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Interoperable Conventional Intercity and HSR Station Location Identification Model

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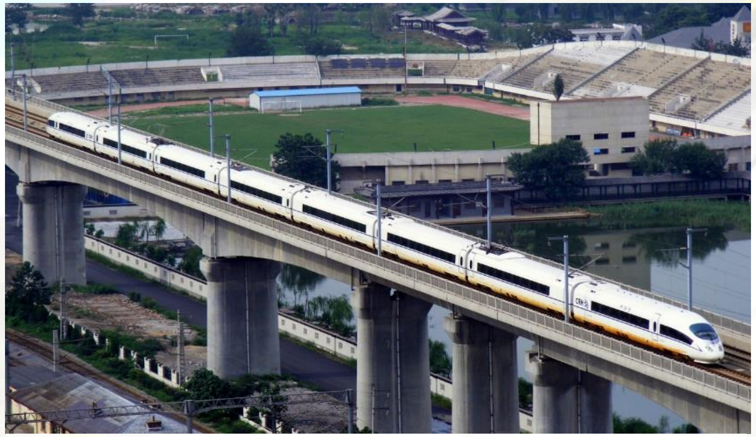
Background

- Important characteristics addressed while planning an HSR system (not limited to) :
  - Technical design details: type of HSR technology, rolling stock, choice of gauge
  - Operational characteristics: exclusive on grade separated right-of-way, shared right-of-way with existing conventional rail and/or freight.
- Generally operate on exclusive or grade separated right-of-way.
- In certain cases: infrastructure designed to facilitate movement of HSR on conventional intercity lines, or vice versa.
- This flexibility of operation: Interoperability.
- Typically observed when HSR corridor being designed coincides with existing conventional and/or freight corridor. Ex. AVE, Spain; ICE, Germany; Eurostar Italia

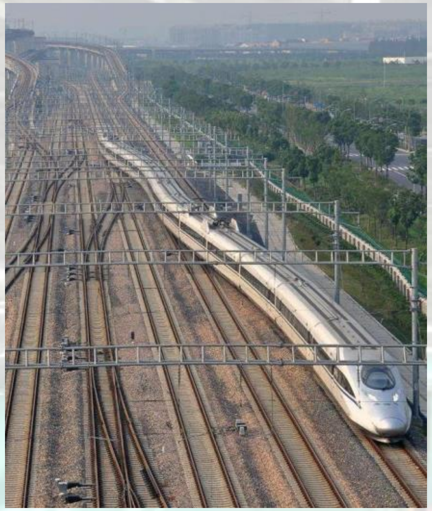
Underground HSR: Shenzen-Hong Kong (Source: Google)



Elevated HSR: Beijing-Tianjin (Source: Google)

- Prerequisites for interoperability:
  - Common technical specifications like track gauge, signalling *etc.*
  - Existing spare line capacity
  - Appropriate facilities (such as stations) capable of serving HSR demand
- Advantages :
  - Ridership perspective: seamless mode transfer and accessibility benefits for the passengers
  - Operator perspective: reduction of infrastructure cost and optimized utilization of existing rail network

Gauge



Spare Line capacity

Passenger transfer

Underlying issues for Interoperability

- All existing stations:
  - May not satisfy the ridership potential, corridor length and inter-station spacing requirements necessary for HSR operation
  - Providing more stations increases the access to intermediate locations, which boosts ridership. However, this increases overall travel time. On the contrary, lesser number of stations or stops, reduces overall ridership of the HSR.
  - A trade-off or balance between both these objectives would yield the optimum number and location of HSR stations.

