low, Medium
Congestion probability	Represents the traffic intensity of the nodes of the road network	High, Low, Medium

Source: Deb, S., Tammi, K., Gao, X. Z., Kalita, K., Mahanta, P., & Cross, S. (2021). A Robust Two-Stage Planning Model for the Charging Station Placement Problem Considering Road Traffic Uncertainty. *IEEE Transactions on Intelligent Transportation Systems*.

Algorithms for solving the Charging Station Placement Problem

- Classical optimization algorithms have their limitation in solving charging station placement problem
- Mostly Nature Inspired Optimization Algorithms (NIOs) are used for solving the charging station placement problem



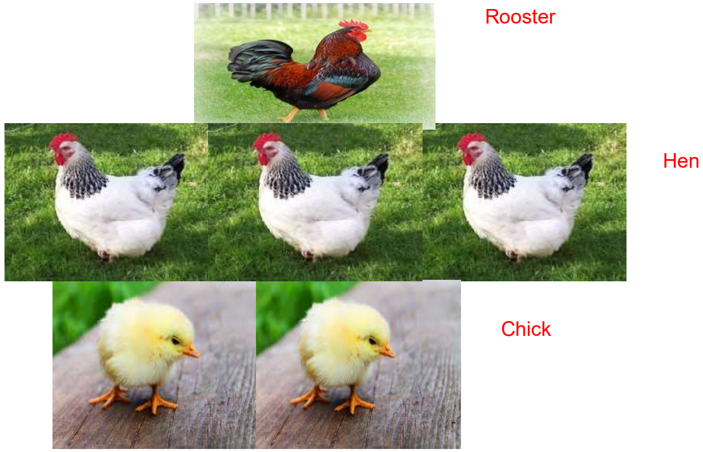
A Novel CSO TLBO for solving the Charging Station Placement Problem

Source: Deb, S., Gao, X. Z., Tammi, K., Kalita, K., & Mahanta, P. (2020). A new teaching–learning-based chicken swarm optimization algorithm. *Soft Computing*, *24*(7), 5313-5331.

Chicken Swarm Optimization Algorithm

- CSO is one of the latest bio-inspired algorithms proposed by Meng et al. in 2014
- The CSO algorithm is inspired by the behavior of chicken swarm
- The population of chicken in the group consists of the dominant rooster, hens, and chicks depending upon the fitness values of the chickens
- The chickens with the highest fitness value are assigned as roosters, chickens with least fitness value are assigned as chicks, and the chickens with intermediate fitness value are assigned as hens
- The algorithm randomly assigns the mother-child relationship in the swarm.
- The hierarchal order and mother-child relationship are updated after every G time steps
- The chickens would try to steal the food found by others thereby giving rise to a competition for food in the group.
- The algorithm can be broadly divided into two steps- Initialization and Update.

Initialization



Update

Update of rooster

The food searching capacities of rooster depend on their fitness value and their update formula is as in equations

$$x_{i,j}^{t+1} = x_{i,j}^{t} \times (1 + Randn\ (0, \sigma^2))$$

If $f_i \leq f_k$ $\quad \sigma^2 = \exp\left(\frac{(f_k - f_i)}{|f_i| + \varepsilon}\right)$

Else $\quad \sigma^2 = 1$

where randn(0,σ2) is a Gaussian distribution function with mean 0 and standard deviation σ2.f is the fitness value of corresponding x, k is randomly selected rooster's index.ε is a small constant value which is used to avoid zero division error.

Update of hen

Competition among chickens

Hens follow their group mate rooster

Hens follow their group mate roosters in their quest for food. There is also tendency among the chickens to steal the food found by other chickens

The mathematical representation of their update formula is

$$x_{i,j}^{t+1} = x_{i,j}^{t} + S1 \times rand \times (x_{r1,j}^{t} - x_{i,j}^{t}) + S2 \times rand \times (x_{r2,j}^{t} - x_{i,j}^{t})$$

$$S1 = \exp\left(\frac{f_i - f_{r1}}{abs(f_i) + \varepsilon}\right) \qquad S2 = \exp(f_{r2} - f_i)$$

where *randn* is a randomly generated number between 0 and 1. r1 is an index of rooster which is i^{th} hen's group mate. And r2 is an index of rooster or hen which is randomly chosen.r1≠r2

