Automation possibilities in metro-rail operations planning

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This talk will soon be available at

www.ee.iitb.ac.in/%7Ebelur/talks

www.ee.iitb.ac.in/%7Ebelur/railways/workshop

www.ee.iitb.ac.in/%7Ebelur/railways

Group: Narayan Rangaraj and others from IIT Bombay

narayan.rangaraj@iitb.ac.in

I-Metro-Workshop, Mar 2023, I-Metro workshop

Outline of the talk

- Need for software tools in operations planning
- Data availability/digitization: machine learning/artificial intelligence
- Tools recently developed by our group in railway operations
- Other tools (non-railway) developed by our group
- FOSS and ‘development-participation & owning’ of tools
- Suggestions about tool-specifications: primarily from ‘shop floor’

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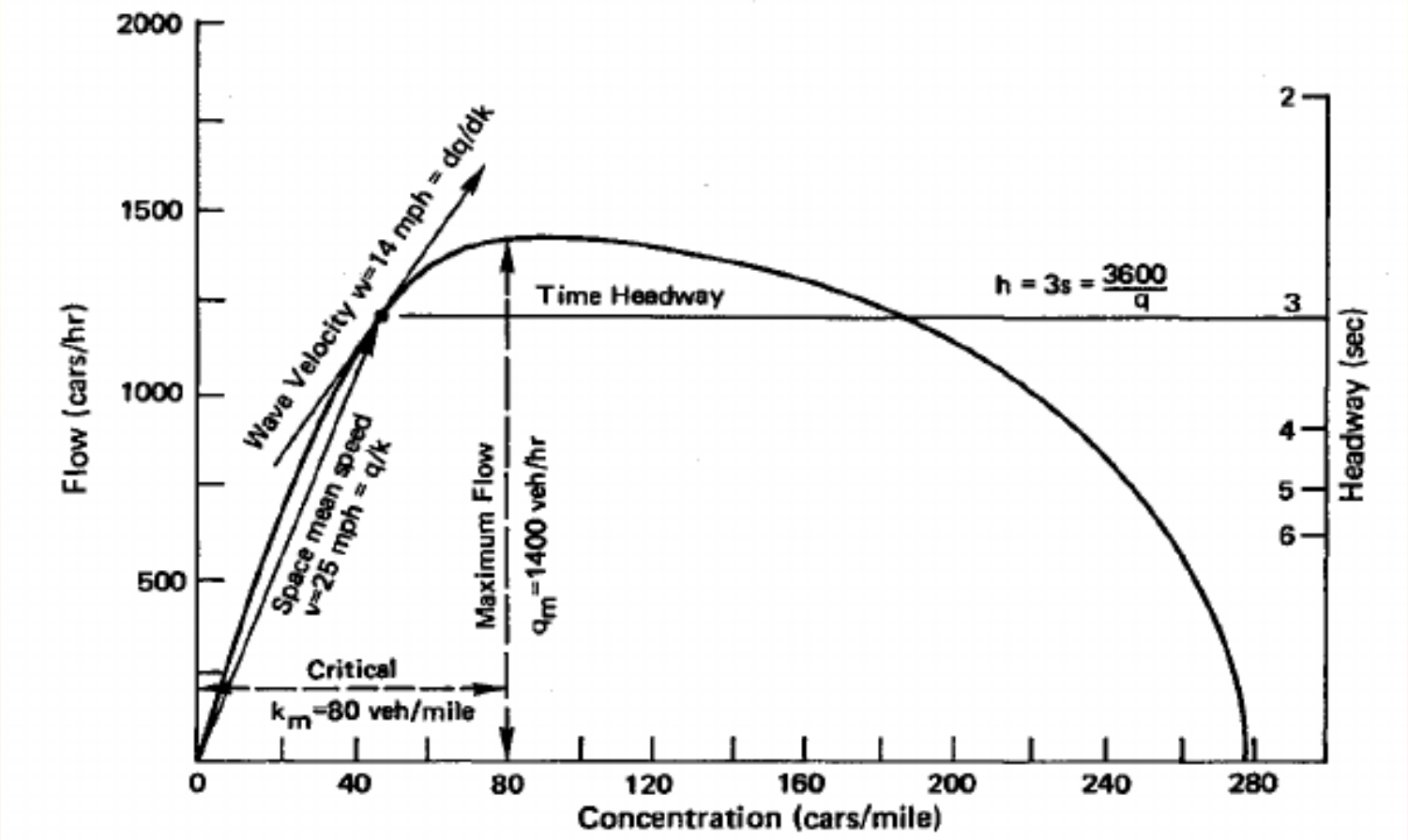
Need to operate at high quantity/quality of service

