OPERATION RESEARCH ON INDIAN RAILWAYS

IIT-IBM Operation Research Workshop

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INDIAN RAILWAYS

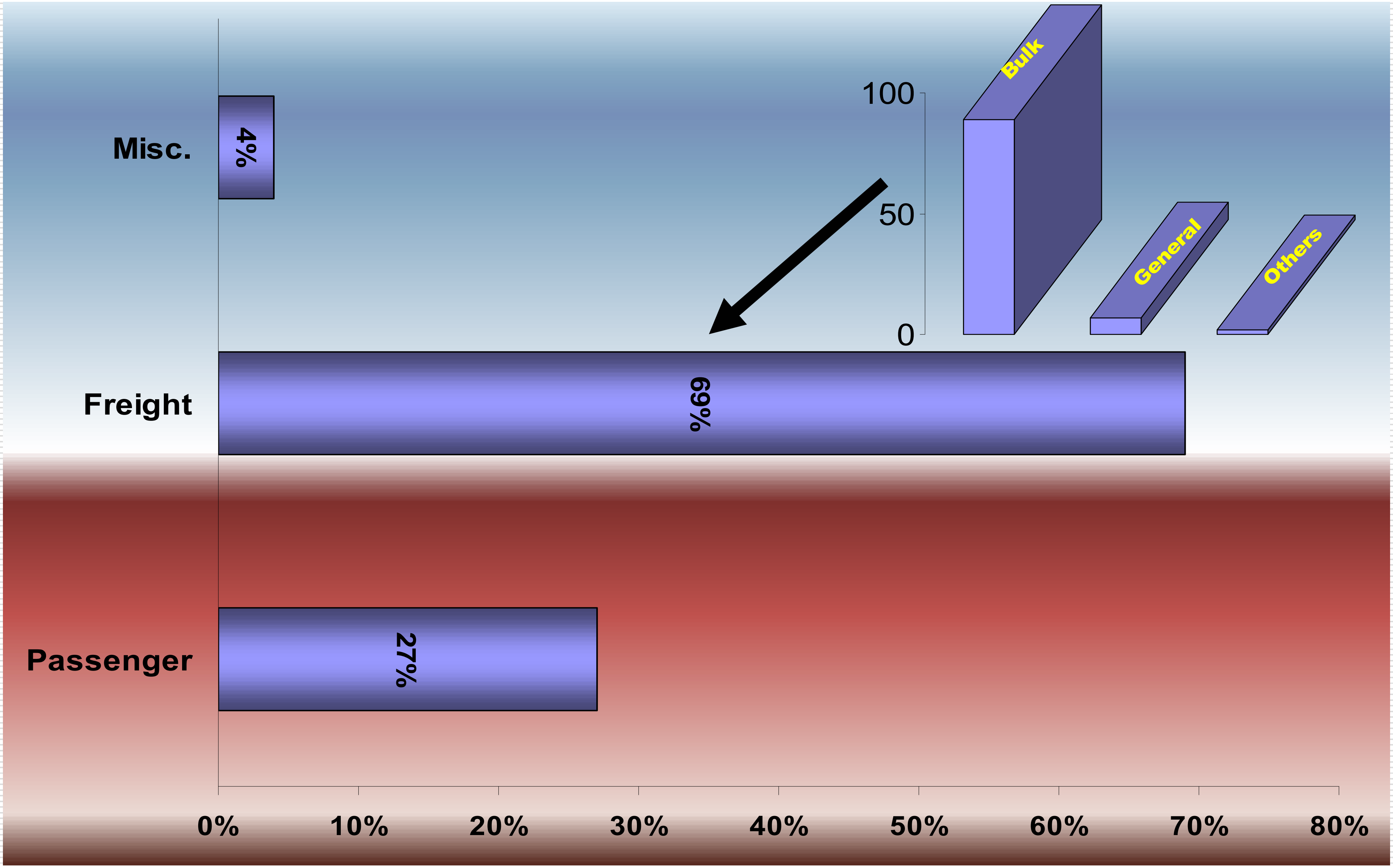
24*7*365 OPERATIONS

Indian Railways

- Largest Railroad under single Management
  - Revenue : US $ 12 Billion
  - Surplus : US $ 2 Billion
  - CAPEX : US $ 2 Billion
    - Planning for ten-fold increase by 2012
  - Traffic
    - Passengers : ~14 million /day
    - Freight : ~2 million tons/day
  - Manpower : 1.4 million

Indian Railways

(Breakup of Revenue)



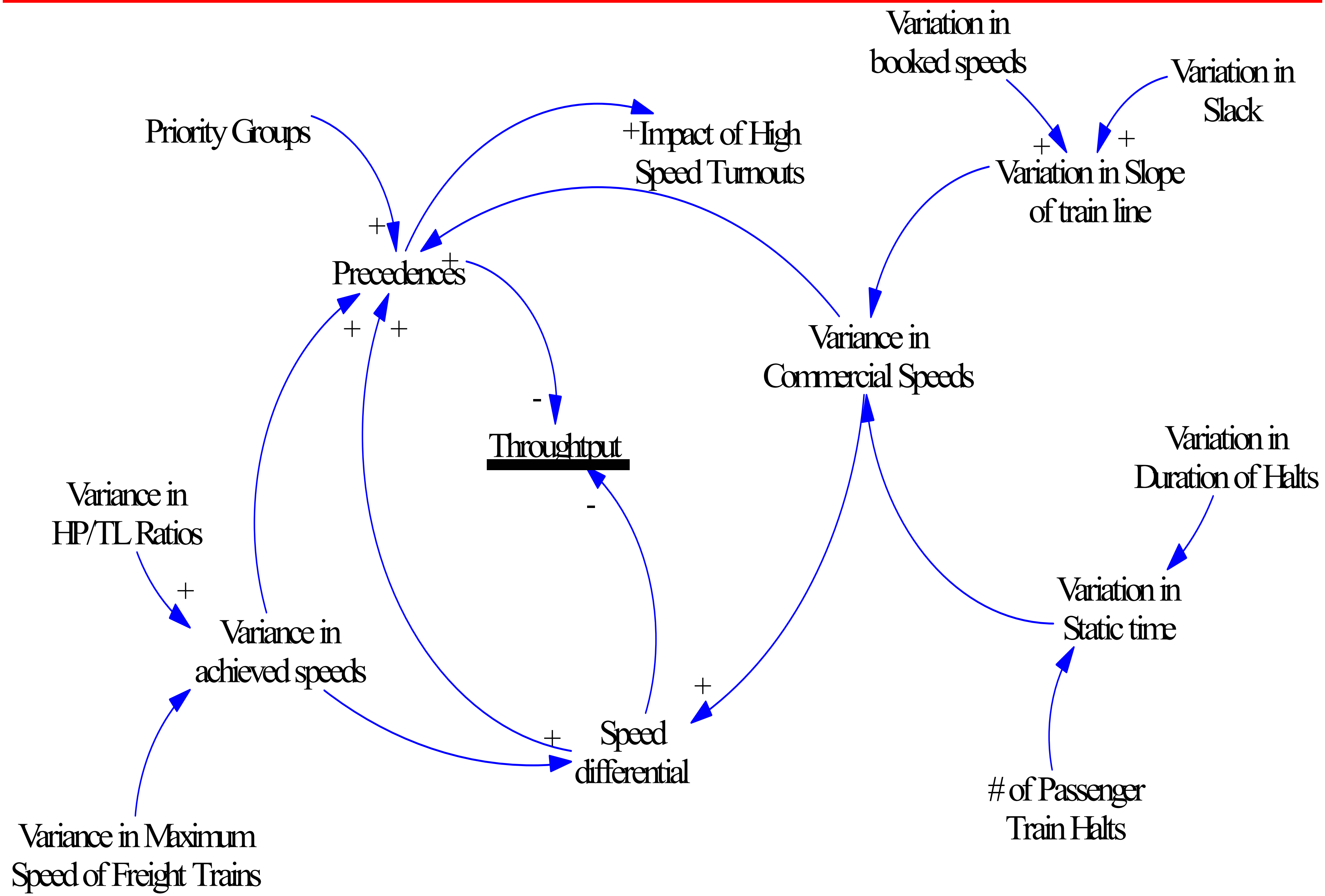
Infrastructure

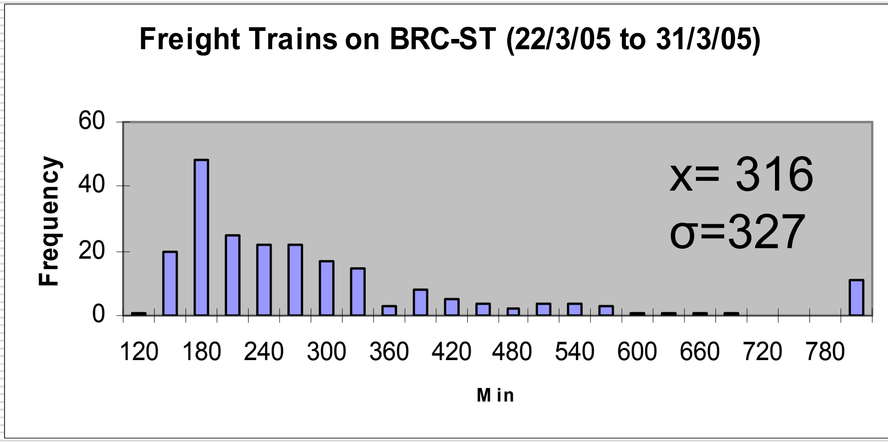
- Track : 63,000 km.
  - BG : 55,000 km.
- Traction
  - Electric : 14,000 km.
  - Diesel : 49,000 km.
- Signaling
  - At stations : 5 types
  - On sections : 6 types