Problem Definition and Formulation

- Objective: **identify station locations which maximize ridership and connect the identified station locations in the shortest route possible** (Current et al. 1985)

$$Max\ Z_1 = \sum_{n=1}^{N_{Smax}} \alpha_n * r_n$$

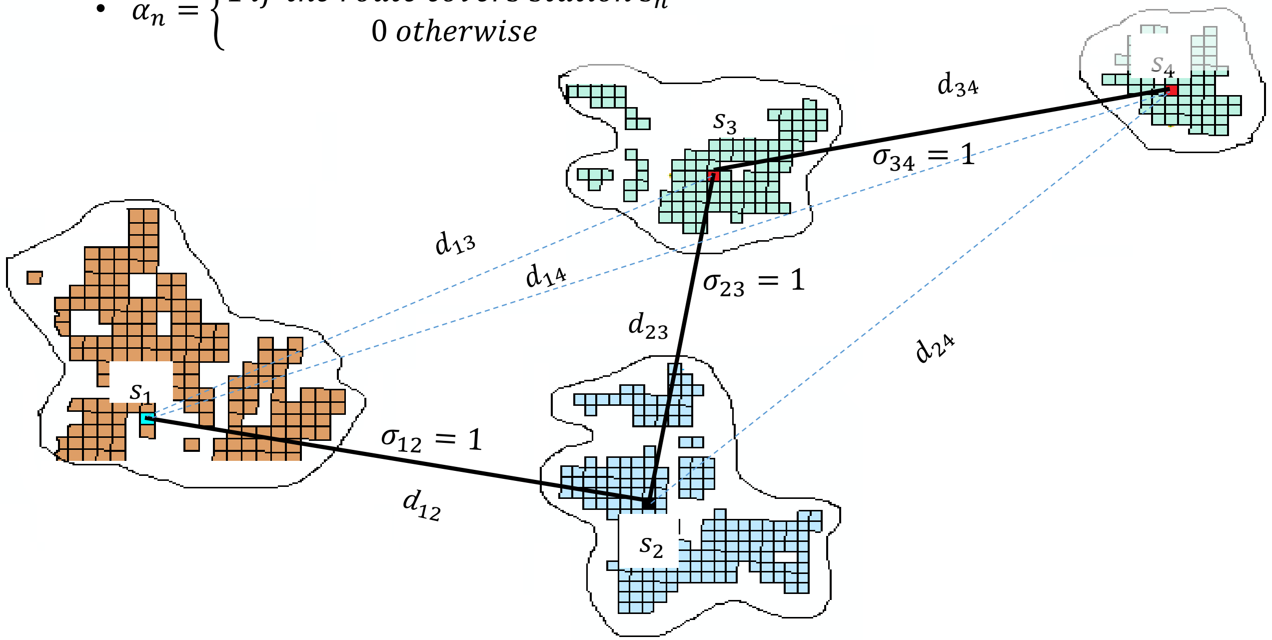
$$Min\ Z_2 = \sum_{i=1}^{N_S - 1} \sum_{j=2, j \neq i}^{N_S} \sigma_{ij} * d_{ij}$$

Combining both objectives into single objective problem using weightage method (Current *et al*. 1985; Zadeh 1963)

$$Max\ Z = \emptyset Z_1 / (1 - \emptyset) Z_2$$

Subject to

- $N_S = \sum_{i=1}^{N_{Smax}} \alpha_n$
- $N_S \leq NS_{max}$
- $N_S \geq NS_{min}$
- $\sum_{i=1, i \neq j}^{N_S - 1} \sigma_{ij} = 1, j \in \{2, \dots, N_S\}$
- $\sum_{j=2, j \neq i}^{N_S} \sigma_{ij} = 1, i \in \{1, 2, \dots, N_S - 1\}$
- $\sum_{i=1}^{N_S - 1} \sum_{j=2, i \neq j}^{N_S} \sigma_{ij} = N_S - 1$
- $d_{n,m} \geq IDS_{min} : \forall \alpha_n = 1, \alpha_m = 1,\ m = n + 1$
- $Z_2 \leq TDS_{max}$
- $\sigma_{ij} = [0,1]$
- $\alpha_{ij} = [0,1]$
- $0.05 \leq \emptyset \leq 0.95$
- $\sigma_{ij} = \begin{cases} 1\ if\ the\ route\ goes\ from\ station\ s_i to\ s_j \\ 0\ otherwise \end{cases}$
- $\alpha_n = \begin{cases} 1\ if\ the\ route\ covers\ station\ s_n \\ 0\ otherwise \end{cases}$