Update (Continued)

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Update of chicks

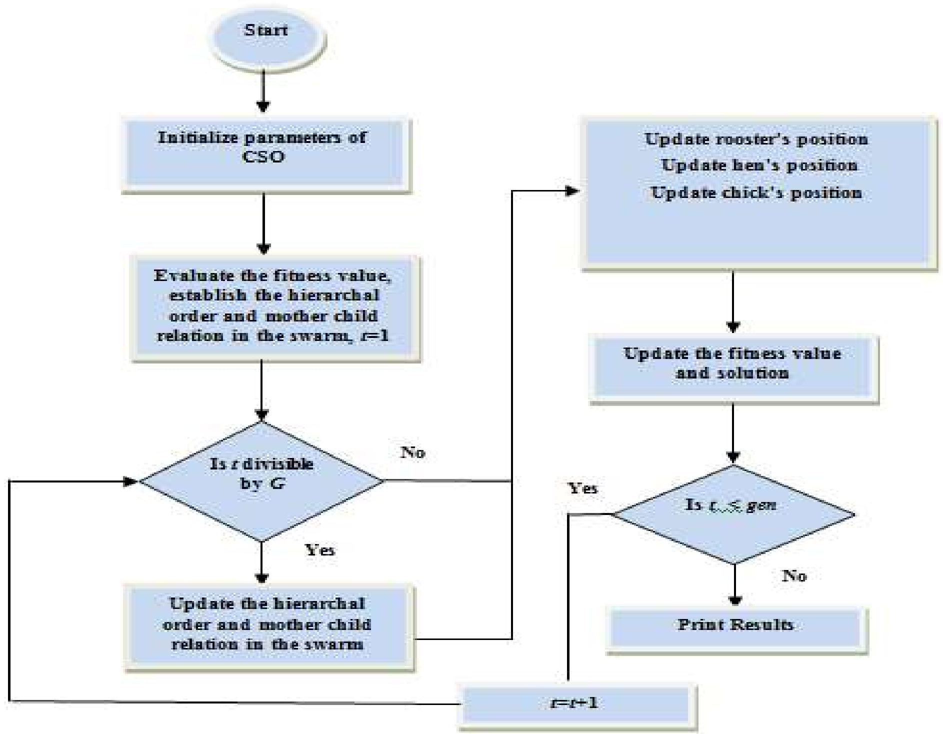
Chicks follow their mother

The natural tendency of chicks to follow their mother is mathematically given by:

$$x_{i,j}^{t+1} = x_{i,j}^{t} + FL \times (x_{m,j}^{t} - x_{i,j}^{t})$$

where *FL* is a parameter which signifies that the chick would follow its mother. *FL* is generally chosen in between 0 and 2

Flowchart of CSO



Teaching Learning Based Optimization Algorithm

- Nature Inspired Algorithm invented by Rao et al.
- Mimics Teaching and Learning Process
- A class of learners constitutes the population here.
- The teacher transfers his/her knowledge to the learners.
- The performance of the learners depends on the knowledge and capability of the teacher.
- The students can learn from the teacher as well as learn from each other by mutual interaction.
- The algorithm is divided into two parts-
- Teacher phase
- Learner phase