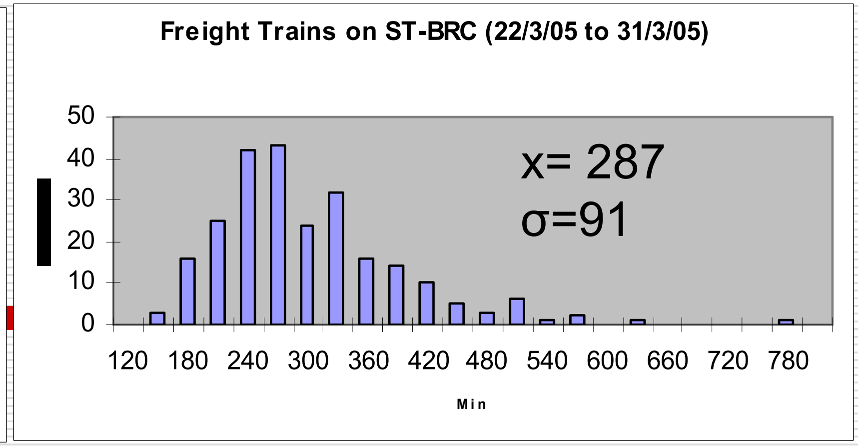
Indian Railways: Complexity

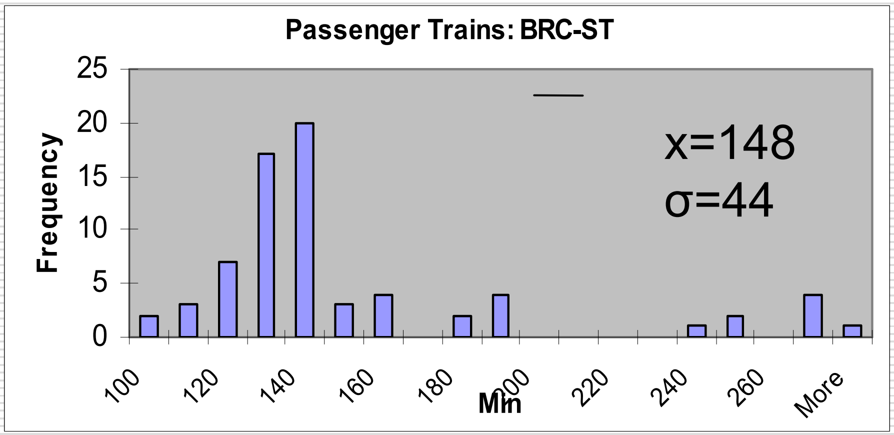
- Complexity of Organization
  - Divided into 16 Zones
  - Investment Planning has been bottoms-up
- Complexity of Investments
  - Investments merely shifts bottlenecks
- 24*7*365 Operations
  - Change is the only constant
  - Large # of Interdependencies
- Complexity of Operations
  - Diversity of Traffic / Operations
    - Mixed Operations

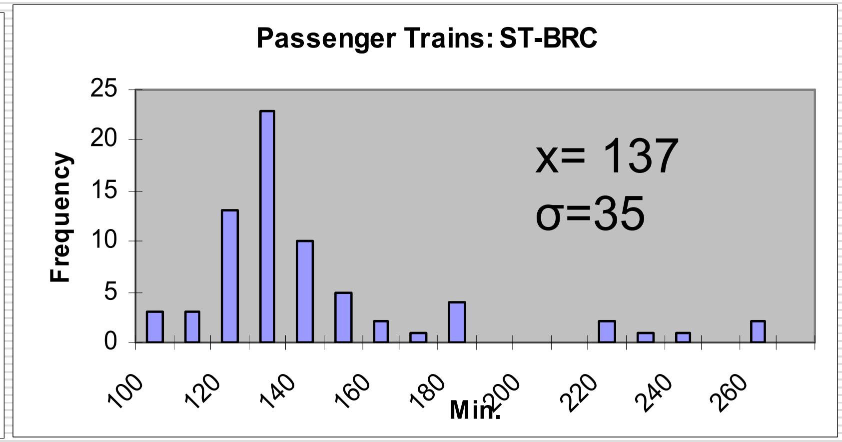
MICRO INTERDEPENDENCIES

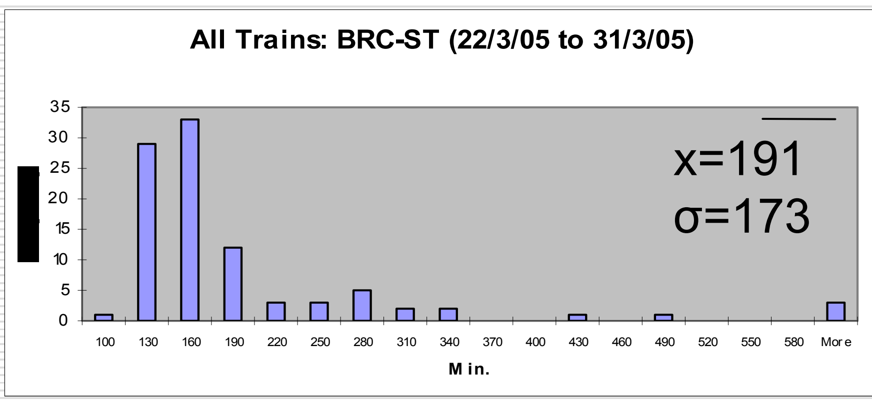


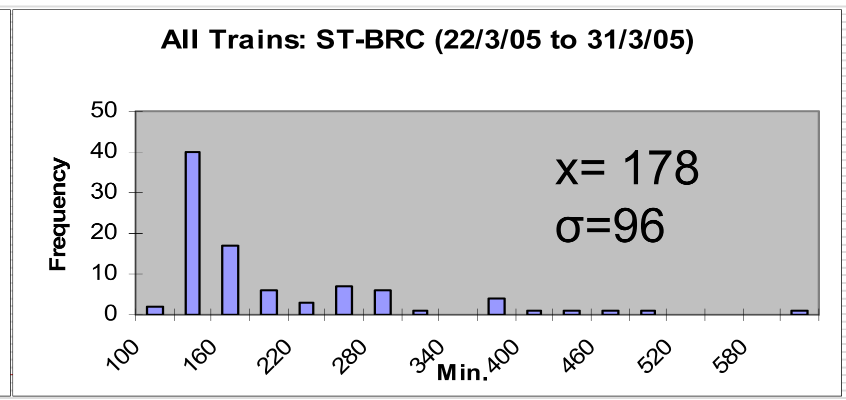

Freight Trains on BRC-ST (22/3/05 to 31/3/05)
Frequency
0
20
40
60
120 180 240 300 360 420 480 540 600 660 720 780
M in
x= 316
σ=327


Freight Trains on ST-BRC (22/3/05 to 31/3/05)
0
10
20
30
40
50
120 180 240 300 360 420 480 540 600 660 720 780
Min
x= 287
σ=91

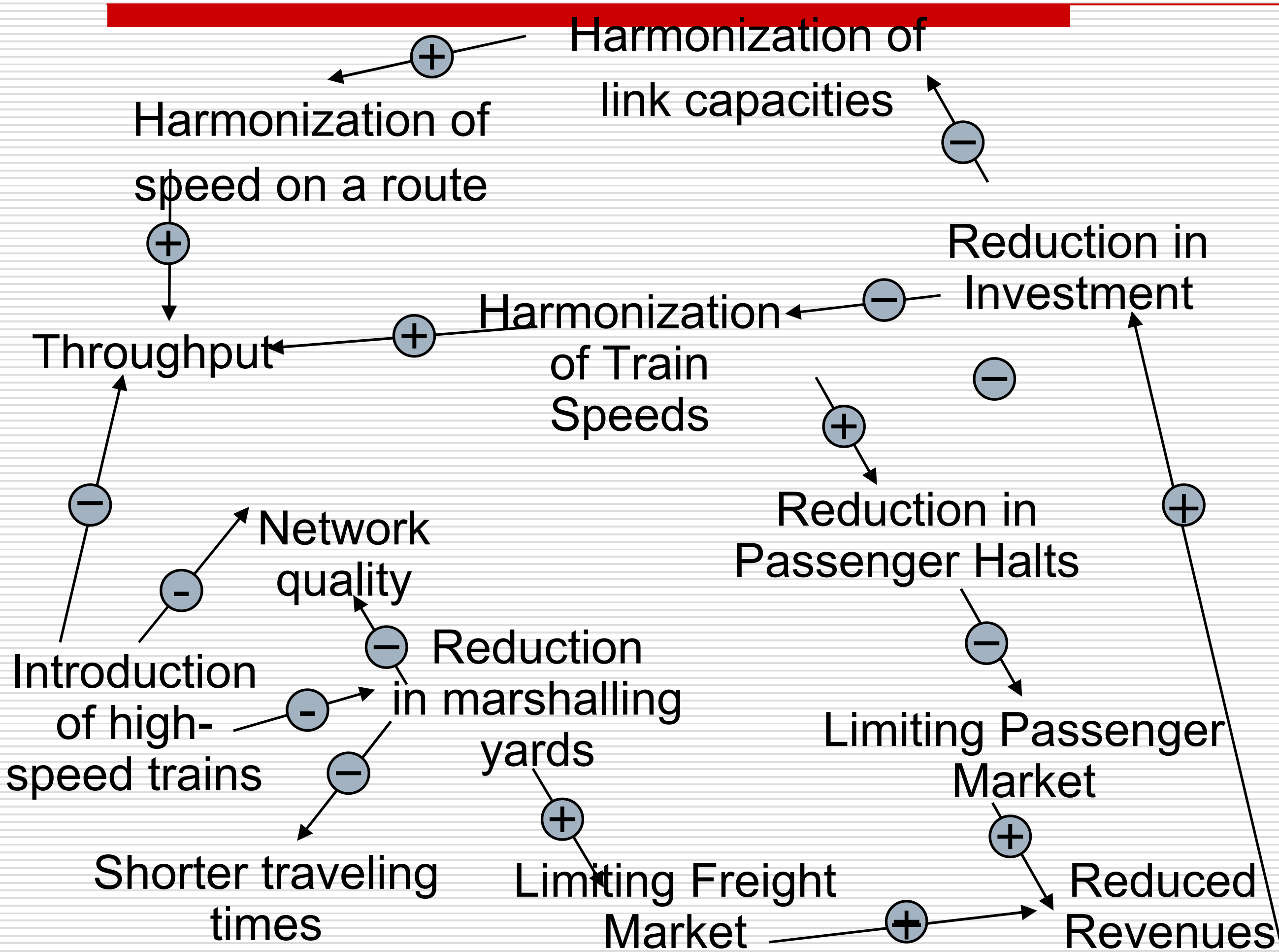

Passenger Trains: BRC-ST
Frequency
0
5
10
15
20
25
100 120 140 160 180 200 220 240 260 More
Min
x=148
σ=44


Passenger Trains: ST-BRC
Frequency
0
5
10
15
20
25
100 120 140 160 180 200 220 240 260
Min.
x= 137
σ=35


All Trains: BRC-ST (22/3/05 to 31/3/05)
0
5
10
15
20
25
30
35
100 130 160 190 220 250 280 310 340 370 400 430 460 490 520 550 580 More
M in.
x=191
σ=173


