French Institute
of Science and Technology
for Transport, Development
and Networks

INDIRA-B Project
INDIcators for Reliability and Variability of Bus Systems'

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IFSTTAR

Sommaire

1. Le projet INDIRA_B
2. Exploitation conjointe des données AVL et ETM
3. Supervision de la fiabilité temporelle
4. Résilience statique du réseaux
5. Résilience dynamique et application aux données de New Delhi

Funding body

IFCPAR/CEFIPRA : Indo-French Centre for the Promotion of Advanced Research

Partners of the project

2 academic partners

IFSTTAR

- **GRETTIA** (Transport Network and Advanced Software Engineering) / **COSYS** (Components and Systems) / **IFSTTAR**

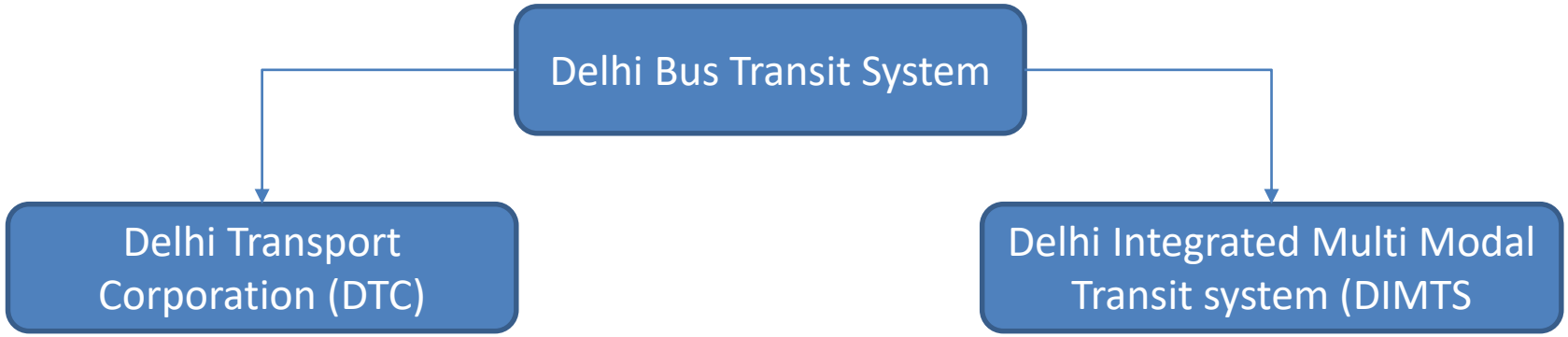
- **TRIPP (**Transportation Research and Injury Prevention Programme)/ **IIT Delhi**

Industrial partner

DIMTS
We help people move

DIMTS (Delhi Integrated Multi-Modal Transit System Ltd), Delhi, India

Delhi Bus Transit MAP



- 100% Government Owned
- Fleet Size = 3900
- Fleet Type = Low Floor CNG Buses
- Services = AC & Non AC buses
- Daily ridership = 3,500,000
- Fare Structure : AC = 10,15,20,25
- NON AC = 5,10,15
- Number of Routes = 500
- Number of bus stops = 4400
- Number of Depots = 40

- 50% Government Owned
- Fleet Size = 1750
- Fleet Type = Semi Low Floor CNG Buses
- Services = Non AC buses
- Daily ridership = 1,000,000
- Fare Structure : 5,10,15
- Number of Routes = 190
- Number of bus stops = 3200
- Number of Depots = 10
- Num of Concessionaire = 10

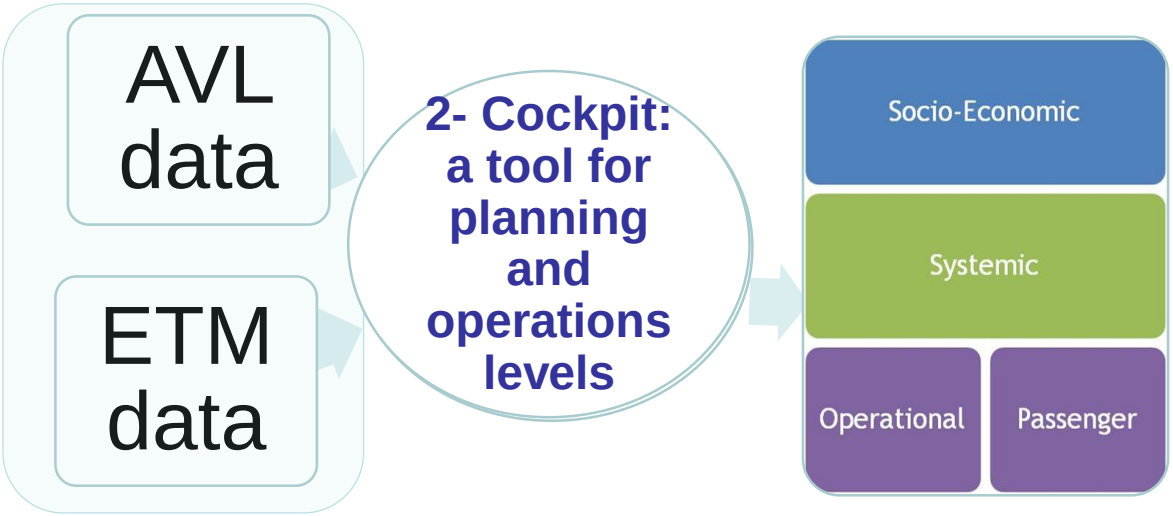
Objective of Indira_B project

To develop performance indicators and design a bus fleet "supervision cockpit”

The originality of our approach lies in at least 4 points

1- Joining AVL and ETM data

3- Multi-criteria analysis



4- Performance indicators: should be clear, easily understandable, useful to the audience

AVL: Automatic Vehicle Location
ETM: Electronic Ticketing Machine

Intégration des données AVL et ETM

DIMTS AVL data

- Stops location
- Road line (LineString)
- Trip details (scheduling at terminus only)
- Bus GPS location (Lon, Lat coordinates each 10 s)

DIMTS ETM data

- Fare stage collection
- Passenger flow between fare stage stops

Claire SITI

Structural

Logical graphs (nodes as stops, links between two stops)

Physical graphs (Point, Poly line)

Vehicle monitoring

Matching algorithm on vehicle tracking along the links)

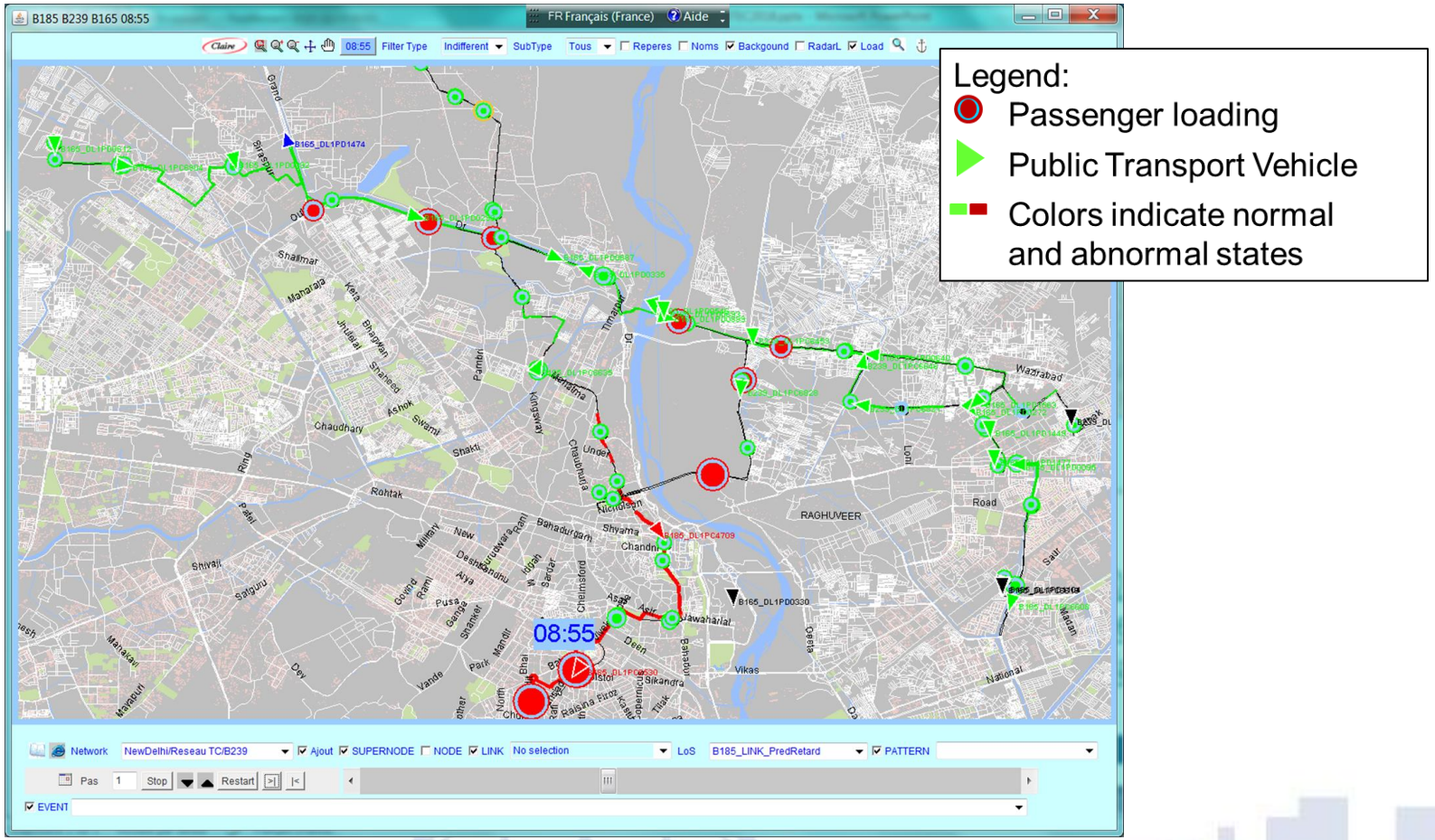
Time performance indicators at vehicle, stop and link levels

(travel time, delay, headway)

Passenger demand indicators

(Boarding, Alighting, Loading)

Example : passengers load at super-nodes and bus delay on links



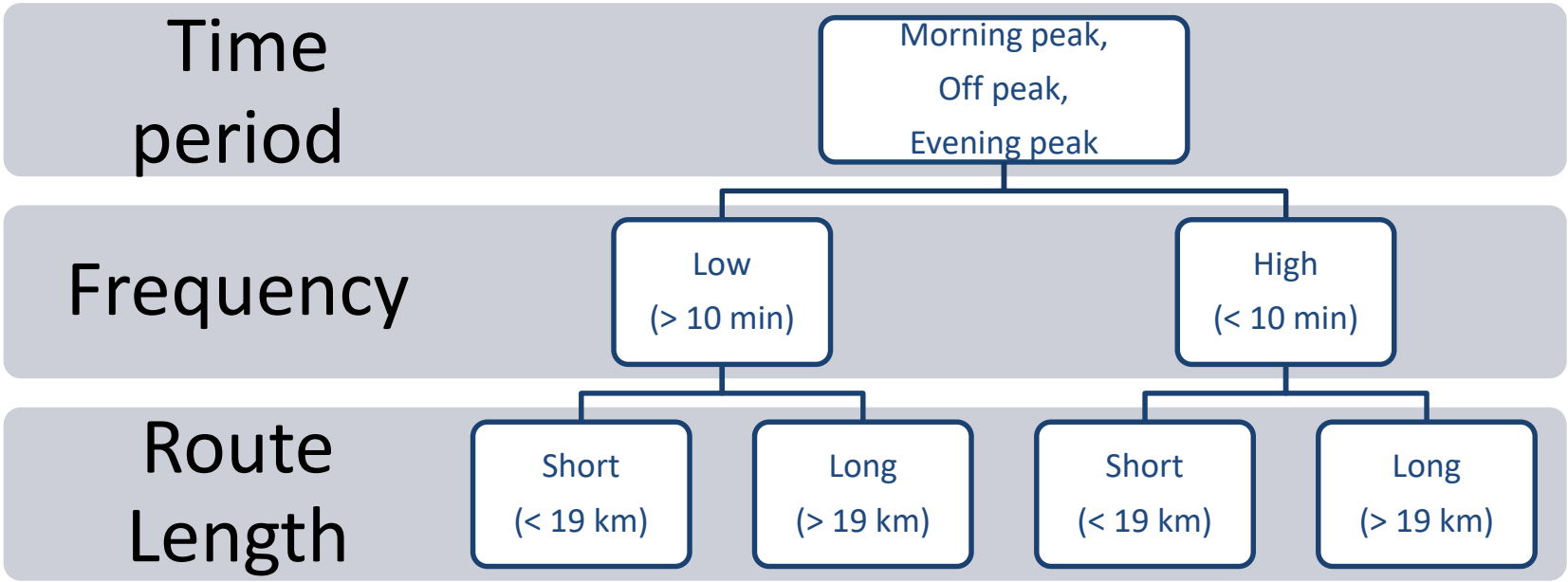
Indicators from only AVL data

- Punctuality
  - Schedule Adherence
  - Variability in departure and arrival times
  - At terminal stops
- Regularity
  - Headway adherence
  - Headway ratio
  - Gini coefficient and Lorenz curve
  - Variability of headway
  - At bus stops
- Link-based speed and travel time
  - Travel time variability (TTV)
  - Distribution of travel times and speeds