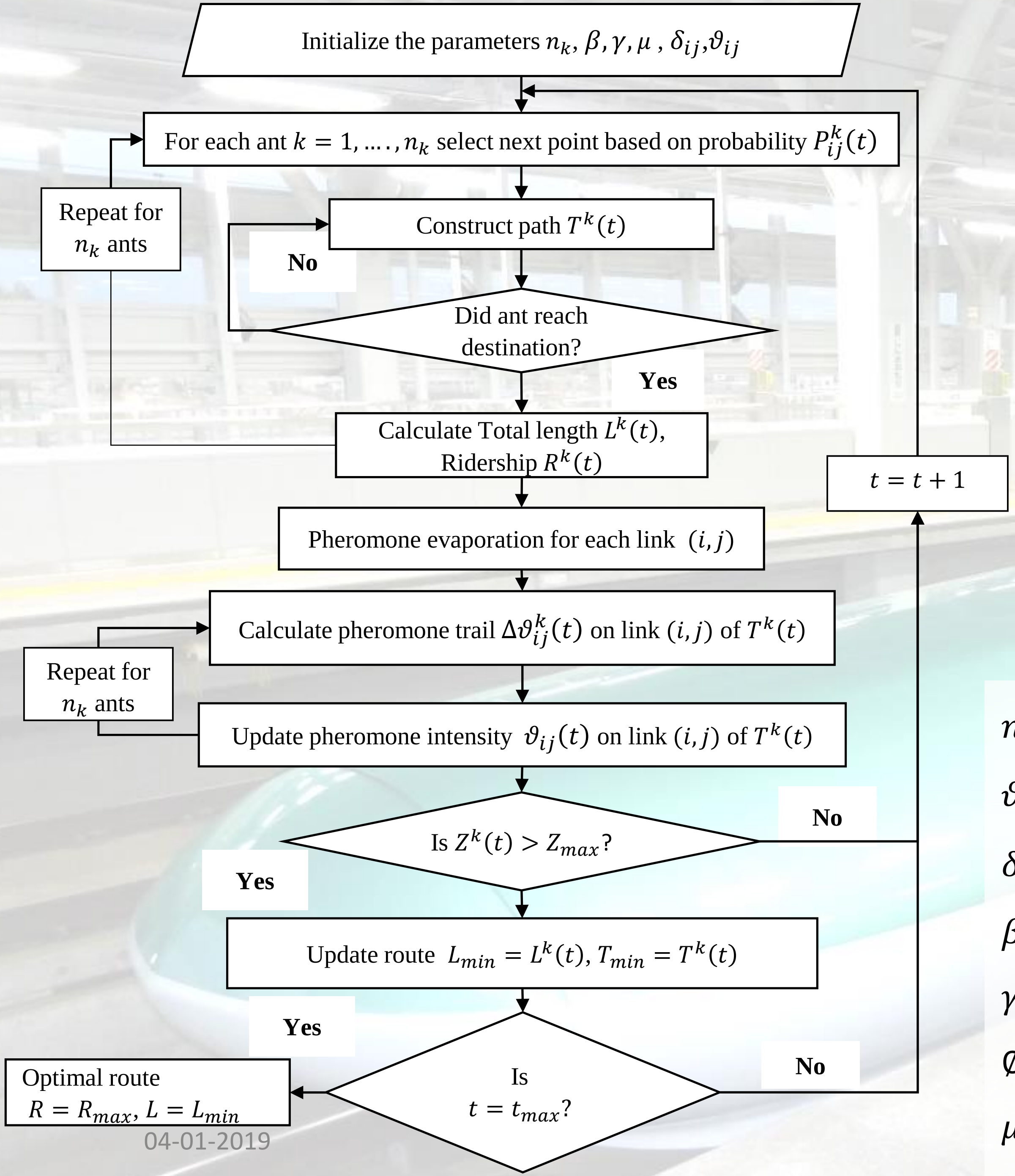


Visual Representation for Problem

Problem definition and Literature Review

- No exclusive literature on HSR
- Shares common features with bus and rail transit design problem, with similar objectives and constraints
- Analytical optimization:
    - Applied to predetermined transit route networks to determine one or few design parameters
    - Successful for problems with smaller networks or lesser decision variables, but their performance efficiency decreased for networks with realistic size, having many parameters
- Meta heuristics:
    - Simultaneously dealt with design of the transit route along with associated parameters