All Trains: ST-BRC (22/3/05 to 31/3/05)
Frequency
0
10
20
30
40
50
100 160 220 280 340 400 460 520 580
Min.
x= 178
σ=96

MACRO - INTERDEPENDENCIES



Solution:
Develop a model with three objectives

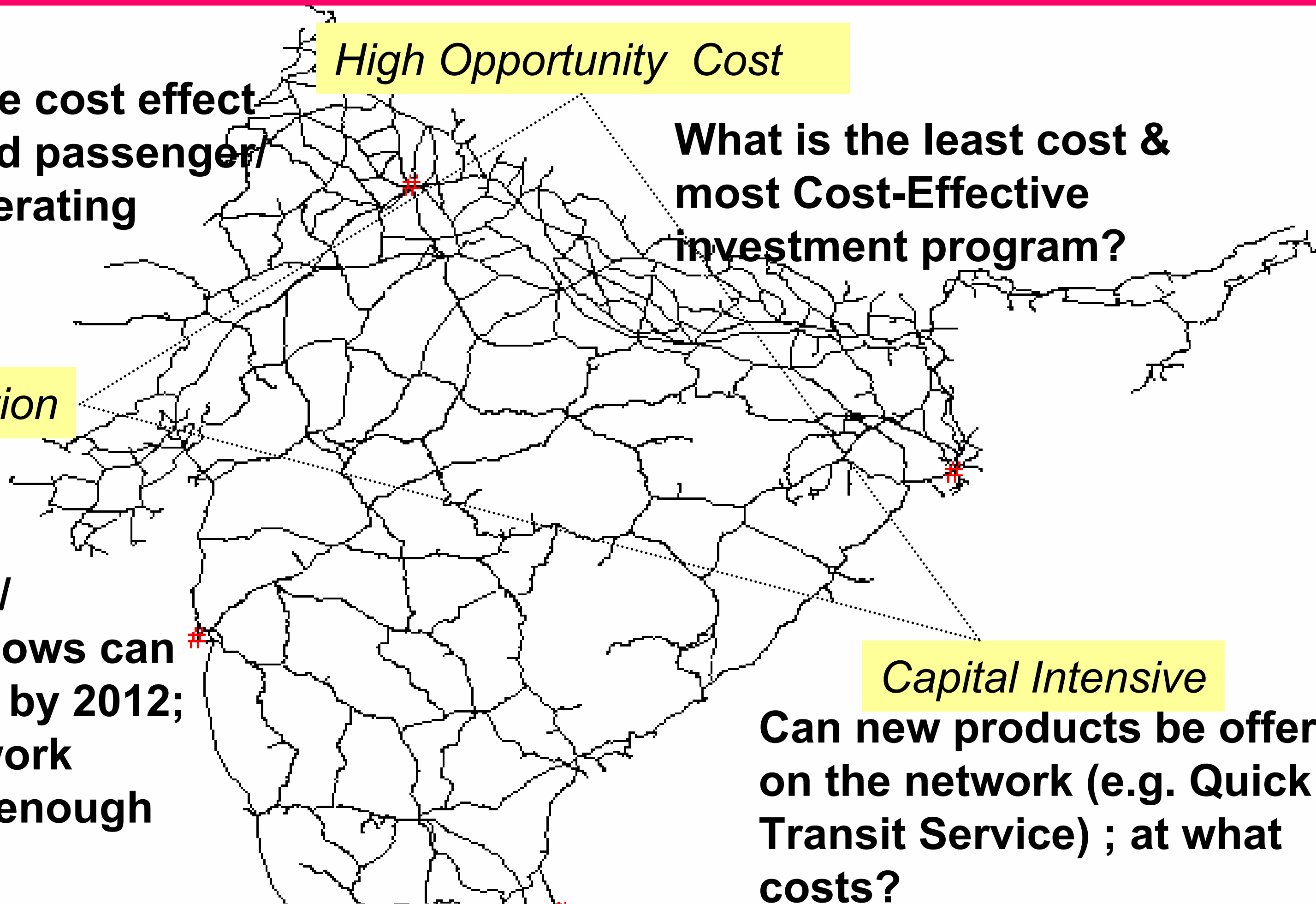
1. Model interdependencies
2. Take network effects into consideration
3. Assess bundle of measures in a uniform way

Source: McKinsey

Need to understand Interdependencies for Network Planning

What is the cost effect of changed passenger/ freight operating policies?

What is the least cost & most Cost-Effective investment program?



What freight/ passenger flows can be expected by 2012; will the network capacity be enough to cope?

Can new products be offered on the network (e.g. Quick Transit Service) ; at what costs?

LONG RANGE DECISION SUPPORT SYSTEM

SUITE OF TOOLS FOR STRATEGY PLANNING

Long Range Decision Support System (LRDSS)

- Public-Private Initiative
- Conceptualized in 1995
- Developed in 1998
- Expanded in 2003

- Powerful tool for pre-feasibility investment analysis for networks

LRDSS – Salient Features

- World-class in providing important desktop information for network planners and decision-makers for:
  - investment planning
  - financial impact analysis
  - market analysis
- Uses Information as an Enterprise Resource for Decision Support

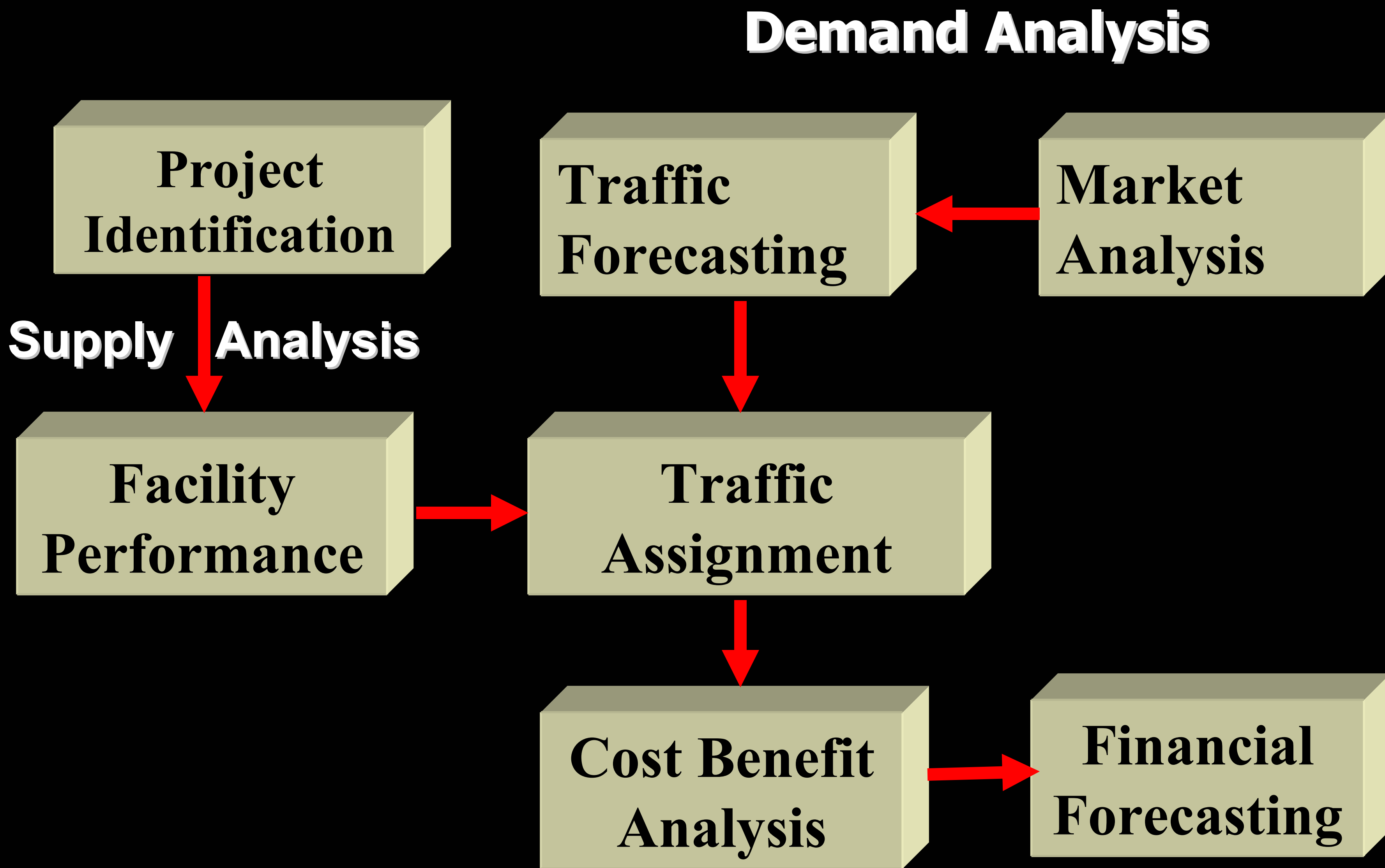
LRDSS : Salient Features

- **Integrative Character:**
  - Interdisciplinary
  - Network Oriented
  - System wide Analysis
- **Strong Decision Support**
  - "What-if" Analysis ("With/Without")
  - "Sensitivity" Analysis
  - Information based & Data Driven.
  - Iterative Evaluation
- **Modular Design**