Indicators from AVL & ETM data

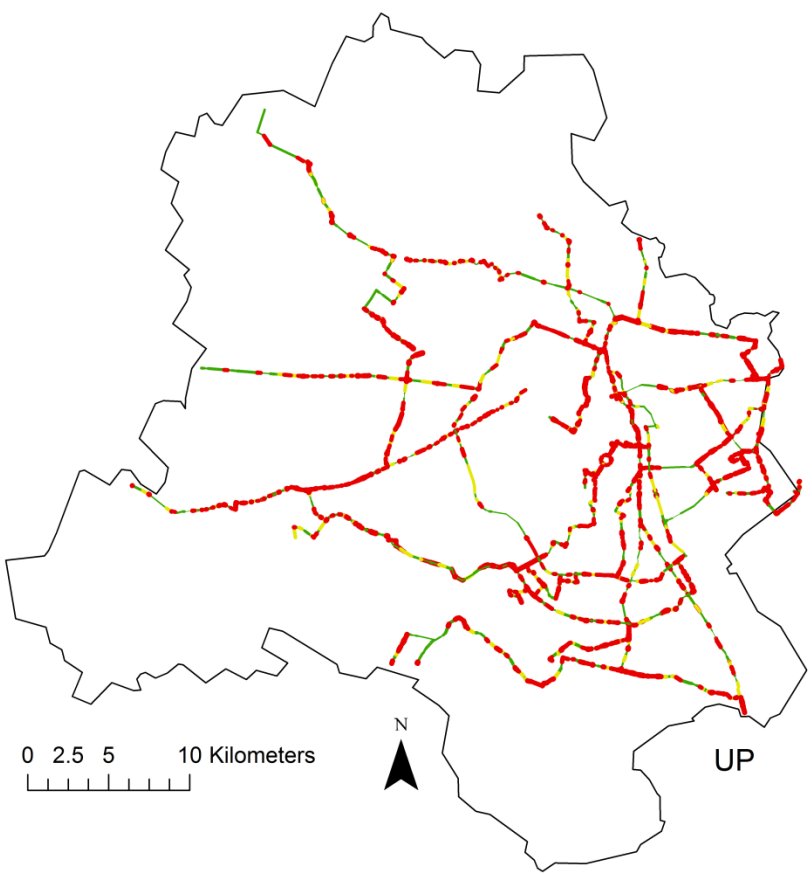
- Passenger demand
  - Passenger loads
  - Flow variation
  - Passenger exchange
- Trip variability
  - Additional travel time for passengers
  - Reliability buffer time

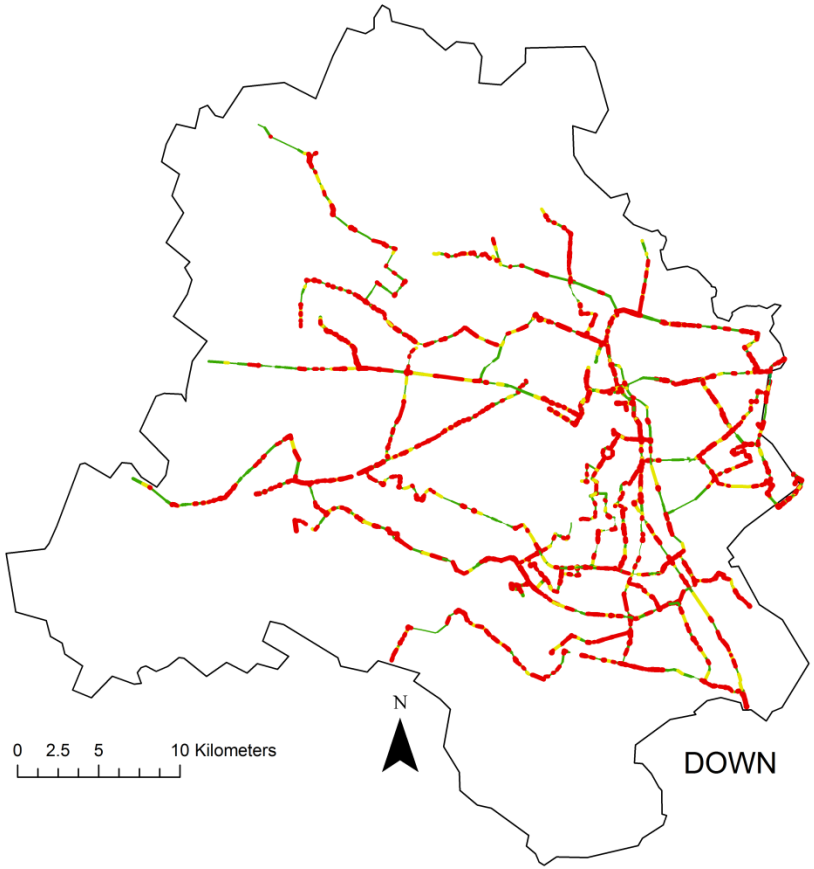
Sample Routes (25) – 1 Month Data



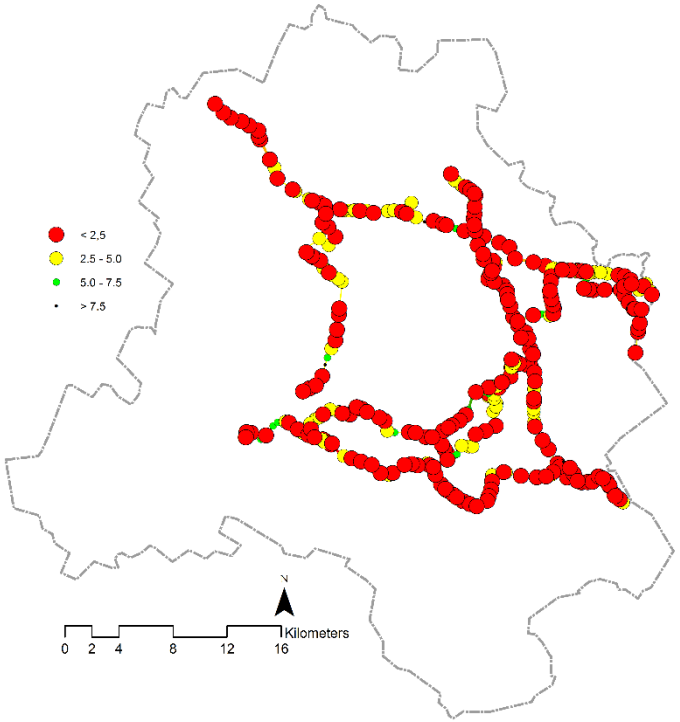
- Ideally high frequency routes should be classified as less than 6 mins
- However, almost no routes in Delhi have frequency less than 10 mins (thus selected as criterion for classification)