Teacher Phase

Selection of Teacher

Learning from Teacher

Learner

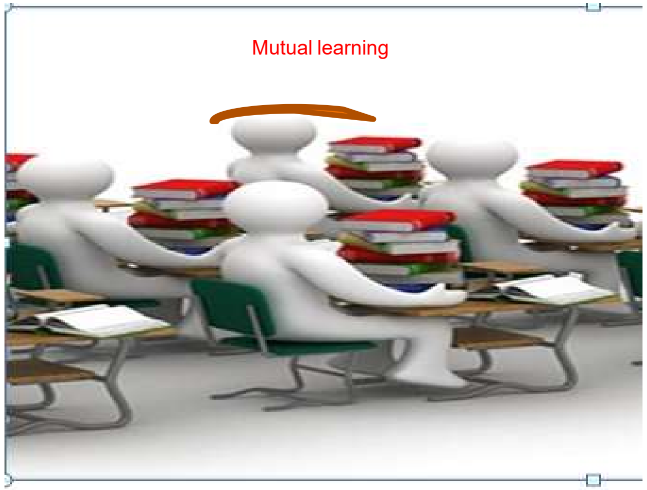
Teacher

Each learner learns from the teacher and is modified by the equations

$$Z_{diff} = rand * (T_k - R_t m_k)$$

$$Z_{new} = Z_{old} + Z_{diff}$$

Learner Phase

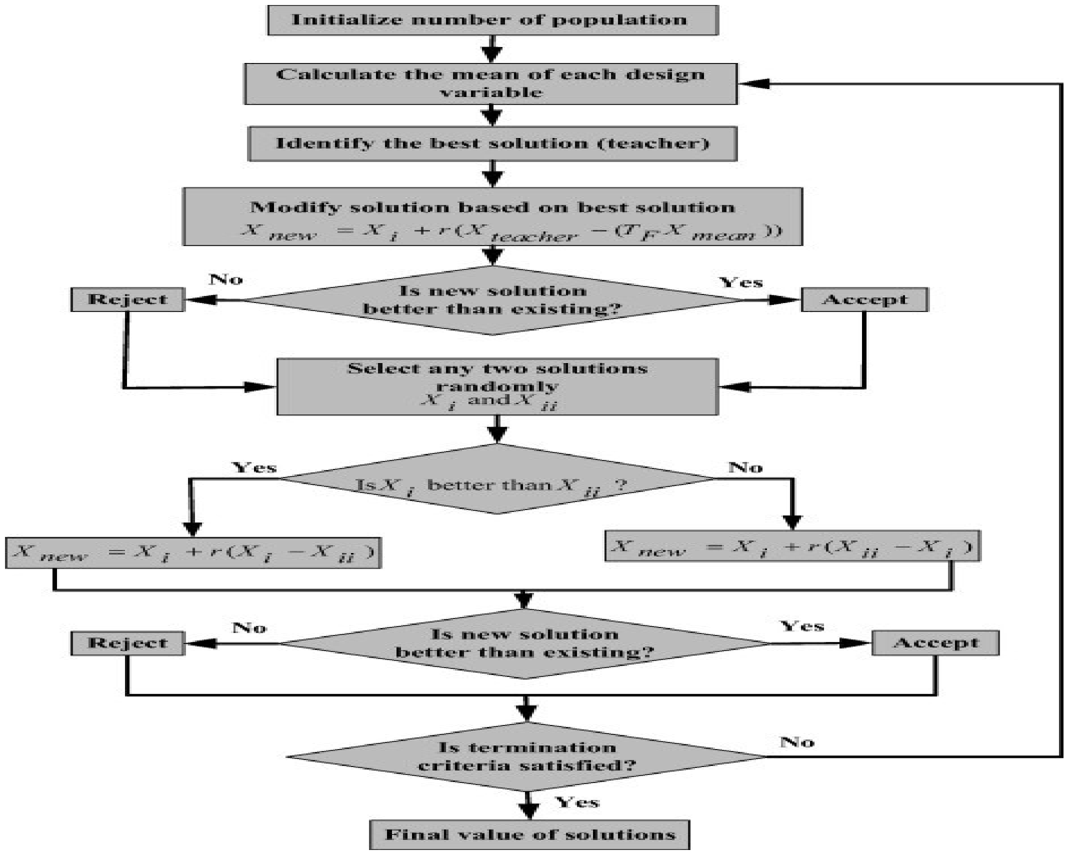


- For each learner Z_i any learner Z_j is chosen arbitrarily from the learner matrix.
- The objective function values are compared arbitrarily for the two aforementioned learners.
- If the value of the objective function of Z_i is lower than the objective function of Z_j then the i^th learner is modified by
- Else, the learner is modified by

$$Z_{new} = Z_{old} + rand \times (Z_i - Z_j)$$

$$Z_{new} = Z_{old} + rand \times (Z_j - Z_i)$$

Flowchart of TLBO



Hybrid CSO TLBO

- **Pseudo code of CSO TLBO**
- *Initialize the population size, gen and the other algorithm specific parameters of CSO TLBO*
- *Set t=1*
- *While (t<gen)*
- *Activate TLBO*
- *If (t mod INV)>0*
- *Activate CSO*
- *End if*
- *t=t+1*
- *Selection based on fitness function*
- *End while*