LRDSS : Salient Features

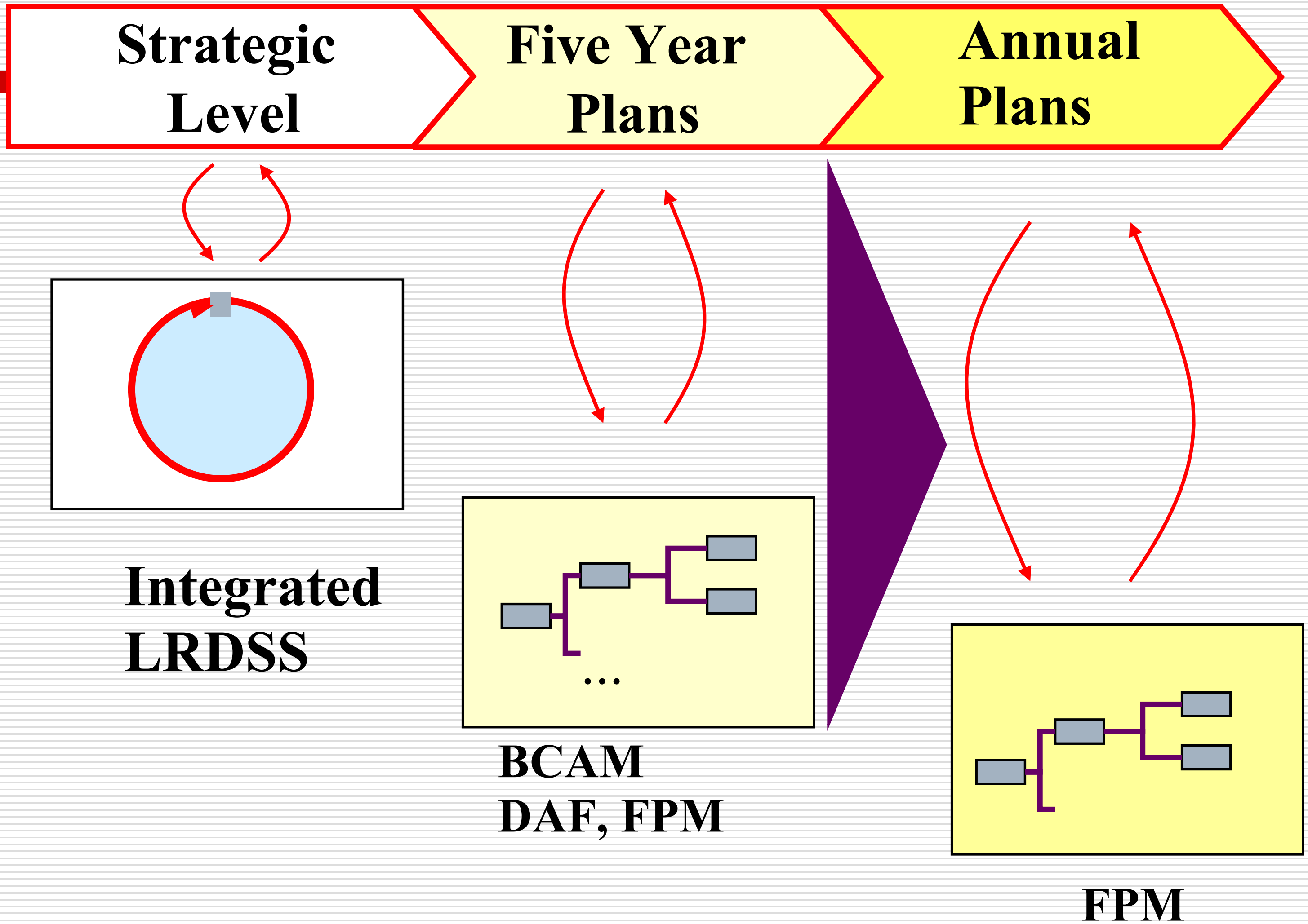
- **Customized GIS Interface**
  - Integration of different data by location
  - Evaluate alternative routes
  - Exhibit pattern of traffic flows
- **Strategic tool**
  - Prioritize Investments by key years
  - Position Services to optimize market share.
  - Analyze Funds required by key year

Broad Structure of LRDSS Model



LRDSS for Decision Support

PLANNING PROCESS



Models to support different time horizons

TRAFFIC ASSIGNMENT MODEL

TAM-Conceptual design

- Replicate Shipper’s Behavior
  - What commodity from where to where?
- Replicate Carriers Behavior
  - What commodity, what route, what train type
- Non Linear Programming Solver
  - MINOS

TRAFFIC ASSIGNMENT MODEL AS ORIGINALLY CONCEPTUALISED

Production Amount

Consumption Amount

Demand Function

Shipper Sub-Module
User Optimized
Elastic Demand
Aggregate Network

→

O-D Demand
By Path from
Production site
To Consumption
Site

→

Decomposition
Algorithm
Path Construction
Path Decomposition

↓

Carrier Sub Module
System-Optimized
Fixed Demand
Detailed Work

↓

Arc Flows, Arc
Paths, Path Flows
Path Costs

Traffic routed over aggregate "network" as Shipper Sees it

Each shipper is non-cooperatively Minimizing landed cost

Model is a distribution, Modal split Traffic Assignment Model

SYSTEM OPTIMIZATION

- Freight Network Equilibrium Model
  - Model Shipper Behavior & Carrier Behavior Explicitly Accounts for the behavior the shipper & carrier (Frietz & Fernandez 1979)

- Non availability of road/inland waterways data prevented Shipper's Assignment

- IR network controlled by single authority
  - At equilibrium,
    - Marginal cost of any path used is same!
    - Transfer of flows to alternative path does not reduce cost

Carrier Model

- Assumption: Single carrier is in control
- Given
  - $(O_i\text{-}D_j)_M$ faced by Indian Railways
  - Path set $P^k{}_r(i..n_1..n_5...g_1....t_5...n_3...n_6..j)$
  - Arc-Path Incidence Matrix
  - Congestion Cost over each arc: $C=a+bX^n$
  - Penalty Functions
  - Shortage Variables
- Optimize Carrier Costs

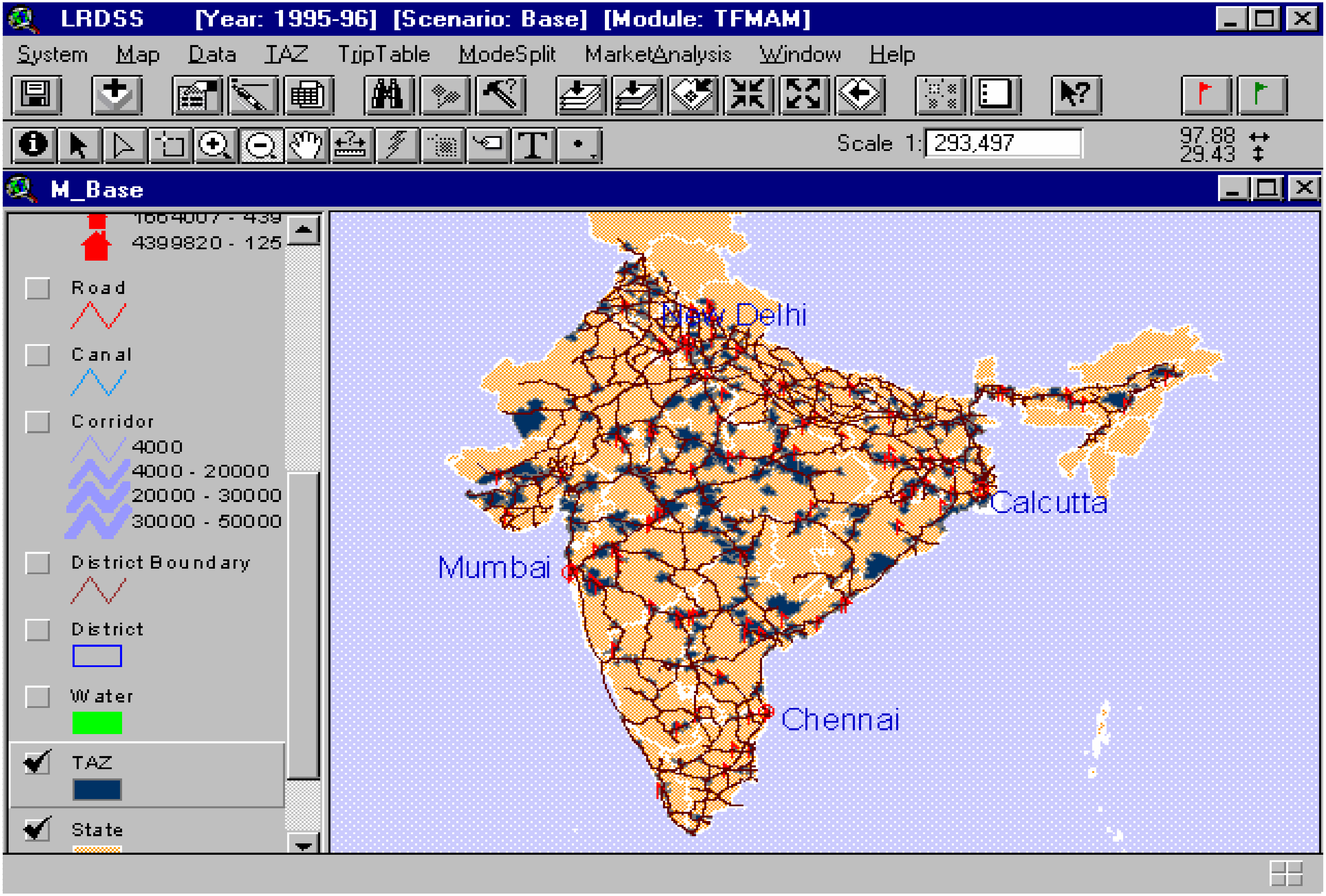
Carrier Model

- Inputs
  - A set of Origins & Destinations
    - O_i, D_j
  - A set of Commodities
    - M_1…….M_n
  - Demand for M_n between O_i, D_j

Demand Modeling

- Different models used for different commodities
  - **GAMS** Linear Programming Model
    - Assigns traffic by minimizing transportation cost.
  - “**Furness**” Trip Generation Model
    - Generates OD flows based on movement pattern in the base year
  - **Factoring**
    - OD flows are projected based on growth rates.