Comparative Up and Down Speed Profiles

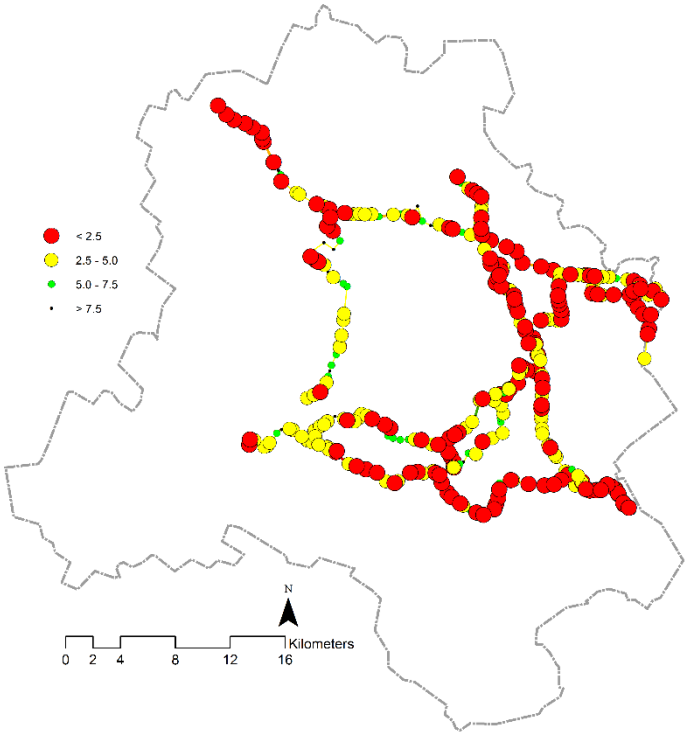




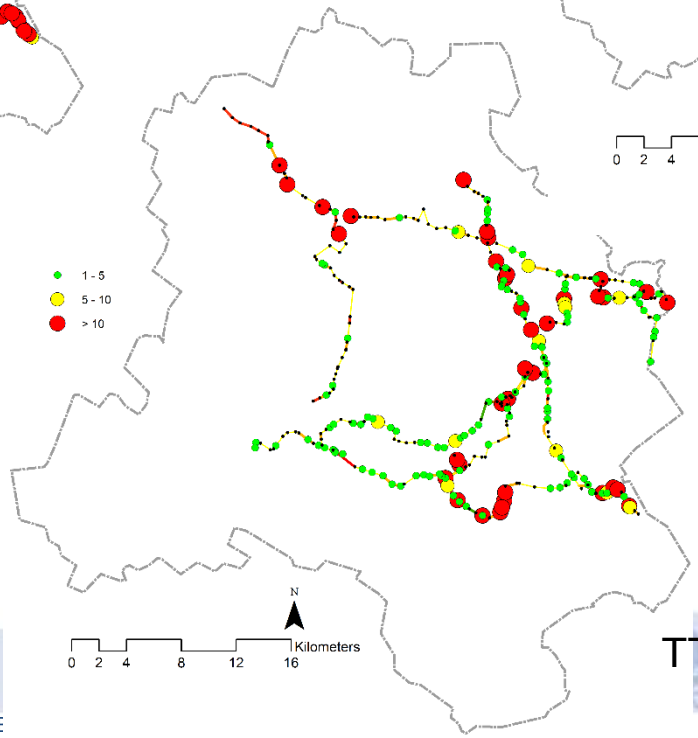
Indicators



Inverse of SD

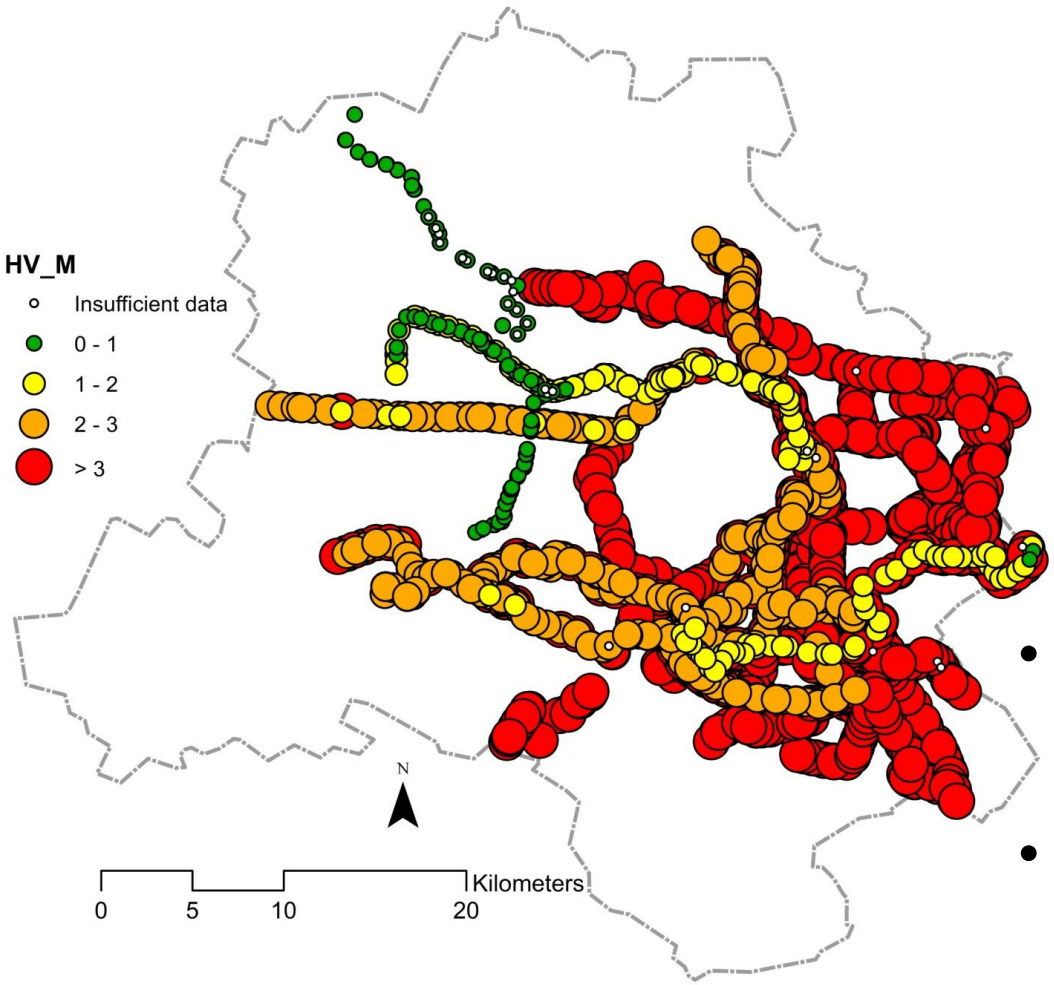


Inverse of CV



TTV

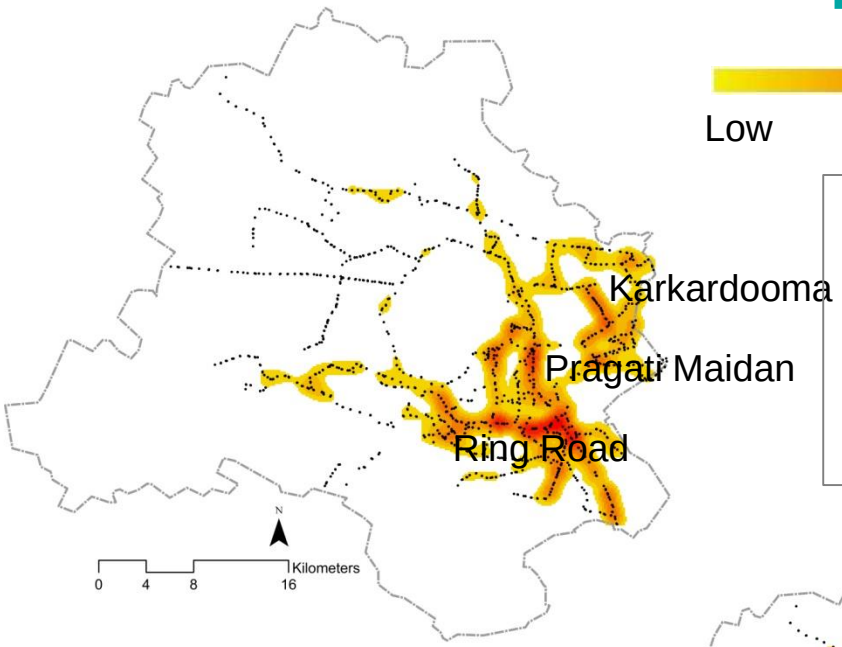
Headway variability (HV)



HV	% of stops (morning peak)	% of stops (off peak)	% of stops (evening peak)
Insuff. data	1.3	0.6	1.2
0 - 1	5.1	5.2	0.4
1 - 2	6.4	4.3	3.3
2 - 3	19.4	8.2	4.8
> 3	67.9	81.9	90.3

- Long length–low freq routes have most stops with lowest HV
- **Short routes** have most stops with highest HV – need to be monitored

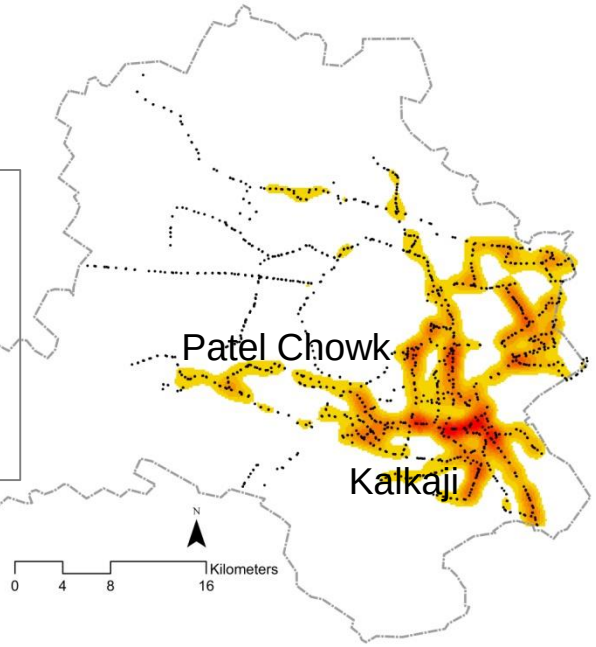
Headway variability (HV)
Heat Map Analysis



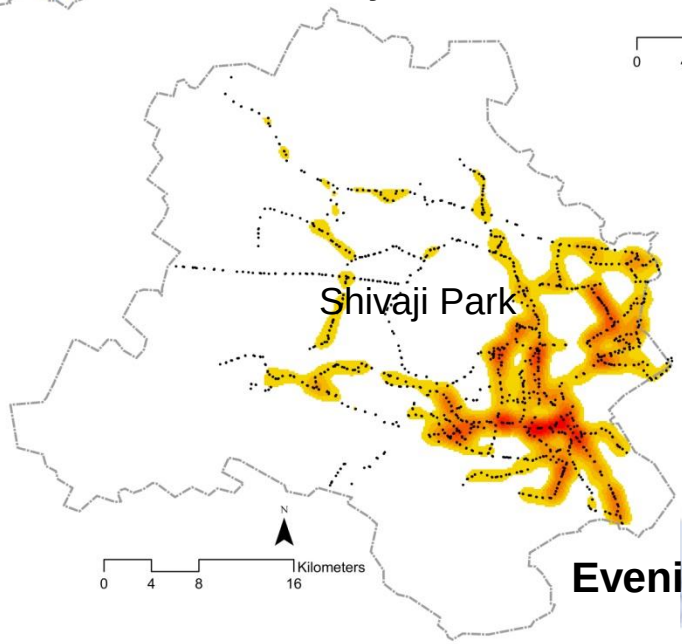
Morning peak

Low High

- Stops on Ring Road and Kaarkardooma experience high HV all day



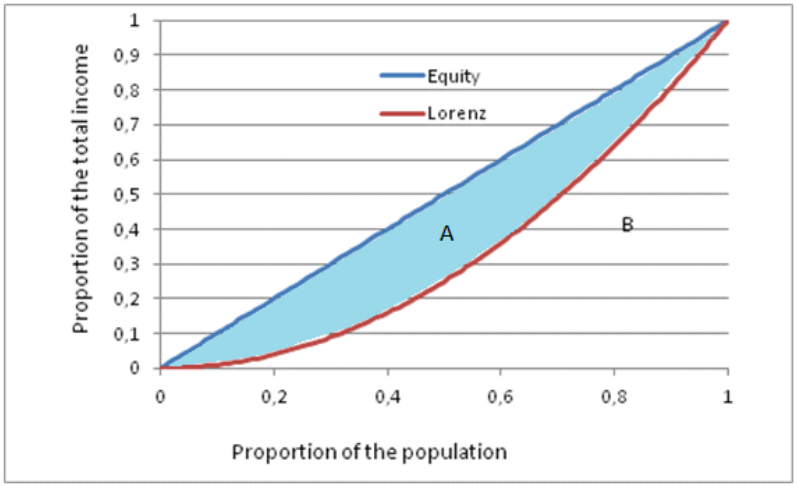
Off-peak



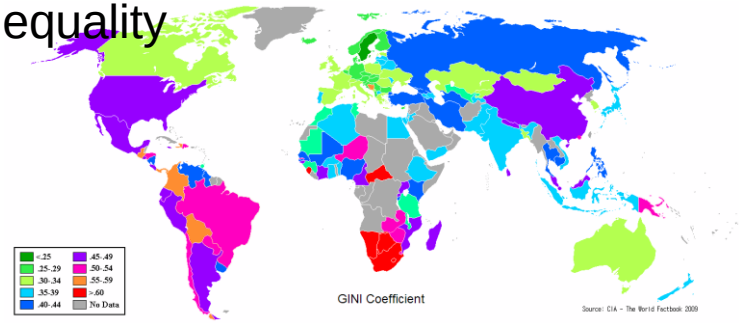
Evening peak

Gini index and Lorenz Curve

A synthetic indicator of inequality used in economic studies mainly to measure the inequality of incomes and health among the population.



Exemple: National income equality



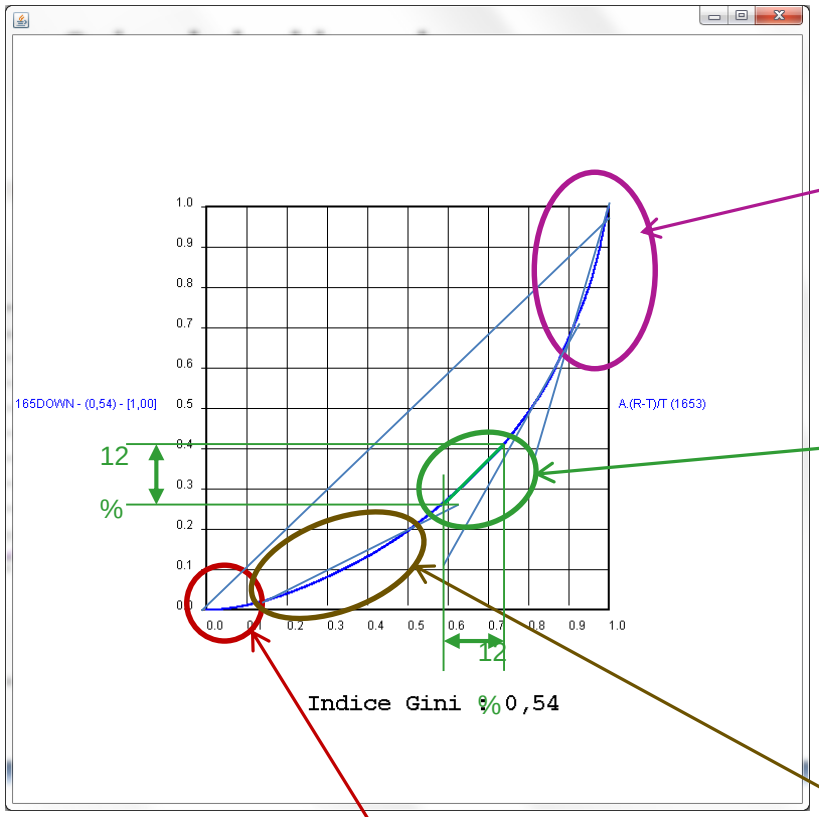
$$Gini = 2\int_0^1 L(X)dX$$

A Lorenz curve plots the cumulative percentages of total income (wealth, ..) received against the cumulative percentage of the population, starting with the poorest individual or household