Performance of Metaheuristics on Charging Station Placement Problem

Formulations

Formulation	Decision variable	Objective function	Constraints
1	b, N_{Fb}, N_{Sb}	$F = \min(VD)^2 VD_i = \lvert V_{base} - V_i \rvert VD = \sum_{i=1}^{n} VD_i$	$0 < N_{Fb} \le n_{fastCS}$ $0 < N_{Sb} \le n_{slowCS}$ $S_{\min} \le S_i \le S_{\max}$ $P_{gi} - P_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0$ $Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0$
2	b, N_{Fb}, N_{Sb}	$F = \min(CIR)$ $CIR = w_{21}\frac{SAIFI_l}{SAIFI_{base}} + w_{22}\frac{SAIDI_l}{SAIDI_{base}} + w_{23}\frac{CAIDI_l}{CAIDI_{base}}$	$0 < N_{Fb} \le n_{fastCS}$ $0 < N_{Sb} \le n_{slowCS}$ $S_{\min} \le S_i \le S_{\max}$ $P_{gi} - P_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0$ $Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0$
3	b, N_{Fb}, N_{Sb}	$F = \min(VRP)$ $V = \frac{VSI_l}{VSI_{base}}$ $P = \frac{P^l_{loss}}{P^{base}_{loss}}$ $R = w_{21}\frac{SAIFI_l}{SAIFI_{base}} + w_{22}\frac{SAIDI_l}{SAIDI_{base}} + w_{23}\frac{CAIDI_l}{CAIDI_{base}}$	$0 < N_{Fb} \le n_{fastCS}$ $0 < N_{Sb} \le n_{slowCS}$ $S_{\min} \le S_i \le S_{\max}$ $P_{gi} - P_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0$ $Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0$
4	b, N_{Fb}, N_{Sb}	$F = \min(Cost)$ $Cost = C_{installation} + C_{operation} + C_{penalty} + C_{travel}$	$0 < N_{Fb} \le n_{fastCS}$ $0 < N_{Sb} \le n_{slowCS}$ $S_{\min} \le S_i \le S_{\max}$ $P_{gi} - P_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0$ $Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0$

Comparison

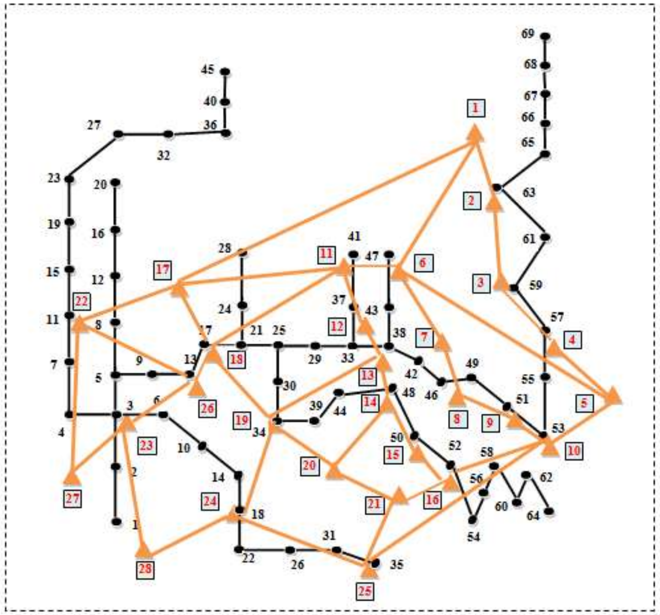
Formulation	Algorithm	Best fitness
1	DE	0.0753
	PSO	0.0757
	CSO	0.0759
	TLBO	0.0755
	GA	0.0749
	CSO TLBO	0.0745
	GA PSO	0.0745
2	DE	0.9097
	PSO	0.9554
	CSO	0.9097
	TLBO	0.9448
	GA	0.9550
	CSO TLBO	0.8573
	GA PSO	0.8643
3	DE	20.9451
	PSO	16.3483
	CSO	15.9208
	TLBO	17.1750
	GA	21.8286
	CSO TLBO	14.3844
	GA PSO	16.0315
4	DE	1.4898
	PSO	1.4898
	CSO	1.4870
	TLBO	1.4878
	GA	1.5075
	CSO TLBO	1.4841
	GA PSO	1.4841