Traffic Analysis Zones



Carrier Model

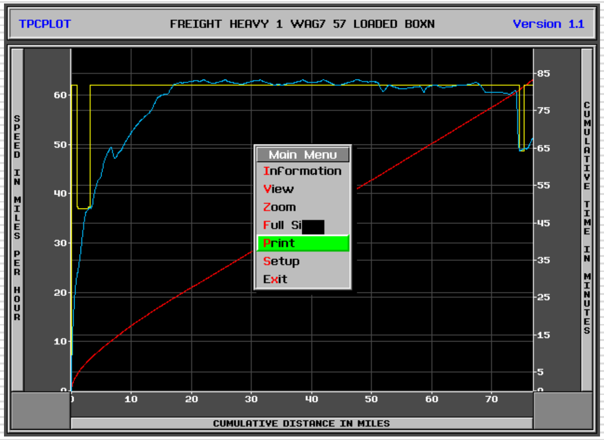
- Given
  - A Set of Paths connecting $O_i - D_j$
  - A Set of Links and Nodes comprising a path
    - $N_1 .... N_x$; $n_1 .... n_y$
  - A link /Node associated with a Cost Function
    - $C_{N_1 m} = A + BX^u$
      - Where A, B, U are constants,
      - $C_{N_1 m}$: Long Term Line Haul variable Cost
- A,B,u depend upon
  - Type of Link
  - Type of Train
  - Type of Operating Policy
  - U taken as 1

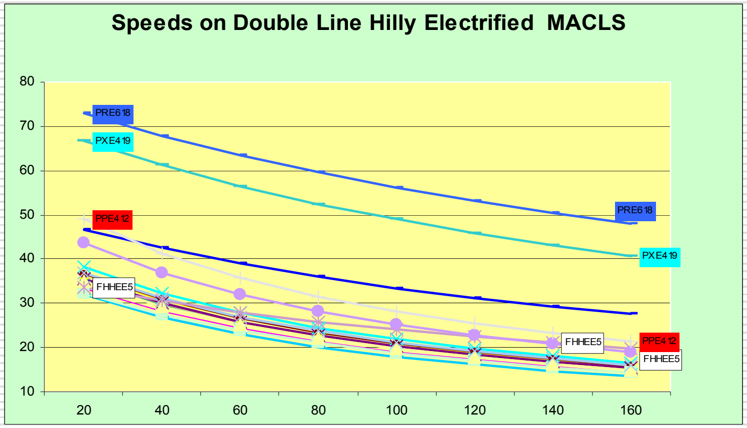
Cost Function Determination

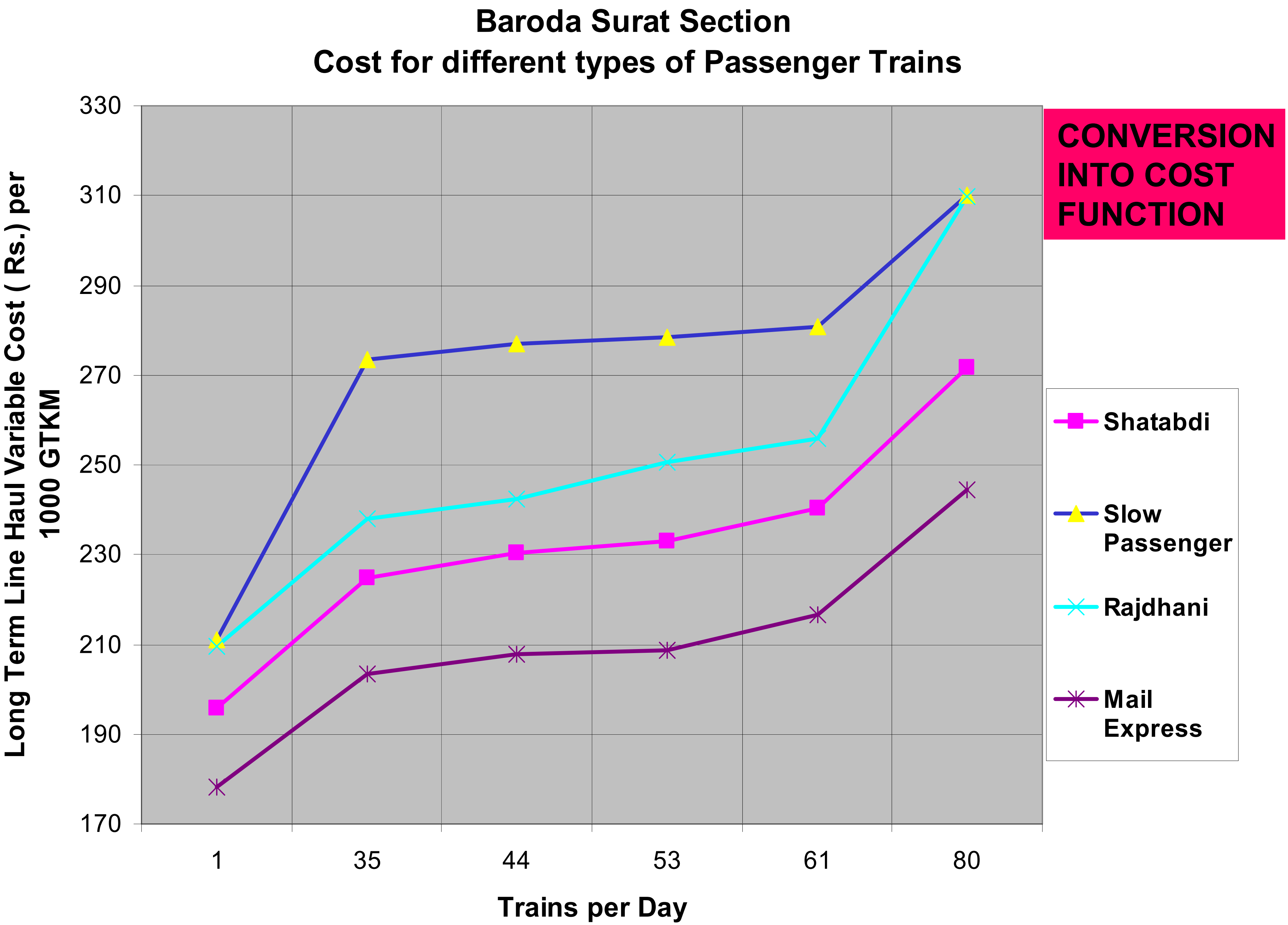
- Congestion Curves obtained
  - For each Train Type
  - Each Link Type
  - Each Operating Policy Set
  - At different levels of Traffic
- Results converted into Cost congestion functions
  - By Train Type, Link Type, Operating Rule set type

Traffic Assignment

- Cold Link with Micro Models for impedance
  - Determination of Transit Times/ Cost per net tons
    - For different trains
    - At different levels of traffic
    - Running on different links
    - Carrying different commodities
    - With different operating policies
- Use of Simulation for micro modeling






Baroda Surat Section
Cost for different types of Passenger Trains
CONVERSION INTO COST FUNCTION
Long Term Line Haul Variable Cost (Rs.) per 1000 GTKM
330
310
290
270
250
230
210
190
170
1
35
44
53
61
80
Trains per Day
Shatabdi
Slow Passenger
Rajdhani
Mail Express

Traffic Assignment

- **Operation Research** based Freight Network Equilibrium Model.
- **Objective function**: Minimize Carrier Cost
  - Assign OD flows on paths using least impedance.
    - (= Σ congestion cost on links/nodes)
  - Each path consists of series of links and nodes.
  - Path Cost = aggregated cost of traffic movement over each link and node.

Sub Modules of TAM

- Network Processor
  - create a logical multi modal network
    - access /egress links,
    - transshipment, traction change points, nodes
  - Output consists of Forward star data structure to be used as input to k path algorithm
- Path generator (K-Short)
  - shortest paths between two O-D Pairs
  - Input to Solver

Path Generator

- Path Generation
- Generate a set of 5 paths (max) from each O_i to each D_j
  - Total TAZ's 1456
- Path generated only populated O_i-D_j Cells in Matrix
- Total paths generated = 40,000
  - K Short Algorithm

Network & Path Database Description

- Network databases
  - Nodes are logical arcs
  - Arcs are codified
  - +,- for diesel
  - *,~ for electric

- Path represented as follows

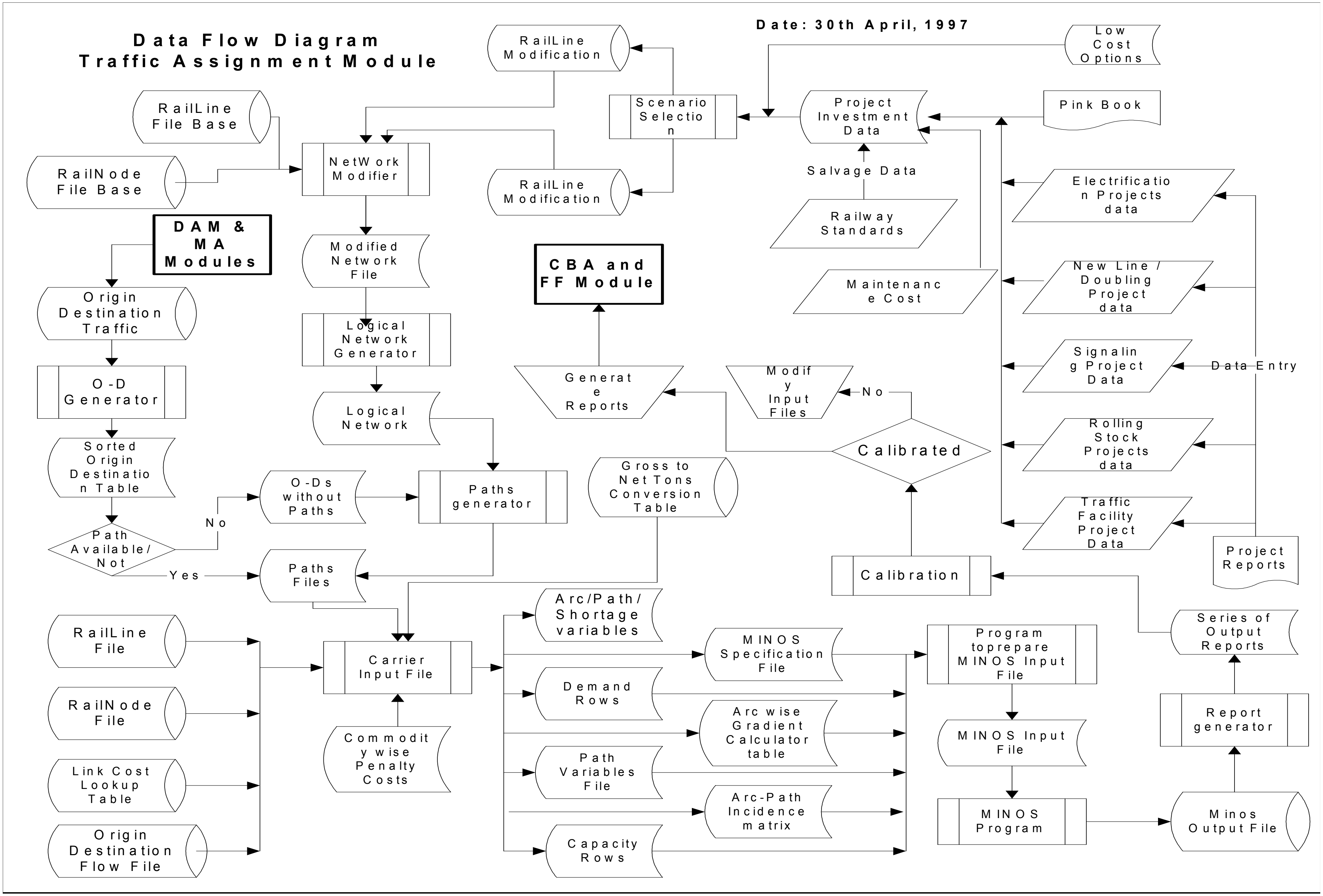
  1 2

  1 704.0 46 804.0 (Physical length= 704, links = 46)

  BL1257+ BD1093+ BN1252+ BD1966+ BC1238- BE1076*BN1237*BE1077~BN1239* BE1083~ BN1246* BE1218~ BN1405* BE1222~ BY1408~ BU1408~

Sub Modules of TAM

- Carrier Input Processor
  - Generates MINOS input file
  - Represents full specifications of carrier model with unit costs specified as a ‘real valued’ function of path flows (non linear)
- Post processor
  - Interprets MINOS solution file.
  - Interfaces with GIS
  - Query based GIS interface allows graphical display of bottleneck links, flows etc.