Gini=0; perfect equality, Gini=1, One person has all the income …

$$Regularity = 1 - Gini = \frac{2\sum_{i=1}^{N}(h_i - H).i}{N^2.H}$$

Lorenz curve analysis

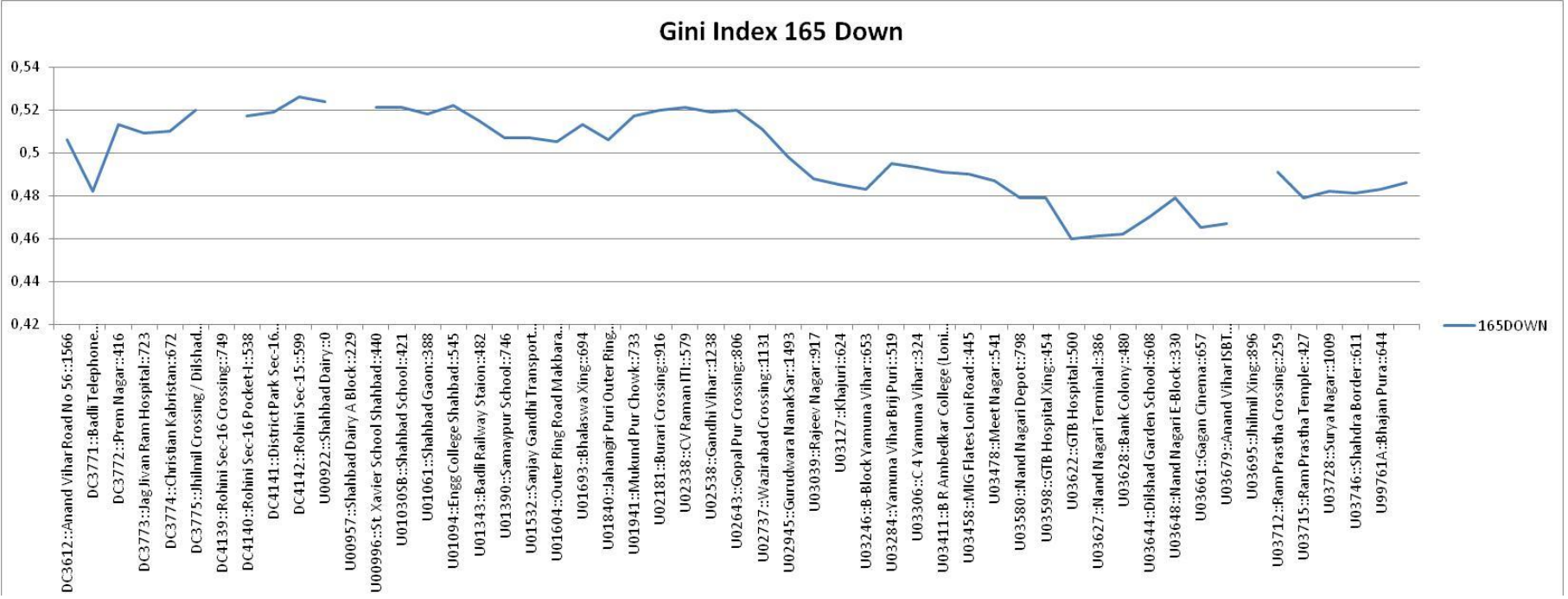


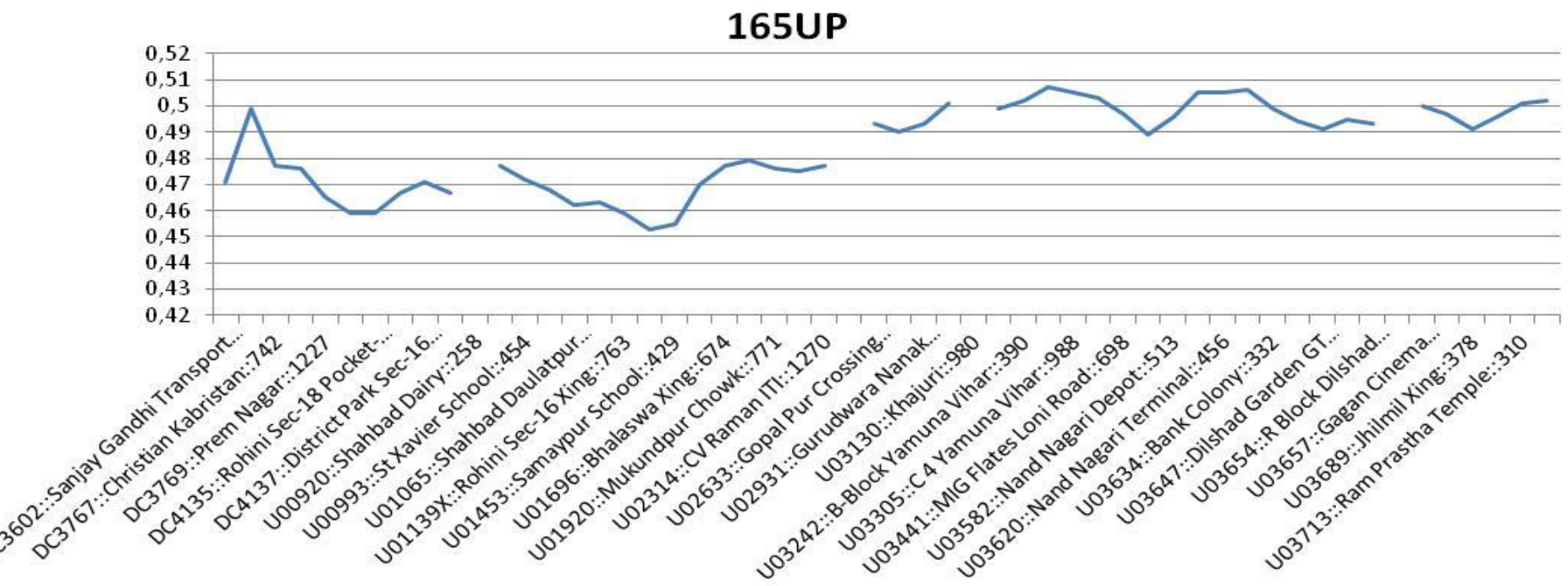
10% of intervals cumulate
30% of the sum of delays

12% of real headways are nearly equal to scheduled headways

40% of real intervals are shorter than scheduled ones

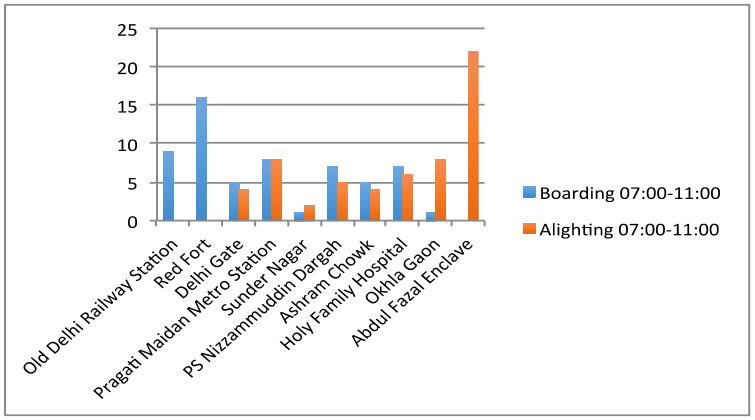
Bus bunching (Hreal/Hscheduled = 0 ➔ Hreal=0)

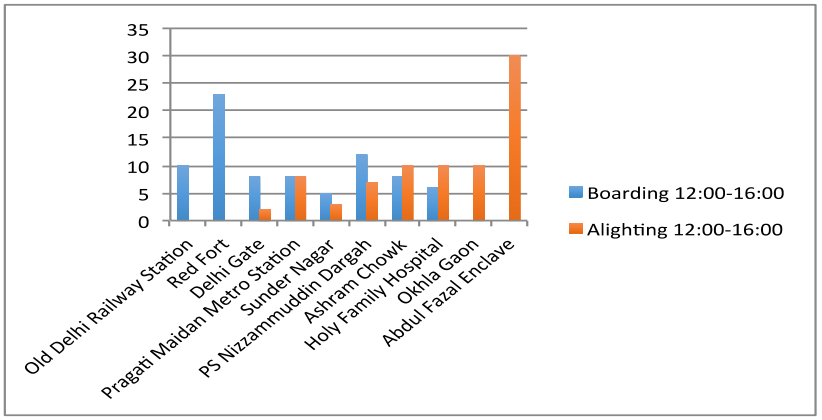

Gini Index 165 Down
0,54
0,52
0,5
0,48
0,46
0,44
0,42
165DOWN
DC3612::Anand Vihar Road No 56::1566
DC3771::Badli Telephone..
DC3772::Prem Nagar::416
DC3773::Jaglivan Ram Hospital::723
DC3774::Christian Kabristan::672
DC3775::Jhilmil Crossing / Dilshad..
DC4139::Rohini Sec-16 Crossing::749
DC4140::Rohini Sec-16 Pocket-I::538
DC4141::District Park Sec-16..
DC4142::Rohini Sec-15::599
U00922::Shahbad Dairy::0
U00957::Shahbad Dairy A Block::229
U00996::St Xavier School Shahbad::440
U01030SB::Shahbad School::421
U01061::Shahbad Gaon::388
U01094::Engg College Shahbad::545
U01343::Badli Railway Staion::482
U01390::Samaypur School::746
U01532::Sanjay Gandhi Transport..
U01604::Outer Ring Road Makbara..
U01693::Bhalaswa Xing::694
U01840::Jahangir Puri Outer Ring..
U01941::Mukund Pur Chowk::733
U02181::Burari Crossing::916
U02338::CV Raman ITI::579
U02538::Gandhi Vihar::1238
U02643::Gopal Pur Crossing::806
U02737::Wazirabad Crossing::1131
U02945::Gurudwara NanakSar::1493
U03039::Rajeev Nagar::917
U03127::Khajuri::624
U03246::B-Block Yamuna Vihar::653
U03284::Yamuna Vihar Brij Puri::519
U03306::C 4 Yamuna Vihar::324
U03411::B R Ambedkar College (Loni..
U03458::MIG Flates Loni Road::445
U03478::Meet Nagar::541
U03580::Nand Nagari Depot::798
U03598::GTB Hospital Xing::454
U03622::GTB Hospital::500
U03627::Nand Nagari Terminal::386
U03628::Bank Colony::480
U03644::Dilshad Garden School::608
U03648::Nand Nagari E-Block::330
U03661::Gagan Cinema::657
U03679::Anand Vihar ISBT..
U03695::Jhilmil Xing::896
U03712::Ram Prastha Crossing::259
U03715::Ram Prastha Temple::427
U03728::Surya Nagar::1009
U03746::Shahdra Border::611
U99761A::Bhajan Pura::644