Analytical optimization	Meta heuristics
Vuchic (1969, 1972) Lesley (1976), Wirasinghe and Ghoneim (1981), Saka (2001) Newell (1979), Leblanc (1988), Boffey and Narula (1998), Current and Schilling (1989, 1994), Hachicha et al. (2000), Wu (2005)	Lampkin and Saalmans (1967), Rea (1971), Silman et al. (1974), Dubois et al. (1979), Ceder and Wilson (1986), Ceder and Israeli (1998), and Laporte et al. (2005). **Artificial intelligence-based** Hasselstrom (1981), Van Nes et al. (1988), Baaj and Mahmassani (1991), and Shih et al. (1998a, b) **Genetic algorithm-based** Pattnaik et al. (1998), Chien et al. (2001), Fan and Machemehl (2004) **Simulated annealing-based** Fan and Machemehl (2005) and Yan et al. (2013)



Solution Methodology : Ant Colony Optimization

$$\delta_{ij}(t) = (r_i + r_j)/d_{ij}$$

$$P_{ij}^k(t) = \begin{cases} \dfrac{[\vartheta_{ij}(t)]^{\beta}\,[\delta_{ij}(t)]^{\gamma}}{\sum_{u \in N_i^k(t)} [\vartheta_{iu}(t)]^{\beta}\,[\delta_{iu}(t)]^{\gamma}} & if\ j \in N_i^k(t) \\ 0 & if\ j \notin N_i^k(t) \end{cases}$$

$$\boldsymbol{\Delta\vartheta_{ij}^k(t) = \frac{\emptyset R^k(t)}{(1-\emptyset)L^k(t)}, (i, j) \in T^k(t)}$$ **(Contribution of this study)**

$$L^k(t) = \sum_{i,j=i+1}^{N_S-1} d_{ij}, (i, j) \in T^k(t)$$

$$\boldsymbol{R^k(t) = \sum_i^{N_S} r_i,\ i \in T^k(t)}$$ **(Contribution of this study)**

$$\vartheta_{ij}(t+1) = (1 - \mu)\vartheta_{ij}(t) + \sum_{k=1}^{n_k} \Delta\vartheta_{ij}^k(t)$$

n_k =number of ants

ϑ_{ij} = pheromone intensity between locations (i, j)

δ_{ij} = visibility or attractiveness of the of location j from location i

β = constant used to amplify the influence of pheromone intensity

γ = and increase the attractiveness towards other locations

$\emptyset$ = weightage factor

μ = evaporation rate

N_i^k = set of feasible locations connected to location i with respect to ant k

Case Study & Data Collection

- Mumbai-Ahmedabad HSR Corridor
- India's 1st HSR Line
- 28 major stations in total between Mumbai and Ahmedabad

- *Number of intercity OD pairs and cities:*

Threshold value of population for cities for HSR implementation: 500,000 (Takeshita, 2012). Population data extracted from website of the Census of India in spreadsheet table format.