Data Flow Diagram
Traffic Assignment Module
Date: 30th April, 1997
RailLine Modification
Low Cost Options
RailLine File Base
Scenario Selection
Project Investment Data
Pink Book
RailNode File Base
NetWork Modifier
RailLine Modification
Salvage Data
Electrification Projects data
DAM & MA Modules
Modified Network File
Railway Standards
CBA and FF Module
Maintenance Cost
New Line / Doubling Project data
Origin Destination Traffic
Logical Network Generator
Signaling Project Data
Data Entry
O-D Generator
Generate Reports
Modify Input Files
No
Logical Network
Calibrated
Rolling Stock Projects data
Sorted Origin Destination Table
O-Ds without Paths
Paths generator
Gross to Net Tons Conversion Table
Traffic Facility Project Data
No
Path Available/ Not
Yes
Paths Files
Calibration
Project Reports
Arc/Path/ Shortage variables
Series of Output Reports
RailLine File
MINOS Specification File
Program toprepare MINOS Input File
Carrier Input File
Demand Rows
RailNode File
Arc wise Gradient Calculator table
MINOS Input File
Report generator
Commodity wise Penalty Costs
Link Cost Lookup Table
Path Variables File
Arc-Path Incidence matrix
MINOS Program
Minos Output File
Origin Destination Flow File
Capacity Rows

Traffic Assignment Module

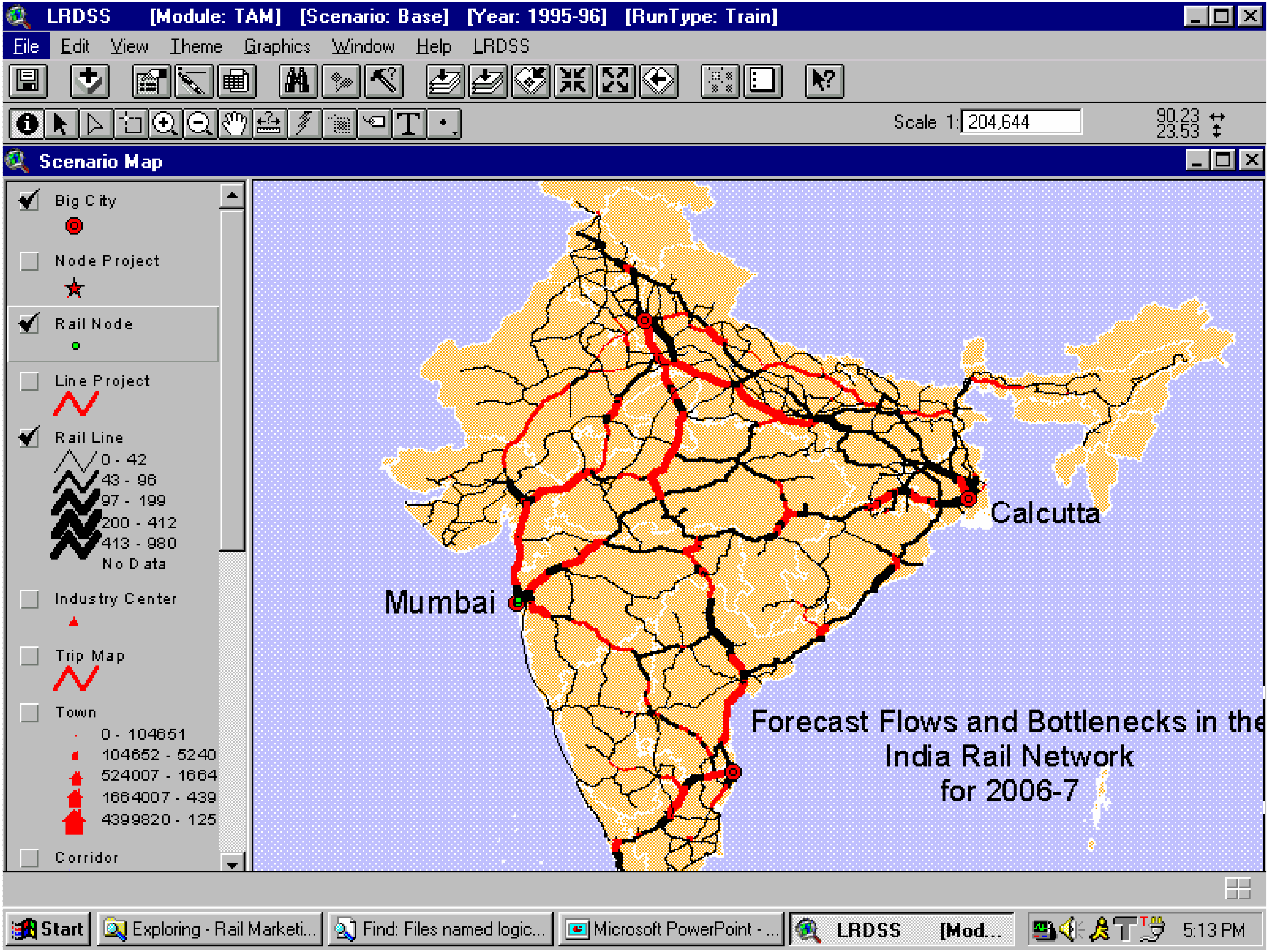
- Basic Inputs to the Model:
  - I : **Demand Side**
    - Existing and Future Traffic
      - Commodity wise flows between pairs of points
      - Traffic for 2006-’07, 2011-’12, 2016-’17
  - II: **Supply Side**
    - Existing and Future Network
      - Sections as well as their Characteristics
      - Stations as well as their Characteristics

Methodology for Assignment

- Base Year: Assignment on Preferred Paths
- Future Years:
  - Assignment on both Preferred & Shortest Paths
  - Assignment with committed works
- Sequential/Simultaneous

Analysis of TAM Results

- Outputs
  - Commodity wise traffic on each link.
  - ODs that use a particular link.
  - Lowest Cost Route path between pairs of points.
  - Utilization of each Node
    - Facility / Resource Planning at nodes
- These reports can be compared for alternative scenarios.

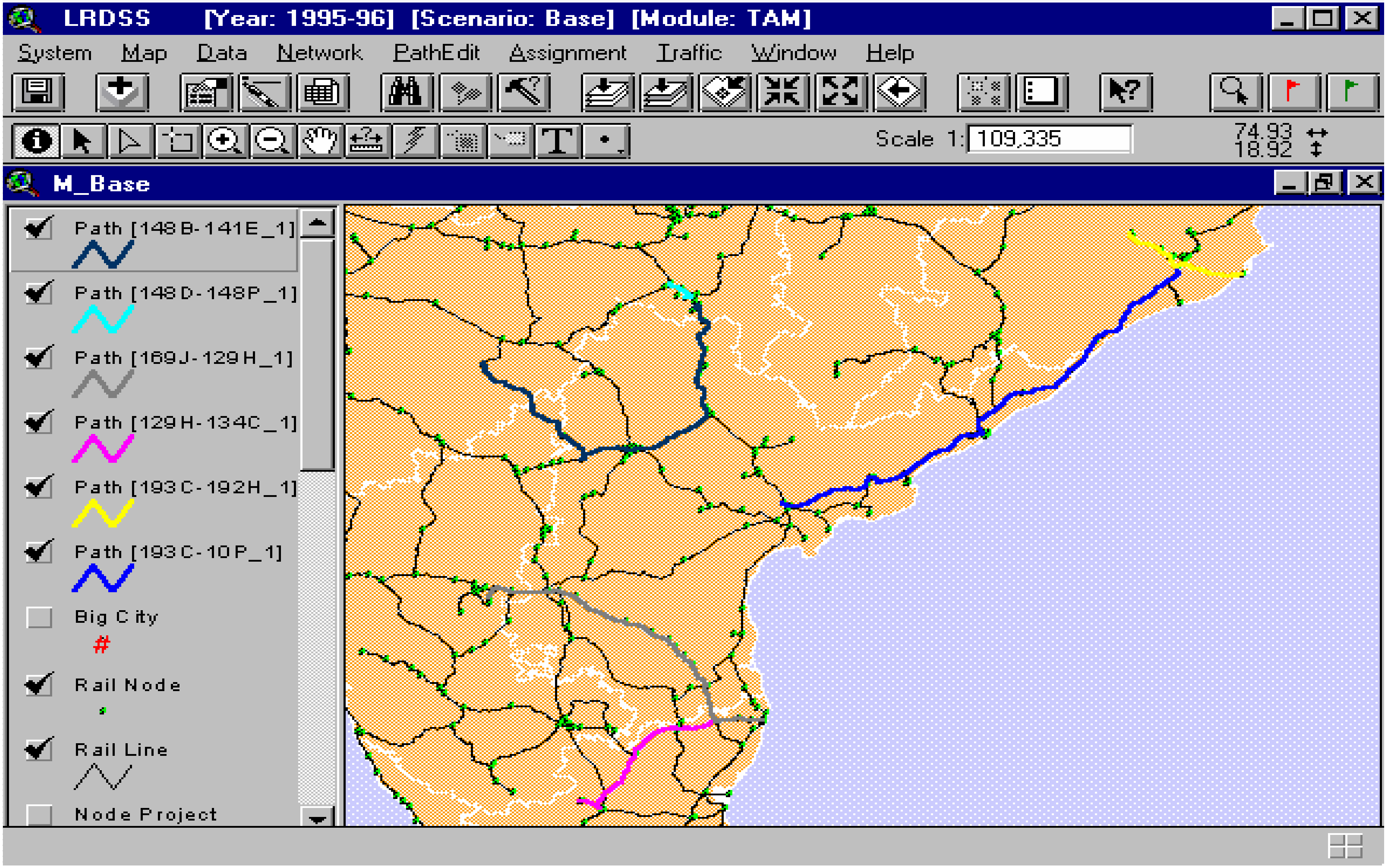


LRDSS [Module: TAM] [Scenario: Base] [Year: 1995-96] [RunType: Train]
File Edit View Theme Graphics Window Help LRDSS
Scale 1: 204,644
90.23
23.53
Scenario Map
Big City
Node Project
Rail Node
Line Project
Rail Line
0 - 42
43 - 96
97 - 199
200 - 412
413 - 980
No Data
Industry Center
Trip Map
Town
0 - 104651
104652 - 5240
524007 - 1664
1664007 - 439
4399820 - 125
Corridor
Calcutta
Mumbai
Forecast Flows and Bottlenecks in the
India Rail Network
for 2006-7
Start
Exploring - Rail Marketi...
Find: Files named logic...
Microsoft PowerPoint - ...
LRDSS [Mod...
5:13 PM