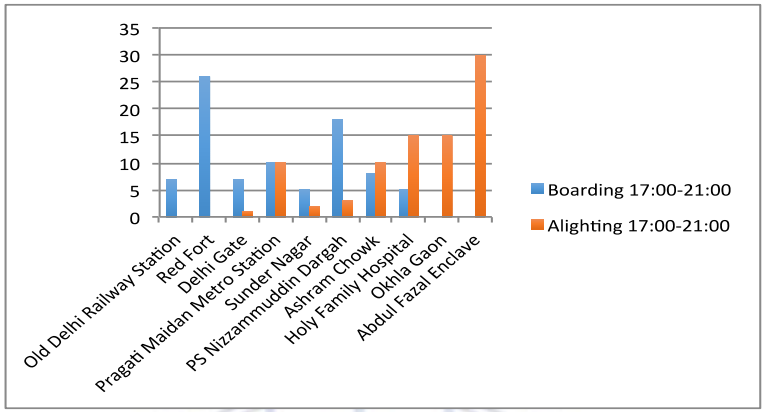

165UP
0,52
0,51
0,5
0,49
0,48
0,47
0,46
0,45
0,44
0,43
0,42
3602::Sanjay Gandhi Transport..
DC3767::Christian Kabristan::742
DC3769::Prem Nagar::1227
DC4135::Rohini Sec-18 Pocket-...
DC4137::District Park Sec-16...
U00920::Shahbad Dairy::258
U00993::St Xavier School::454
U01065::Shahbad Daulatpur...
U01139X::Rohini Sec-16 Xing::763
U01453::Samaypur School::429
U01696::Bhalaswa Xing::674
U01920::Mukundpur Chowk::771
U02314::CV Raman ITI::1270
U02633::Gopal Pur Crossing...
U02931::Gurudwara Nanak...
U03130::Khajuri::980
U03242::B-Block Yamuna Vihar::390
U03305::C 4 Yamuna Vihar::988
U03441::MIG Flates Loni Road::698
U03582::Nand Nagari Depot::513
U03620::Nand Nagari Terminal::456
U03634::Bank Colony::332
U03647::Dilshad Garden GT...
U03654::R Block Dilshad...
U03657::Gagan Cinema...
U03689::Jhilmil Xing::378
U03713::Ram Prastha Temple::310

PASSENGER INDICATORS

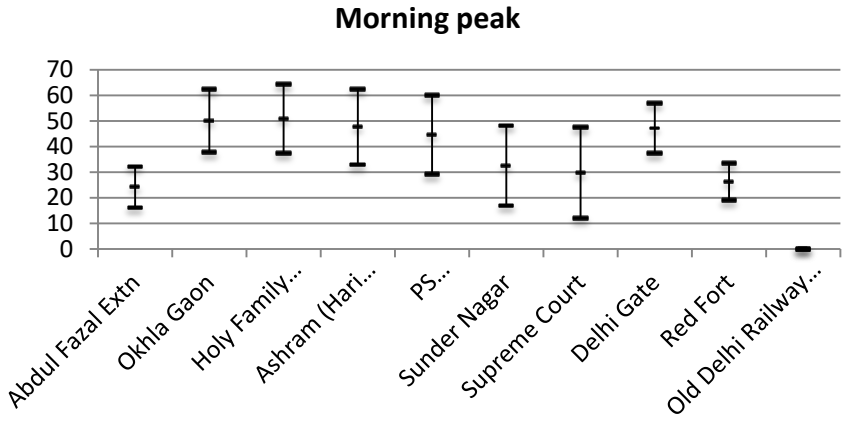
Boarding Alighting

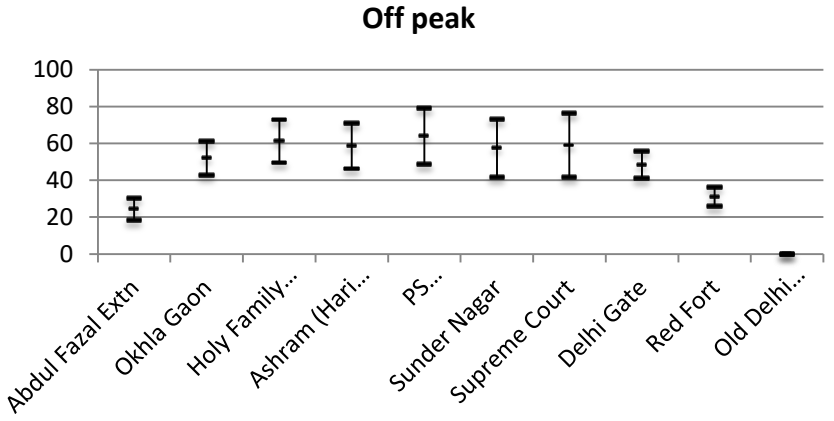


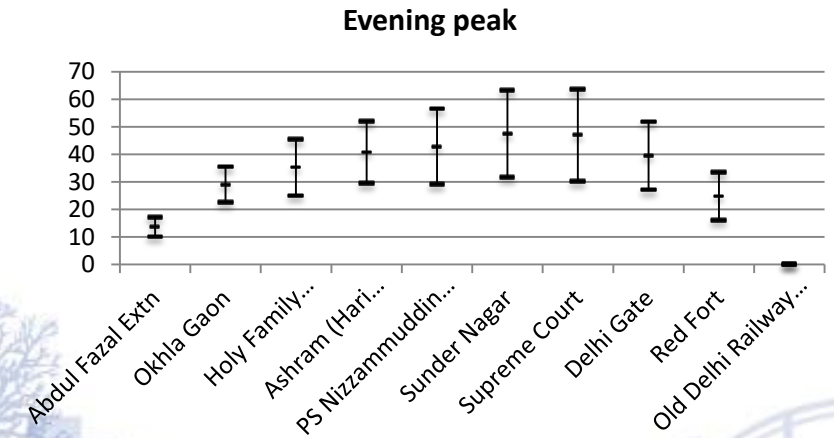




Passenger Load Indicators

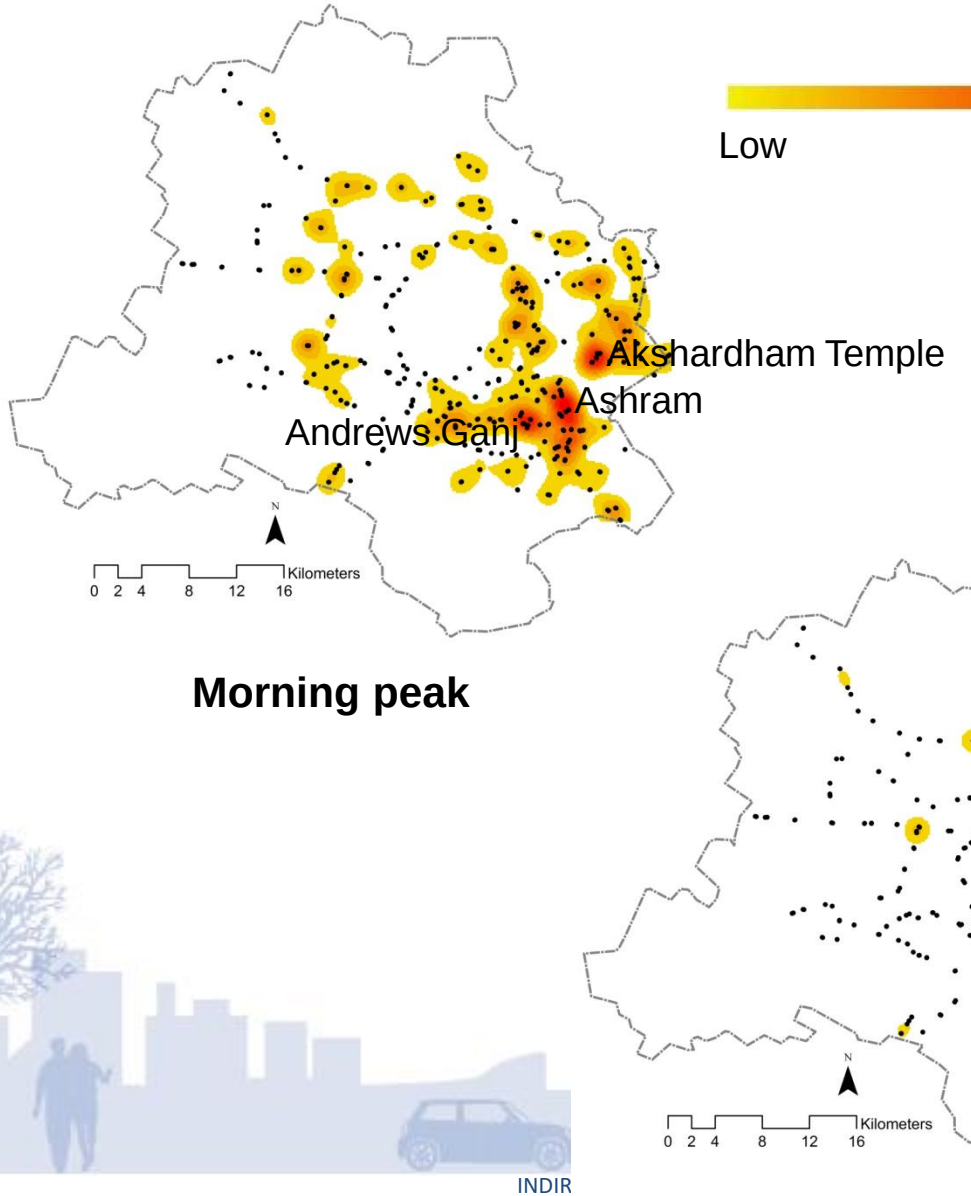




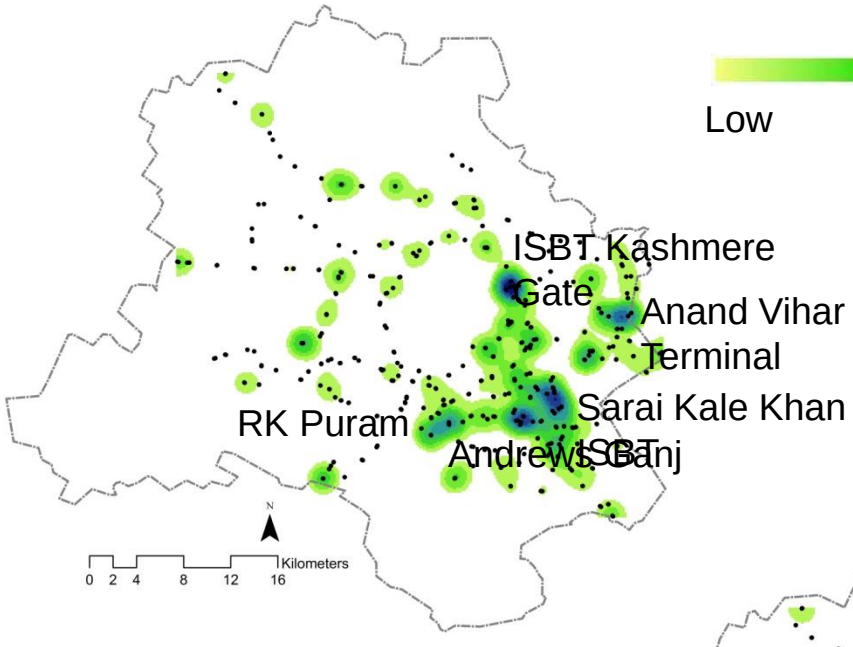


Passenger Variables	Morning	Off-peak	Evening
Average Passenger Volume, P_{avg}	44	55	39
Coefficient of flow variation, $\eta_f=P_{max}/P_{avg}$	1.144	1.285	1.413
Coefficient of passenger exchange, $\eta_x=B_L/(B_L-\Sigma\lvert b_i-a_i\rvert)$	1.019	1.031	1.023