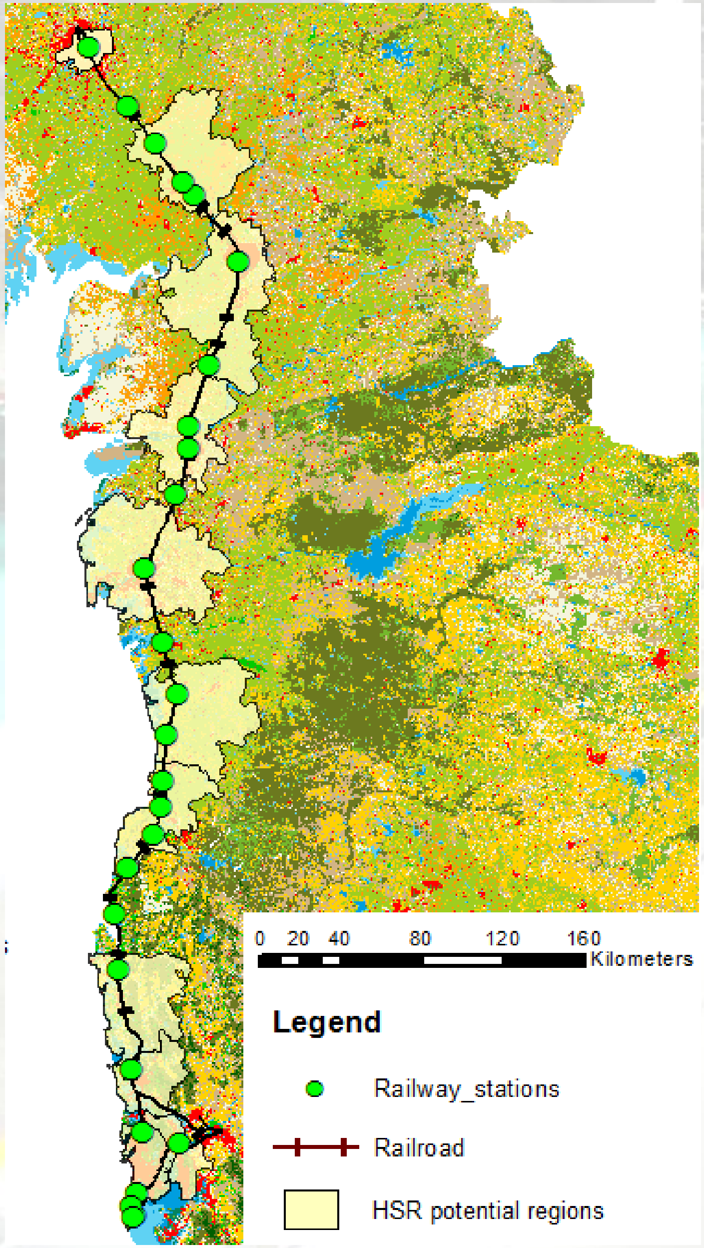
A Python based search program was created to identify sub districts and cities that had the estimated population level over the threshold value

11 regions (sub-districts and cities) were identified in the Mumbai-Ahmedabad corridor: Ahmedabad, Anand, Bharuch, Vadodara, Surat, Valsad, Vapi, Thane, Boisar, Vasai-Virar, and Mumbai.

- *GIS Shapefiles:*

Source: Open Street Maps [2017]

Point shapefiles: locations, transportation points (bus stops, railway stations)