Vehicles flow models: flow rate (throughput) vs density

(Partly relevant for trains)

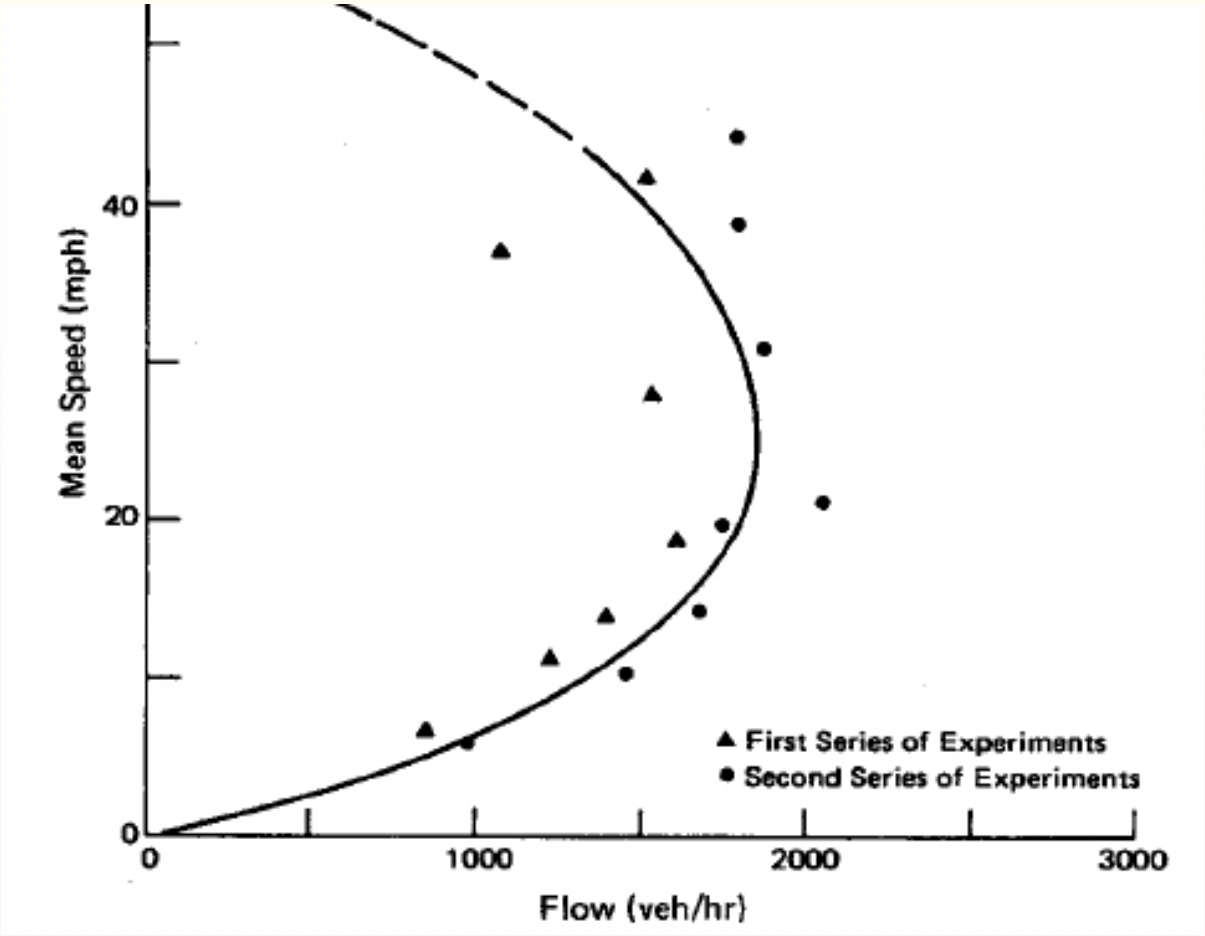


Source: Traffic Flow Theory, D.L. Gerlough and M.J. Huber (1975)