Passenger boarding per bus

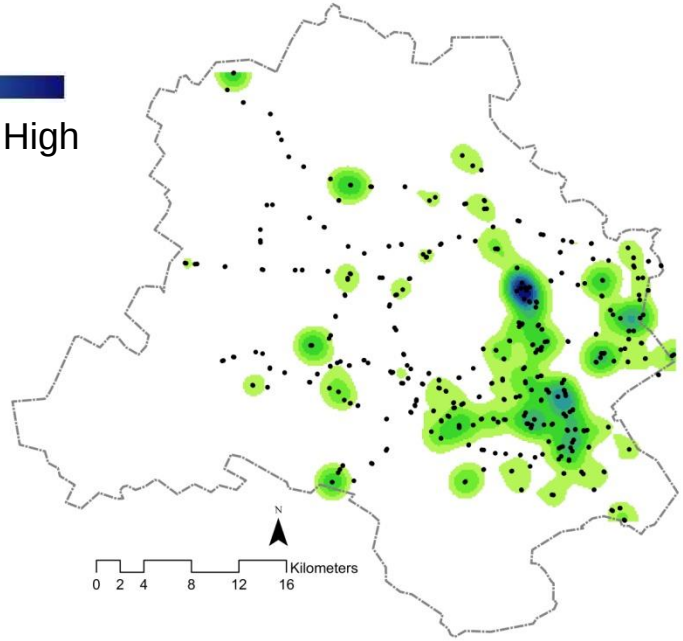


Passenger alighting per bus

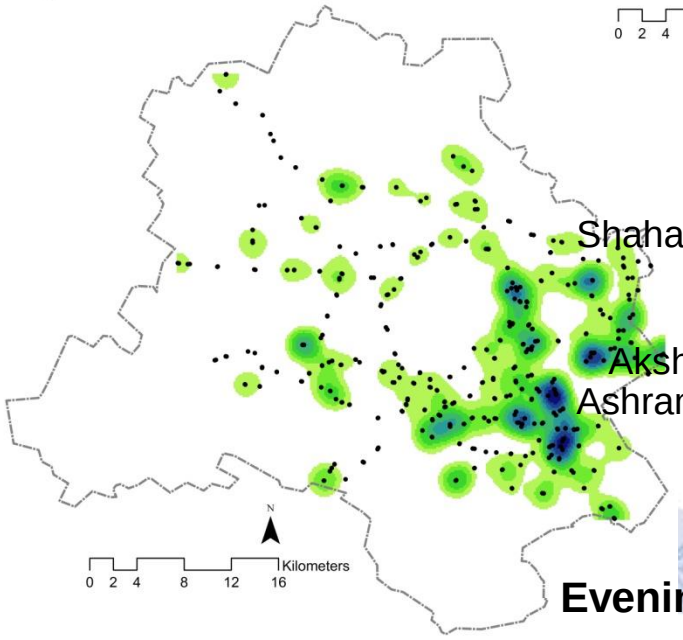


Low High

Morning peak

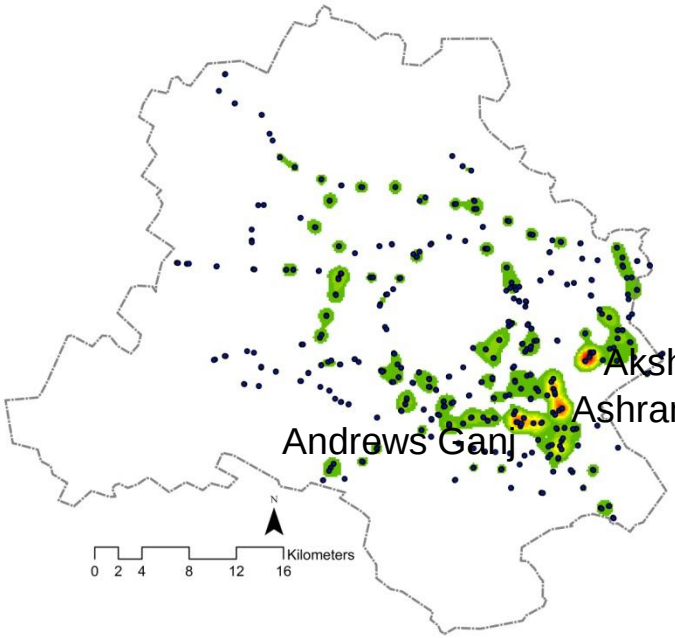


Off-peak



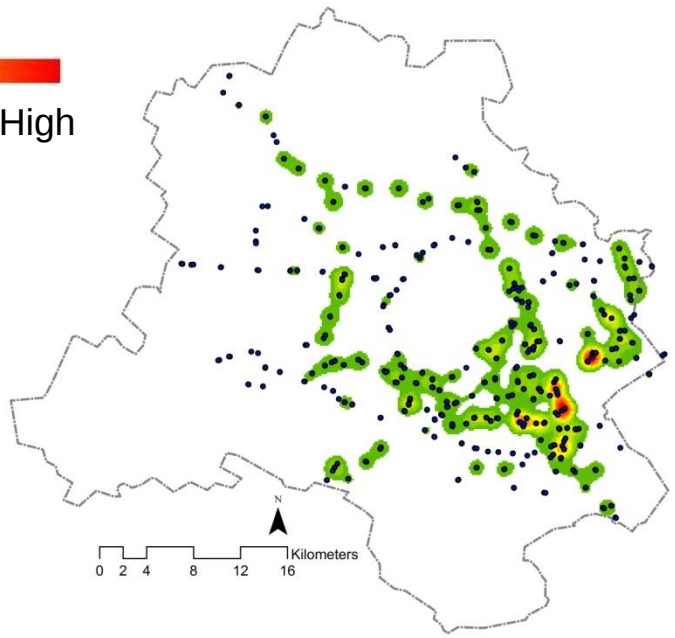
Evening peak

In-vehicle passengers per bus

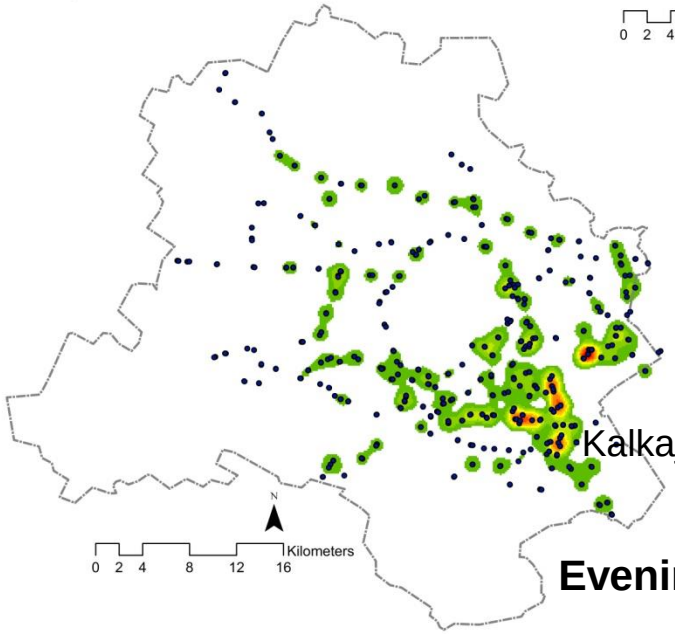


Morning peak

Low High



Off-peak



Evening peak

Global Efficiency Indicator for Resilience Measurement

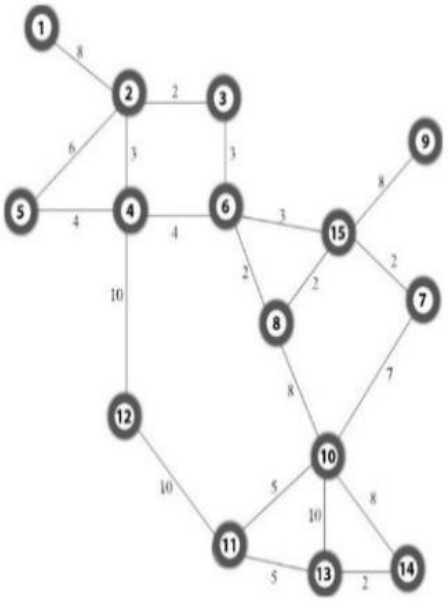
Robustness
Reliability
Recovery
Excess Capacity
Resourcefulness
Managing Index
Adaptability

Table 1. : Formulation of physcial and flow reliability indicators

Indicator	Formulation
OD reliability	$Rl^{od}(G,P) = \sum_{k=1}^{n} P(D_k)$
System reliability	$Rl^{sys.}(G,P) = \frac{1}{N(N-1)} \sum_{o=1}^{n} \sum_{d=1}^{n} Rl^{od}$
Nodal flow reliability	$F^{node}(G,P) = \sum_{d=1}^{n} W_{od} \times Rl^{od}$
Loss of system flow reliability	$L^{sys.}(G,P) = \sum_{o=1}^{n} \sum_{d=1}^{n} W_{od}(1 - Rl^{od})$
Node range flow reliability	$F^{node}_{range}(G,P) = \mid W_{od} \times Rl^{od}_{max} - W_{od} \times Rl^{od}_{min} \mid$
Node reliability range	$Rl^{node}_{range}(G,P) = \mid Rl^{od}_{max} - Rl^{od}_{min} \mid$

Assessment of System resilience – Sample Mandl Swiss Network

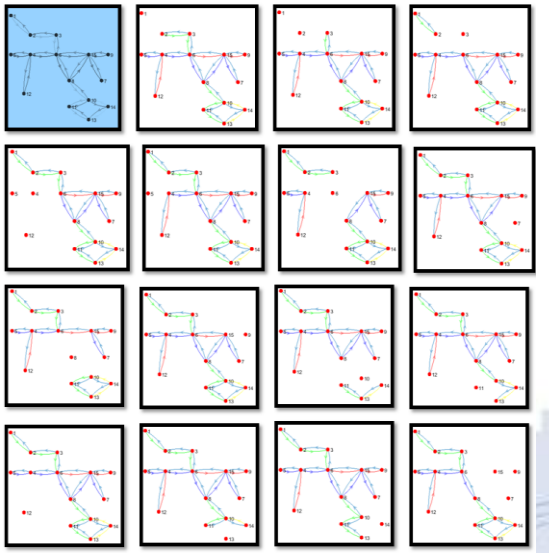
OD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	400	200	60	80	150	75	75	30	160	30	25	35	0	0
2	400	0	50	120	20	180	90	90	15	130	20	10	10	5	0
3	200	50	0	40	60	180	90	90	15	45	20	10	10	5	0
4	60	120	40	0	50	100	50	50	15	240	40	25	10	5	0
5	80	20	60	50	0	50	25	25	10	120	20	15	5	0	0
6	150	180	180	100	50	0	100	100	30	880	60	15	15	10	0
7	75	90	90	50	25	100	0	50	15	440	35	10	10	5	0
8	75	90	90	50	25	100	50	0	15	440	35	10	10	5	0
9	30	15	15	15	10	30	15	15	0	140	20	5	0	0	0
10	160	130	45	240	120	880	440	440	140	0	600	250	500	200	0
11	30	20	20	40	20	60	35	35	20	600	0	75	95	15	0
12	25	10	10	25	15	15	10	10	5	250	75	0	70	0	0
13	35	10	10	10	5	15	10	10	0	500	95	70	0	45	0
14	0	5	5	5	0	10	5	5	0	200	15	0	45	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



15 nodes

21 links

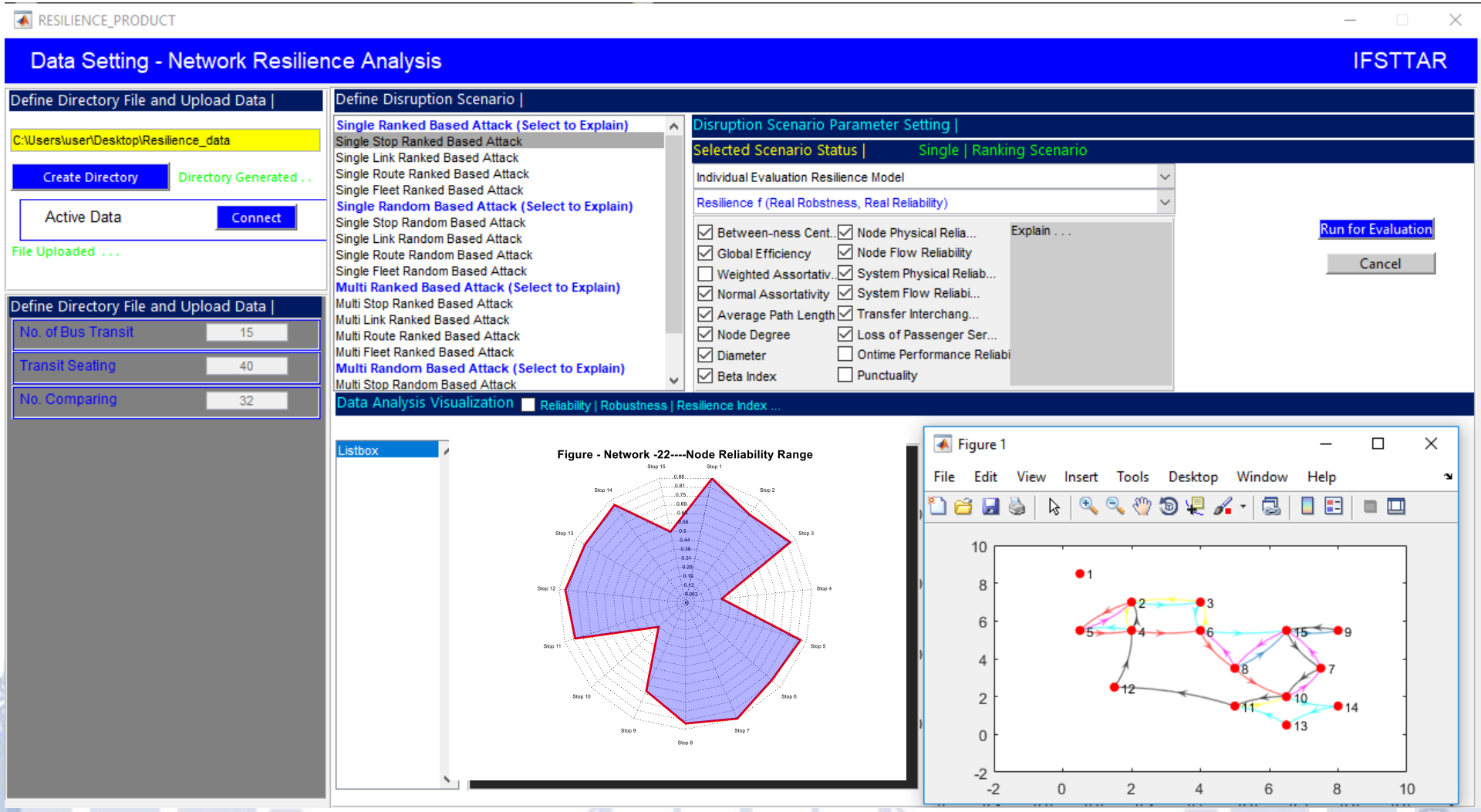
total demand of 15570 passenger trips as average number of bus passengers per hour for peak time