Study area

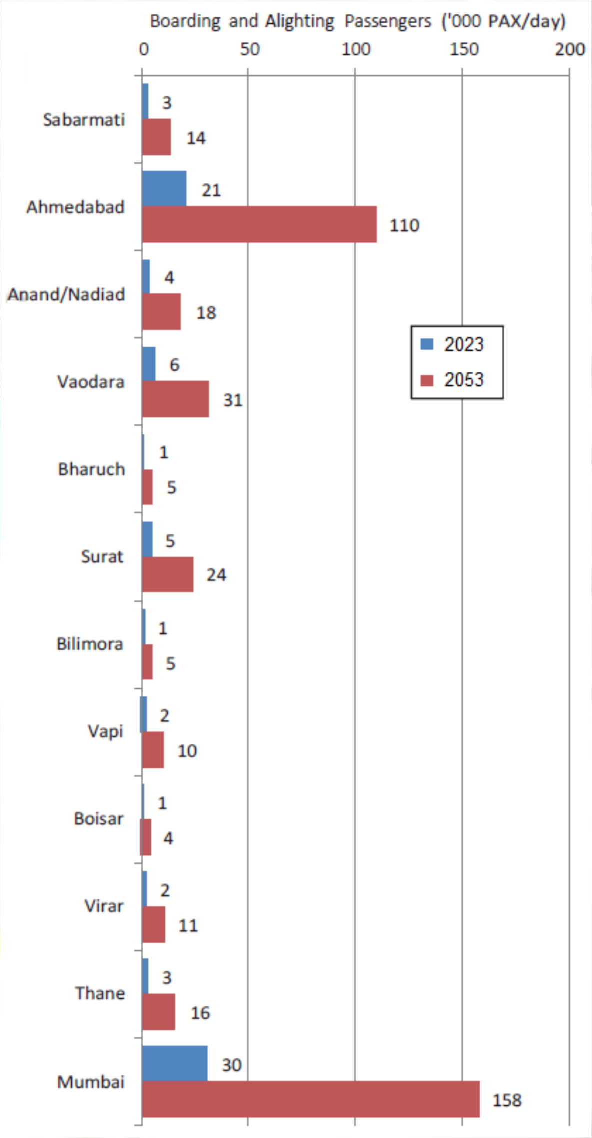
Data Collection

- ***<u>Ridership data:</u>***

Taken from report on the Joint Feasibility Study for Mumbai-Ahmedabad High Speed Railway Corridor (2015) prepared by JICA for horizon year 2023.

Table 1. Input Parameters

Input parameters	Values	Source
Factors controlling trail β	1.0	Brezina and Cickova, 2011
Factors controlling visibility γ	2.0	
Pheromone evaporation rate τ	0.5	
Number of ants n_k	500	Assumed
Maximum number of generations	400	Assumed
Distance between Consecutive Stations IDS_{min}	24km	Stanford Research Institute, 1968
Maximum Distance between Terminal Stations TDS_{max}	800km	Takeshita, 2012
Minimum Number of Stations in the Corridor NS_{min}	2	Assumed
Maximum Number of Stations in the Corridor NS_{max}	11	RITES, 2013; JICA, 2015



Boarding and Alighting Passenger for HSR in 2023 and 2053 (JICA 2015)

Results

- Proposed model was run by varying the values of weightage factor Ø for sufficient number of iterations until the results converged
- With increase in travel distance, access and ridership coverage increases, and vice versa.
- When Ø changes from 0.35 to 0.4, 0.7 to 0.75: significant change in travel distance, ridership and access coverage (number of stations)
- Ø variation between 0.4 to 0.7 provides a reasonable trade off as the variation in travel distance with ridership and access coverage is significantly less within this range

Table Ridership coverage and travel distance trade-off

Weightage Ø	Ridership covered Z_1 (pass./day)	Travel distance Z_2 (km)	Ridership per distance unit	Number of stations
0	53000	421.48	125.7474	3
0.05	53000	421.48	125.7474	3
0.10	59000	422.96	139.4931	5
0.15	59000	422.96	139.4931	5
0.20	59000	422.96	139.4931	5
0.25	59000	422.96	139.4931	5
0.30	59000	422.96	139.4931	5
0.35	59000	422.96	139.4931	5
0.40	72000	445.70	161.5436	9
0.45	72000	445.70	161.5436	9
0.50	72000	445.70	161.5436	9
0.55	73000	448.29	162.841	10
0.60	73000	448.29	162.841	10
0.65	73000	448.42	162.7938	10
0.70	73000	448.42	162.7938	10
0.75	76000	472.69	160.7819	11
0.80	76000	472.69	160.7819	11
0.85	76000	472.69	160.7819	11
0.90	76000	472.69	160.7819	11
0.95	76000	472.69	160.7819	11
1.00	76000	473.982	160.3436	11

Conclusion

- Integrated interoperable rail systems facilitate movement of high speed rail (HSR) trains on conventional intercity lines, or vice versa
- Preferred that HSR station are at existing intercity rail station locations
- All existing intercity stations may not satisfy the ridership potential, corridor length and inter-station spacing requirements necessary for HSR operation
- A trade-off or balance must be obtained between ridership, access coverage and travel distance/time
- Geographical Information System (GIS) based interoperable HSR station location identification approach along existing intercity rail
- A combined ridership maximization and travel distance/time minimization formulation is developed using weightage method
- Threshold inter-station travel time/distance between intended station locations, total end to end corridor travel distance/time and threshold population used as constraints
- Ant colony as the heuristic method to optimize the formulated problem
- Required trade-off necessary for designing an interoperable HSR system obtained for weightage factor variation between 0.4 to 0.7

THANK YOU

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