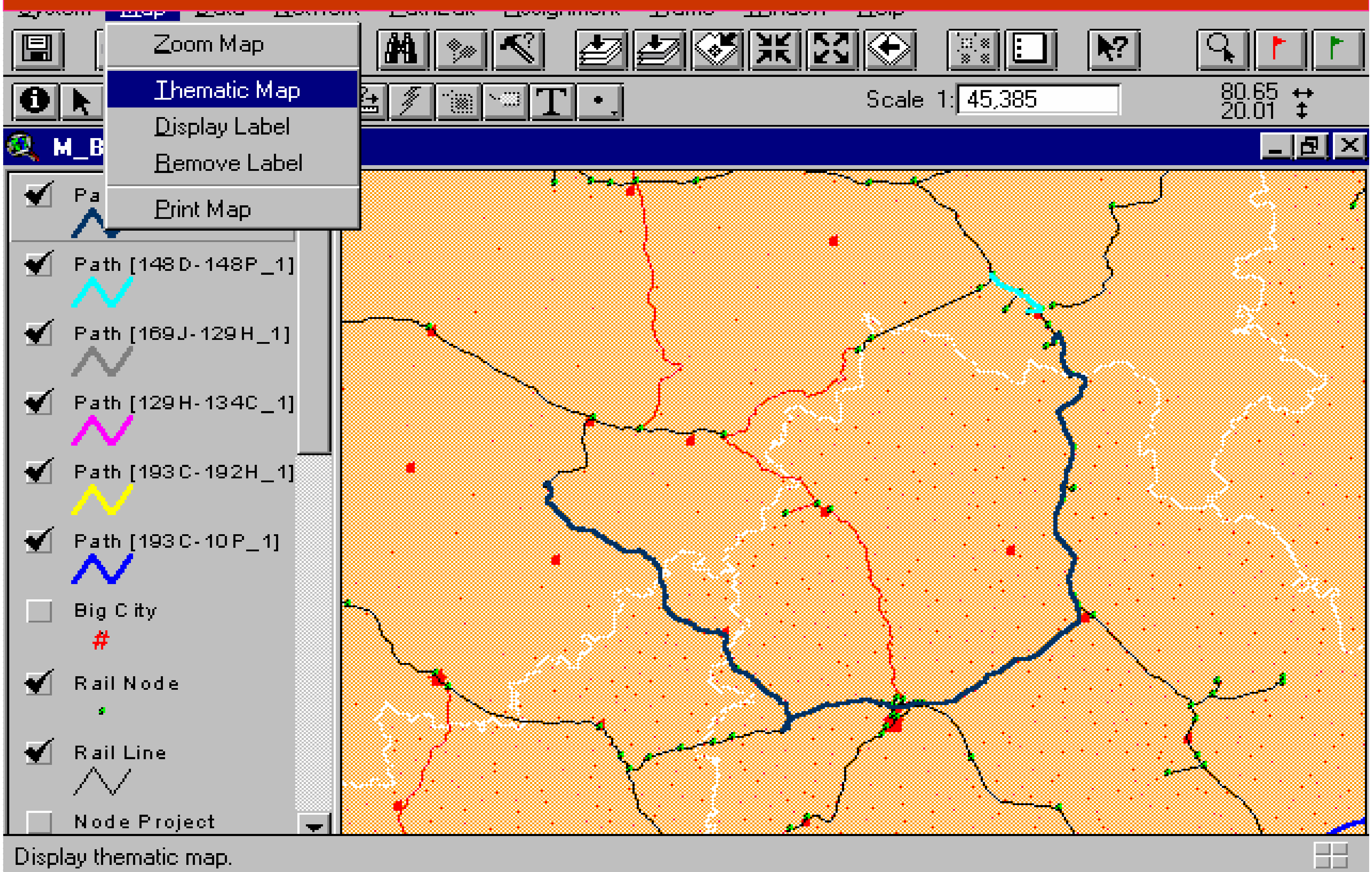
GIS & LRDSS

- Avenue based Path Editor used to check paths generated by K-short
  - transshipments, traction change, reversals
  - create new paths via certain given stations
- User Interface to facilitate Data Analysis through
  - Data browser
  - Query Builder
  - Chart generator