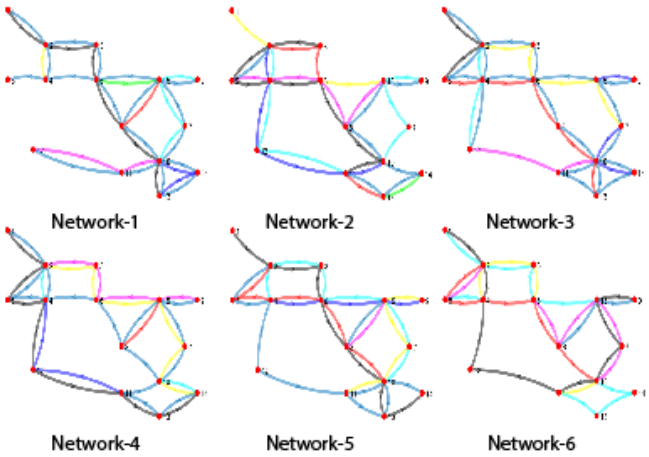


35 different Mandl Swiss Bus Networks

Node Disruption scenarios

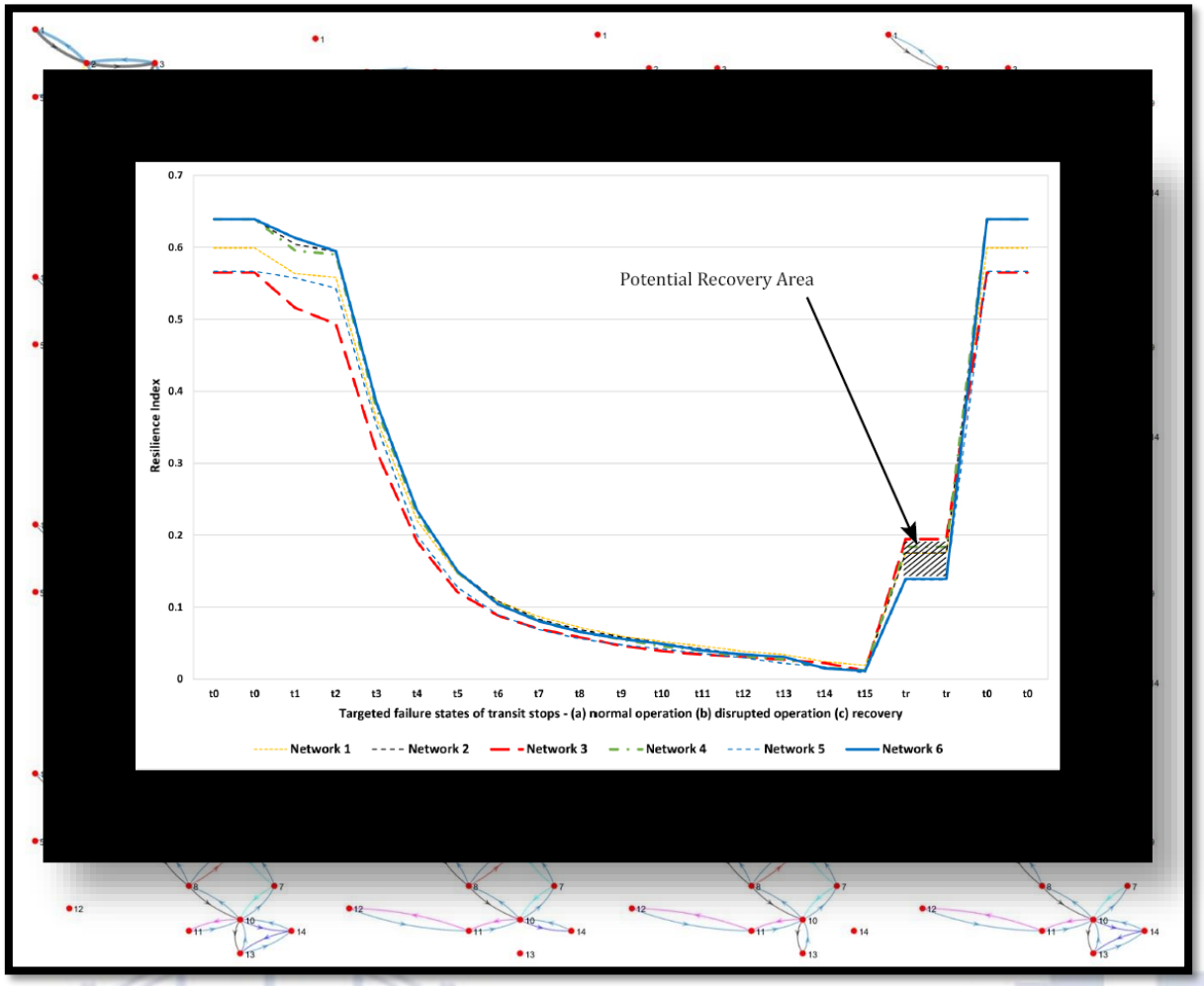
Example for network with 4 routes: 15 nodes


RESILIENCE_PRODUCT
Data Setting - Network Resilience Analysis
IFSTTAR
Define Directory File and Upload Data |
C:\Users\user\Desktop\Resilience_data
Create Directory
Directory Generated . .
Active Data
Connect
File Uploaded . . .
Define Directory File and Upload Data |
No. of Bus Transit
15
Transit Seating
40
No. Comparing
32
Define Disruption Scenario |
Single Ranked Based Attack (Select to Explain)
Single Stop Ranked Based Attack
Single Link Ranked Based Attack
Single Route Ranked Based Attack
Single Fleet Ranked Based Attack
Single Random Based Attack (Select to Explain)
Single Stop Random Based Attack
Single Link Random Based Attack
Single Route Random Based Attack
Single Fleet Random Based Attack
Multi Ranked Based Attack (Select to Explain)
Multi Stop Ranked Based Attack
Multi Link Ranked Based Attack
Multi Route Ranked Based Attack
Multi Fleet Ranked Based Attack
Multi Random Based Attack (Select to Explain)
Multi Stop Random Based Attack
Disruption Scenario Parameter Setting |
Selected Scenario Status |
Single | Ranking Scenario
Individual Evaluation Resilience Model
Resilience f (Real Robstness, Real Reliability)
Between-ness Cent..
Global Efficiency
Weighted Assortativ..
Normal Assortativity
Average Path Length
Node Degree
Diameter
Beta Index
Node Physical Relia...
Node Flow Reliability
System Physical Reliab...
System Flow Reliabi...
Transfer Interchang...
Loss of Passenger Ser...
Ontime Performance Reliabi
Punctuality
Explain . . .
Run for Evaluation
Cancel
Data Analysis Visualization
Reliability | Robustness | Resilience Index ...
Listbox
Figure - Network -22----Node Reliability Range
Figure 1
File Edit View Insert Tools Desktop Window Help