Source: Deb, S., Gao, X. Z., Tammi, K., Kalita, K., & Mahanta, P. (2019). Nature-Inspired Optimization Algorithms Applied for Solving Charging Station Placement Problem: Overview and Comparison. *Archives of Computational Methods in Engineering*, 1-16.

Case Study : Charging Station Placement for Tianjin, China

Source: Deb, S., Tammi, K., Gao, X. Z., Kalita, K., Mahanta, P., & Cross, S. (2021). A Robust Two-Stage Planning Model for the Charging Station Placement Problem Considering Road Traffic Uncertainty. *IEEE Transactions on Intelligent Transportation Systems*.

Test System



Type	Node No
Residential	1,2, 12, 13, 14, 15, 16, 22, 23
School	3, 6, 7, 8, 17, 19, 24
Market	5, 11, 20, 21, 26, 27
Office	4, 9, 10, 18, 25,28
Charging demand	1, 7, 12, 15, 20, 25

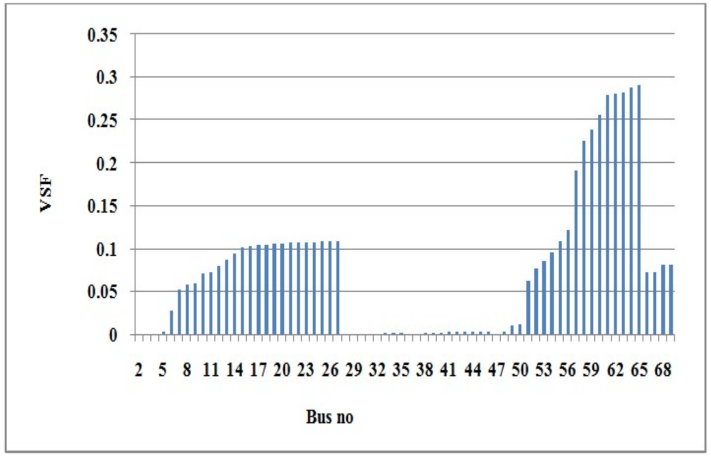
The EVs follow the routes- (1-2-3-4-5-10-9-8-6-11-12-13-14-15-16-21-20-19-18-17) and (1-2-3-4-5-10-9-8-6-11-12-13-14-15-16-21-20-19-18-26-22-27-23-28-24-25)

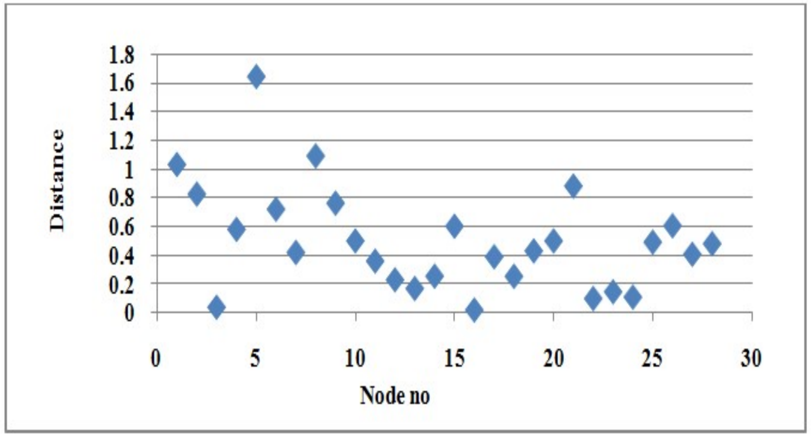
Input Parameters

Parameter	Value
C_{fast}	3000 $
C_{slow}	2500 $
CP_{fast}	50 kW
CP_{slow}	19.2 kW
$P_{electricity}$	65 $/MWhr
w_1	0.1
w_2	0.7
w_{21}	0.2
w_{22}	0.4
w_{23}	0.1
w_3	0.2
λ_s	1.4/hr
λ_f	5.6/hr