Path Editor to display/define routes

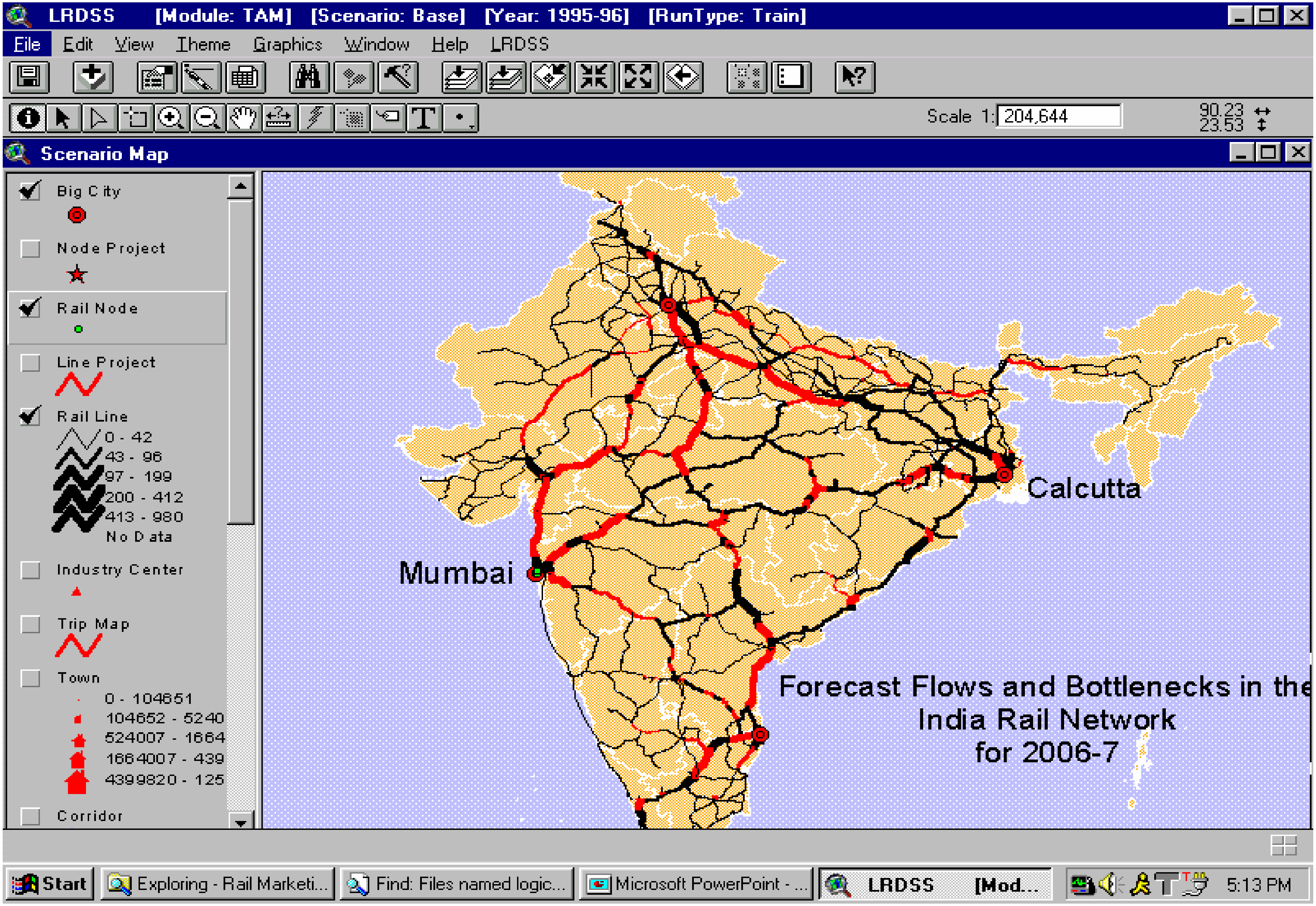


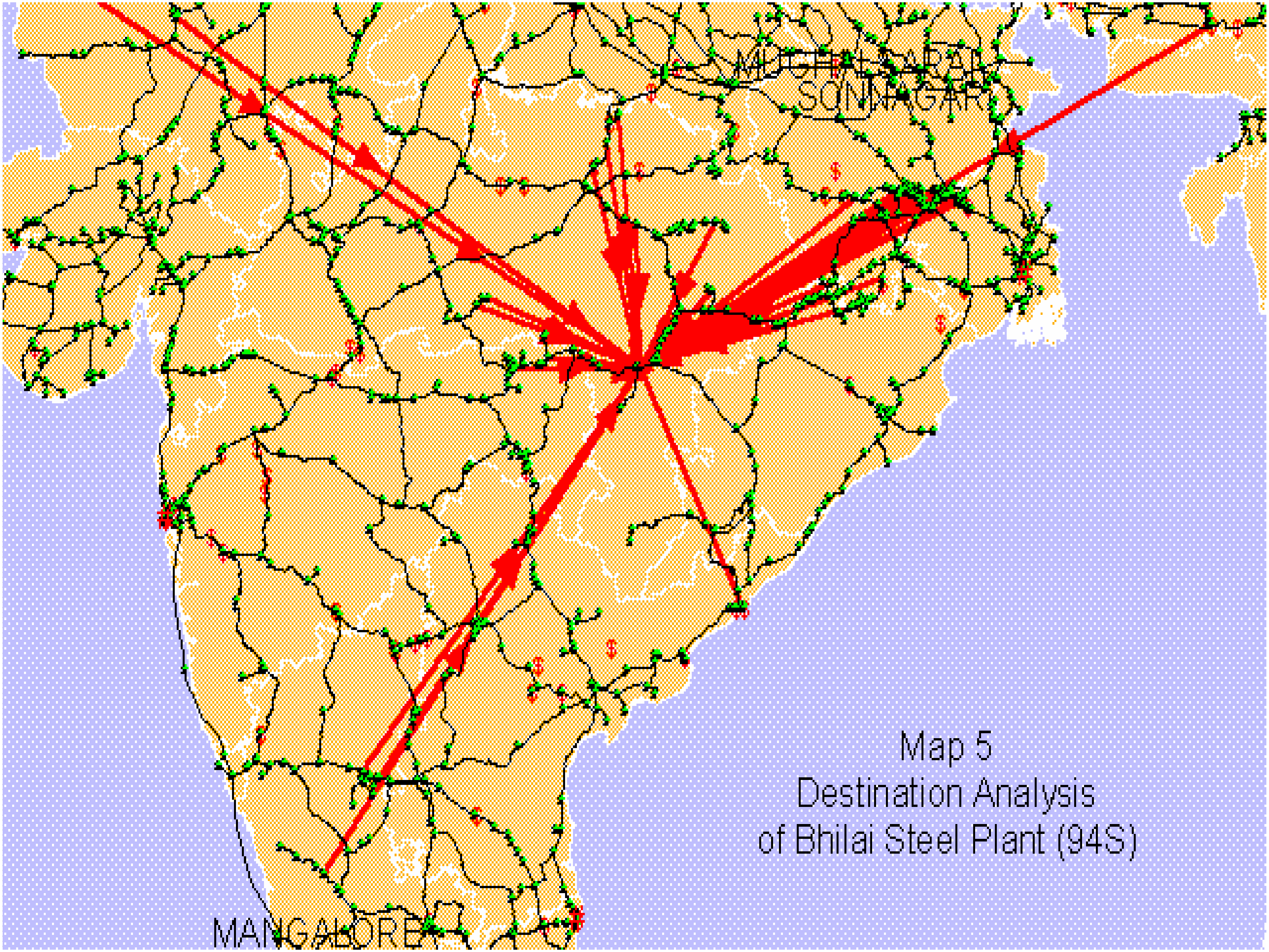
Path Editor



Zoom Map
Thematic Map
Display Label
Remove Label
Print Map
Scale 1: 45,385
80.65
20.01
M_B
Pa
Path [148D-148P_1]
Path [169J-129H_1]
Path [129H-134C_1]
Path [193C-192H_1]
Path [193C-10P_1]
Big City
Rail Node
Rail Line
Node Project
Display thematic map.

Bottlenecks in 2006-07 (Est. Capacity (188))





Map 5
Destination Analysis
of Bhilai Steel Plant (94S)

IMPACT OF LRDSS

- Focused Management on
  - Long term planning
  - Congestion Modeling
    - Technology
    - Process Improvements
  - Market Analysis
    - Pricing of products
    - Quality of Service

PASSENGER OPERATIONS

Challenge the Clouds!

OVERVIEW

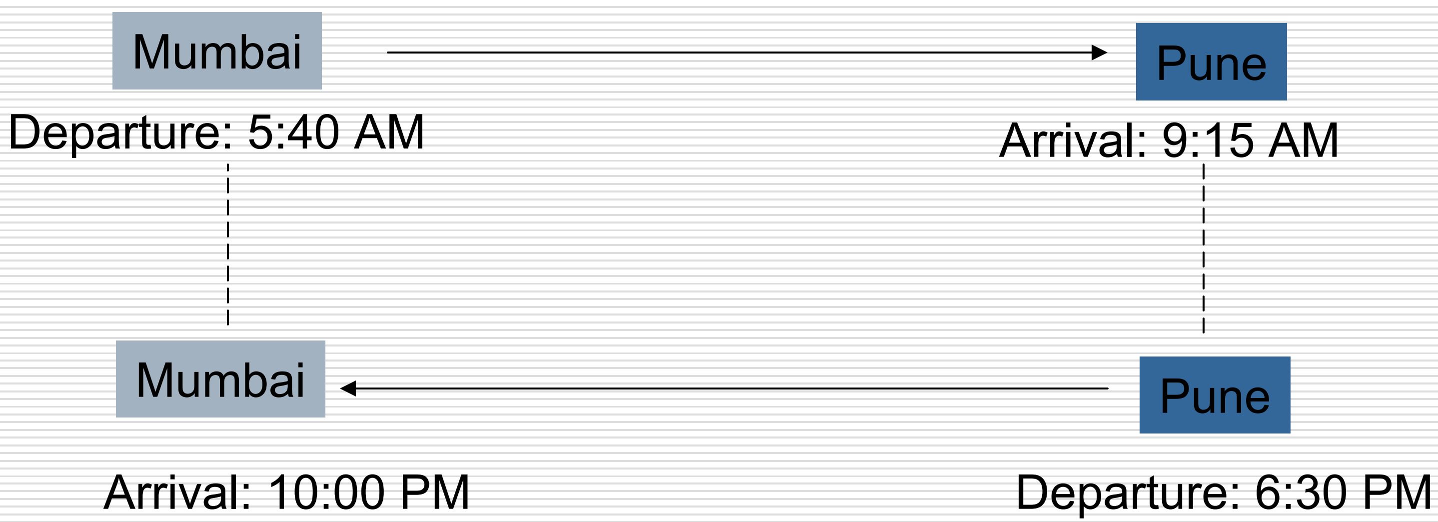
- Passenger Trains per day: 8000
  - Slow Passenger: 2500
  - **Long Distance Mail Express: 1500**
    - **Contribute 90% of passenger revenues**
  - Local Trains:3000
  - MEMU Trains: 1000

OVERVIEW

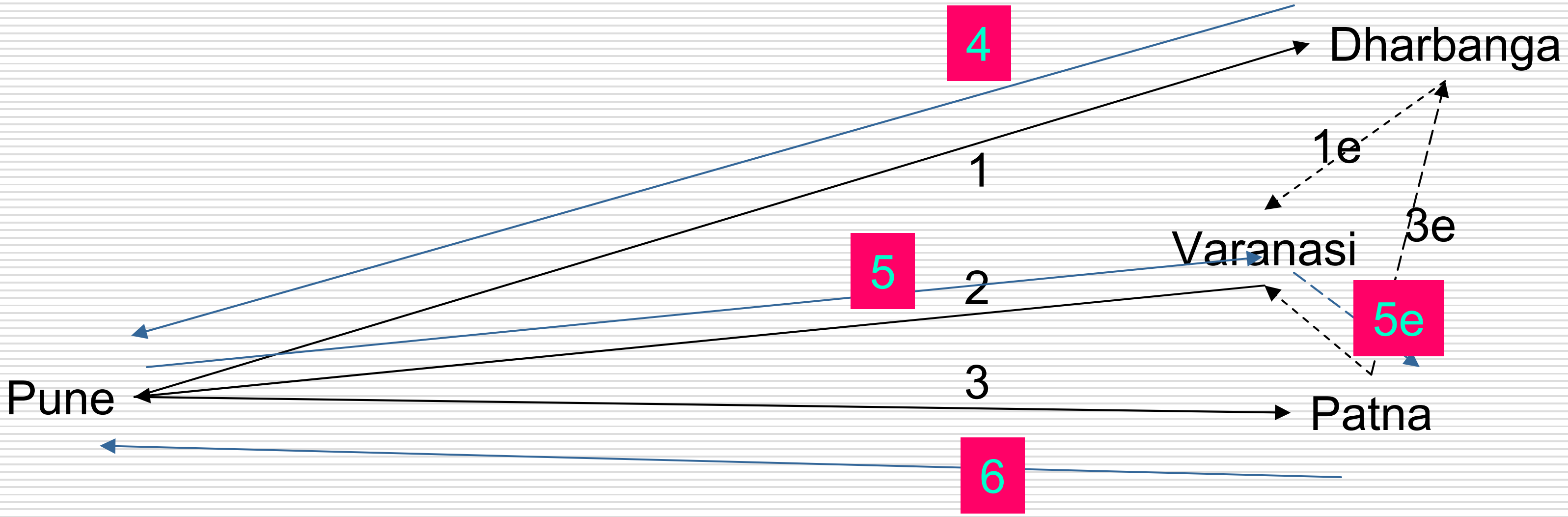
- Long Distance Services/year: 303576
  - ~Trains per day = 1430
- Investment = US $ 10 billion
- Revenues = US $ 2.4 billion
- Total Cars = 20,000
- Rake Sets = 1351
  - Non Integrated Rake Links = 1000
  - Integrated rake Links = 351
  - Average Investment / rake set ~ US $ 6 mill.

Example: Non Integrated Rake

Utilization of the rake: 31%
Investment in Rake : US $ 4 million



Example: Integrated Link



Integrated Links Improve Utilization of Rolling Stock
Utilization of rake: 85%

RAKE UTILIZATION

- Current Rake Utilization
  - 52%
- Sensitivity:
  - Improvement in rake utilization from 52% to 62%
    - Saving in Rolling Stock Investment = US $ 1.3 b
    - Additionally, revenue generation US $ 0.24billion
    - Net implication = US $ 1.54 billion
- Improvement in Rake Utilization is critical

Current Approach

- Problem is impossible to solve
  - "Trains will not run: services will be skipped for want of rakes"
  - Hence, don't even attempt it!
- Local optimization strategies
  - Look at busy stations
    - Analyze incoming trains
    - Compare arrival timings and departures
    - If close by, then match (subject to constraints)
      - Length of trains
      - Maintenance issues
      - Train Configuration
- Result: Sub System Optimization but system sub-optimization

Proposed Approach ?

- OR + Project Management
  - Service resembles a "project"
  - Projects have a defined "start" and "end"
    - Geography is an additional complication
  - A train set is a resource
  - Service utilize resources
  - Objective: Complete all projects in time with minimum resources

Proposed Approach?

- Constraints
  - Project start & end
  - Location of starts & ends
  - Location of resources
    - Projects are attached to resources
    - When Projects are completed, resource is available for next Project
  - Resources are of different kinds
    - 18 cars, 22 cars, 26 cars
  - Projects seek specific resources

Proposed Approach?

- Use Traveling Salesman Analogy
  - Consider 1351 salesmen are available
  - Salesmen must depart & arrive at specific "stations" at "pre-specified time"
  - Salesmen have pre-defined capacities
    - Salesmen are not fully interchangeable
  - Aim: Minimize no of salesmen

THANK YOU