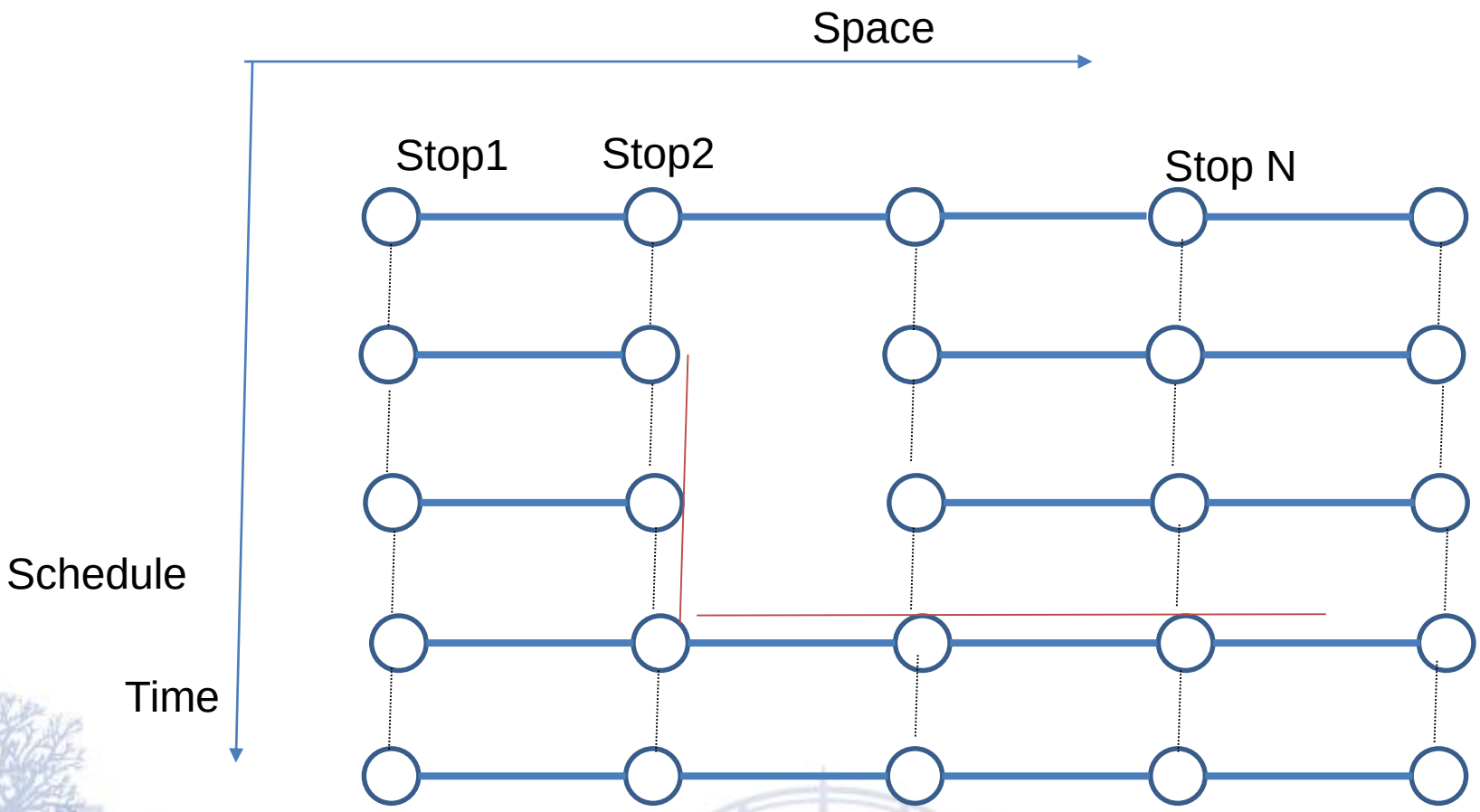


Disruption Scenario Modeling of Networks

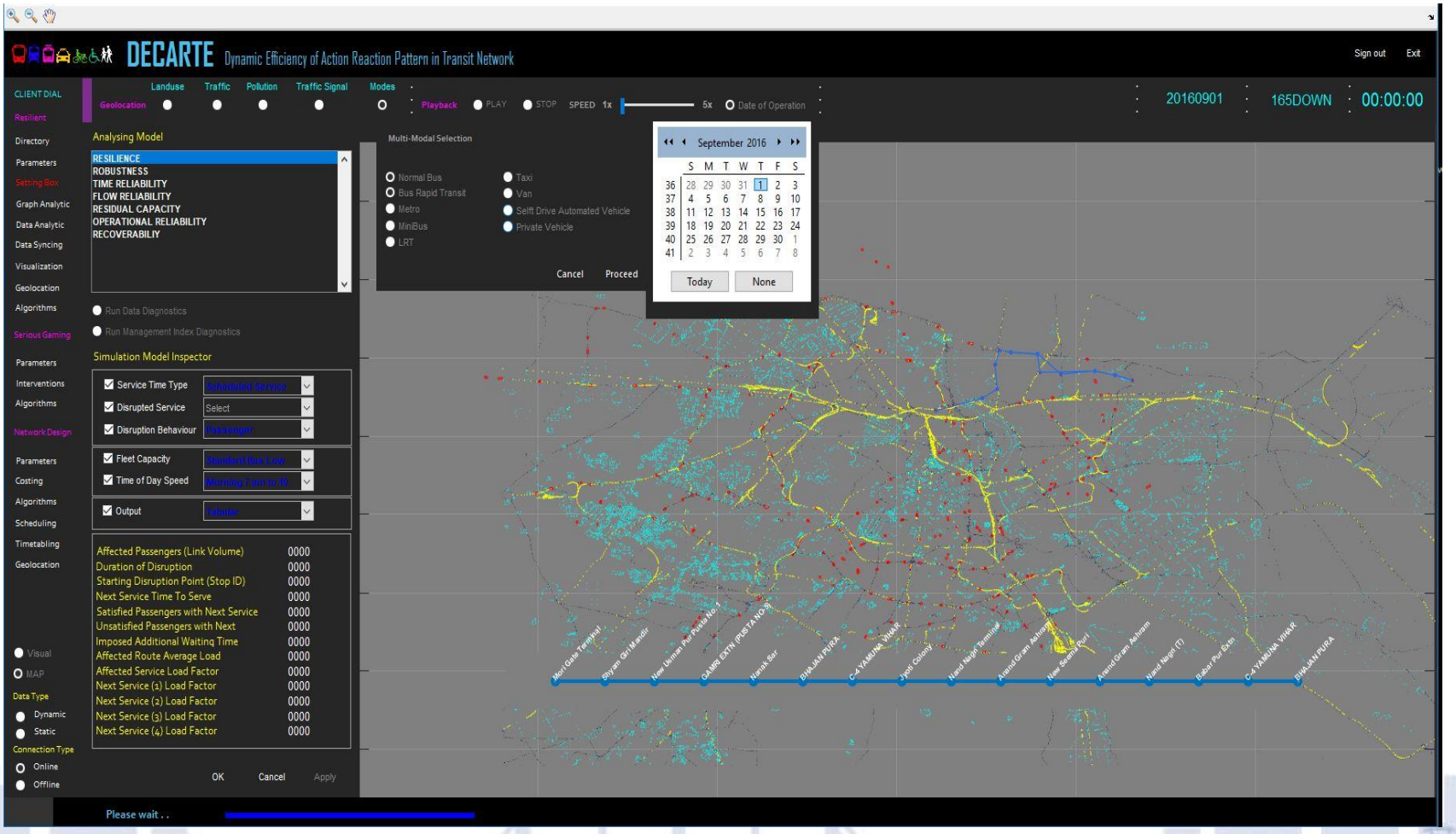
Transit Stop Disruption



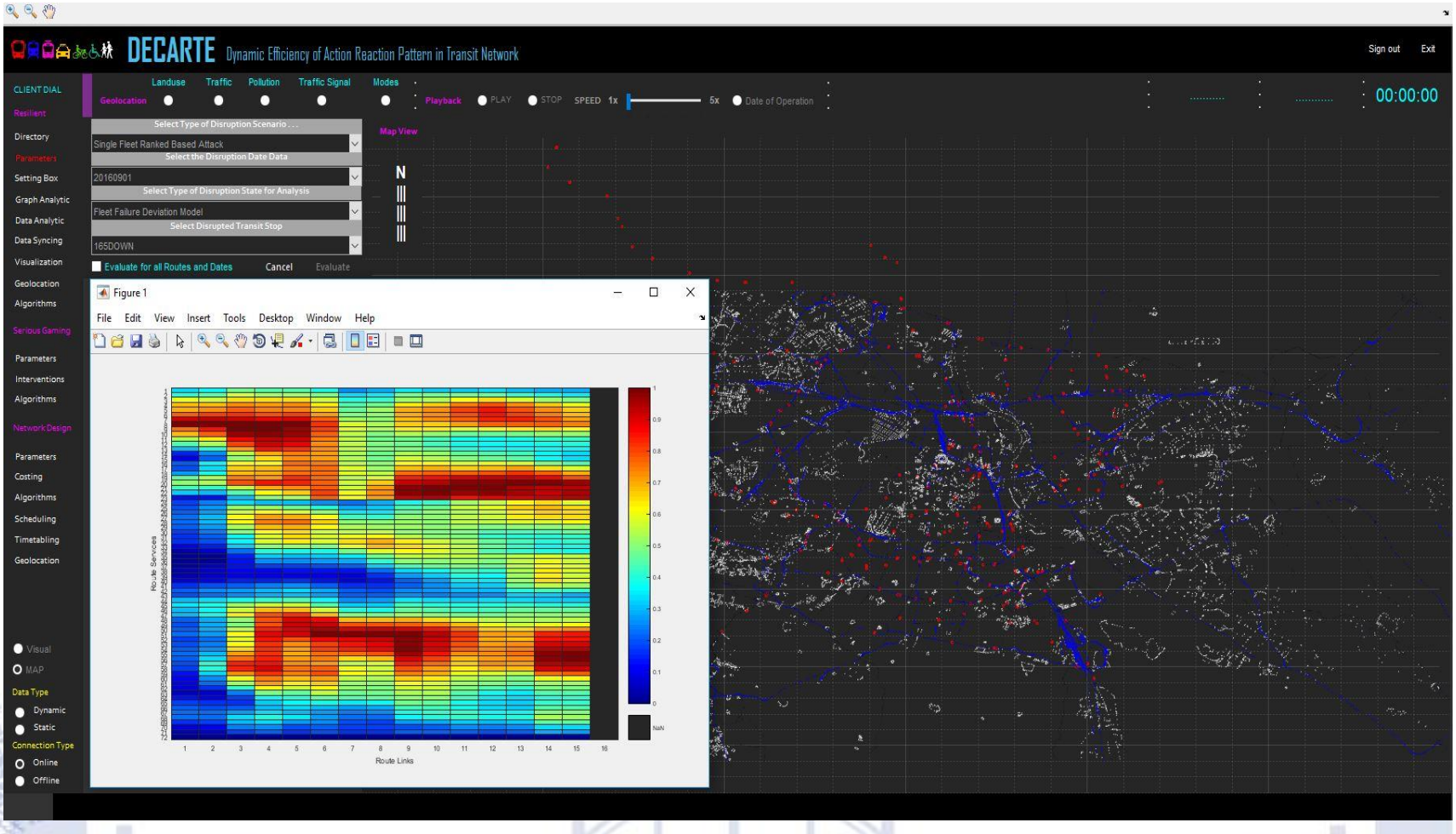
Dynamic Resilience



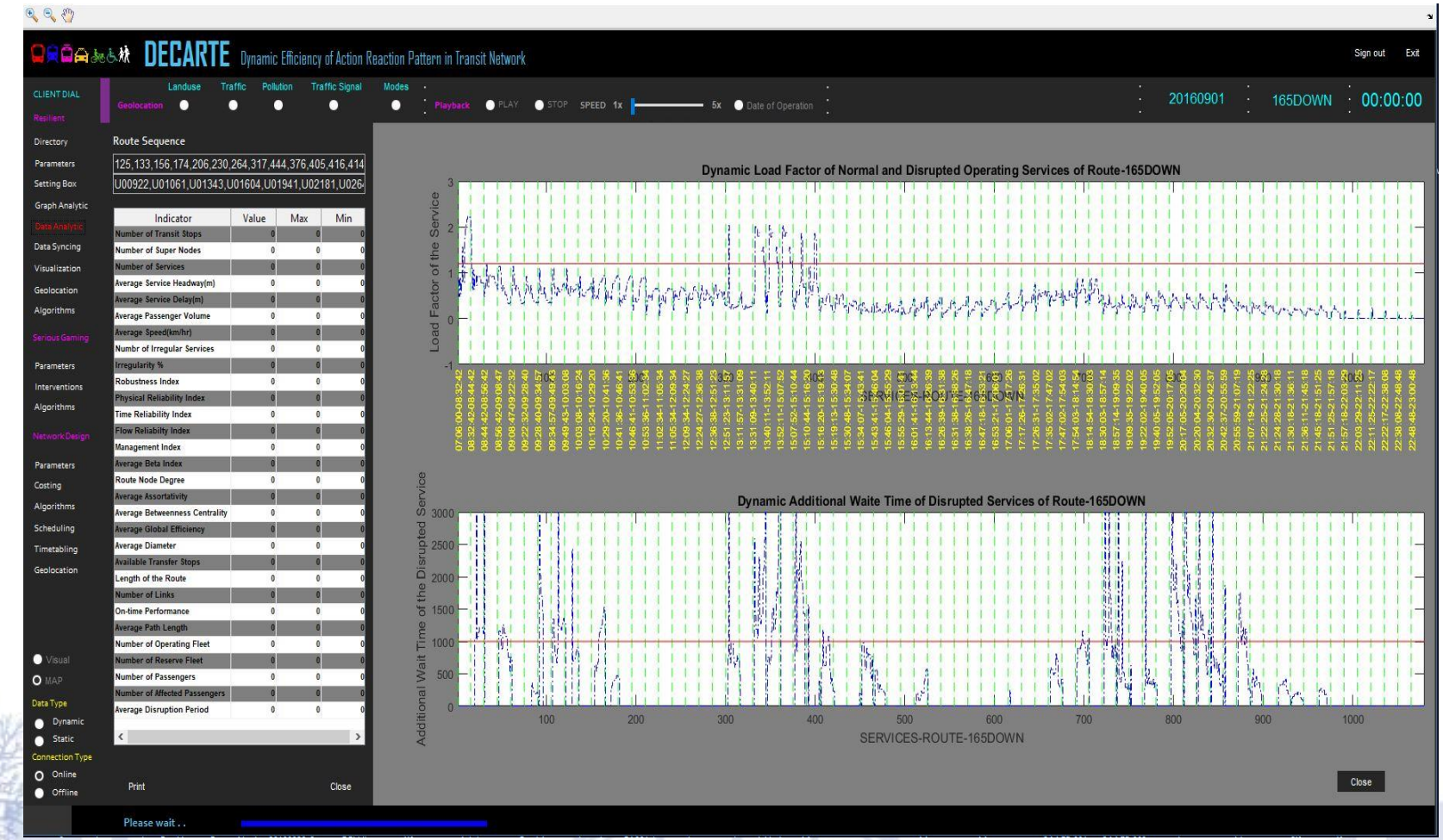
Résilience dynamique



Résilience dynamique



Résilience dynamique



Perspectives

Projet TIGA sur la mobilité intelligente de Rennes Métropole

Proposition de recherche sur la « Résilience du réseau multimodal »

Dépôt en Avril 2019.

Suite du projet INDIRA_B, projet franco-indien en construction

- partenaires académiques: IFSTTAR et IIT Delhi
- partenaires industriels **: DIMTS** et Bengalor ? RATP ? ???

- Recherche d'un partenaire industriel français !