S_{max}	3	s_{max}	20
F_{max}	2	f_{max}	10
S_{min}	1	s_{min}	6
F_{min}	1	f_{min}	4

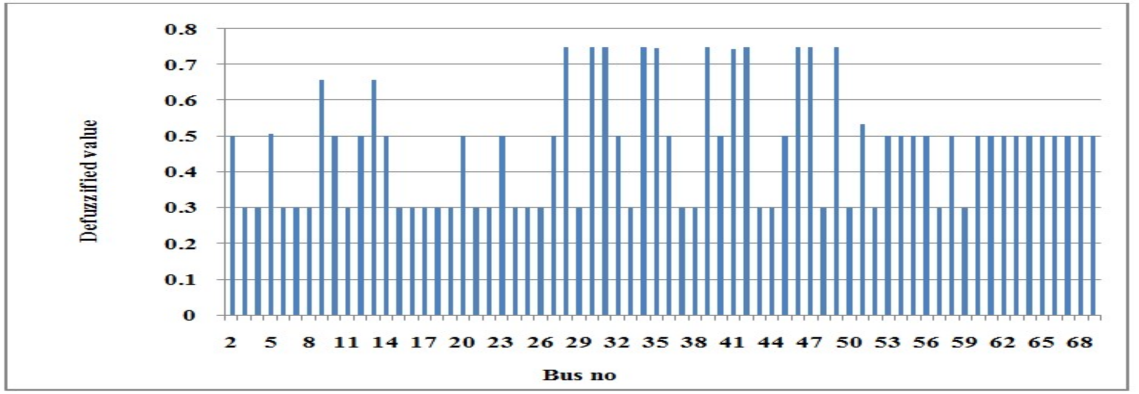
Stage I Results





Area	Congestion Probability
Residential	0.72
School	0.153
Residential	0.72
School	0.153

Stage I Results (Continued)

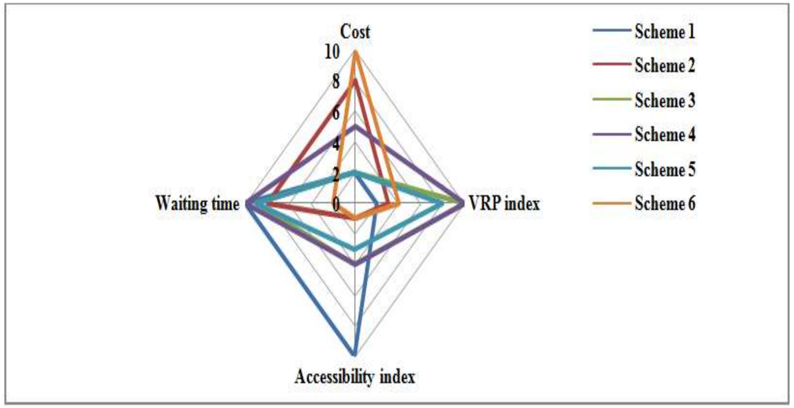


$P_{candidate}$	Reduction in search space
{5, 9, 13, 28, 30, 31, 34, 35, 39, 41, 42, 46, 47, 49, and 51}	78.26%

Stage II Results

NDS	p	F_p	S_p	f_p	s_p	NDS	p	F_p	S_p	f_p	s_p
1	13	1	1	6	11	4	39	1	1	6	10
	35	1	1	10	8		34	1	1	6	11
	34	1	1	7	8		28	1	1	6	11
2	34	1	1	5	7	5	39	1	2	5	9
	28	1	1	5	8		28	1	1	6	8
	13	1	1	5	8		35	2	1	4	11
3	34	1	1	8	8	6	28	1	1	3	9
	39	1	1	7	16		34	1	2	6	7
	28	1	1	6	14		13	1	1	3	6

Final Decision Making



Radar charts of all the plans

Scores of each plan

Plan	Cost	VRP index	A	W_t
1	2	2	10	10
2	8	3	1	8
3	2	10	4	9
4	5	10	4	10
5	2	8	3	9
6	10	4	1	2

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beyond
the obvious

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