Throughput peaks at an optimum density

Vehicles flow models: average speed vs flow

Quality of service vs quantity of service



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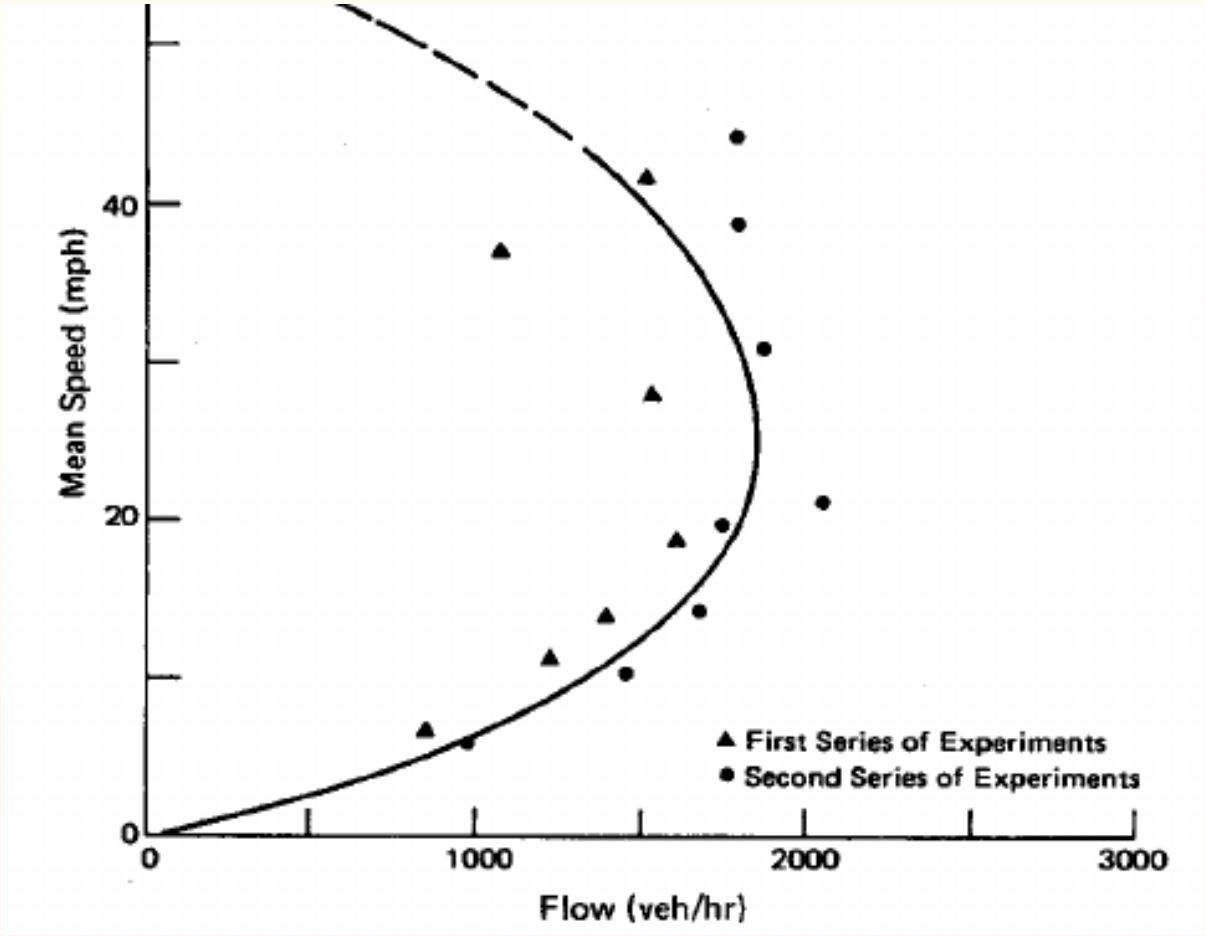

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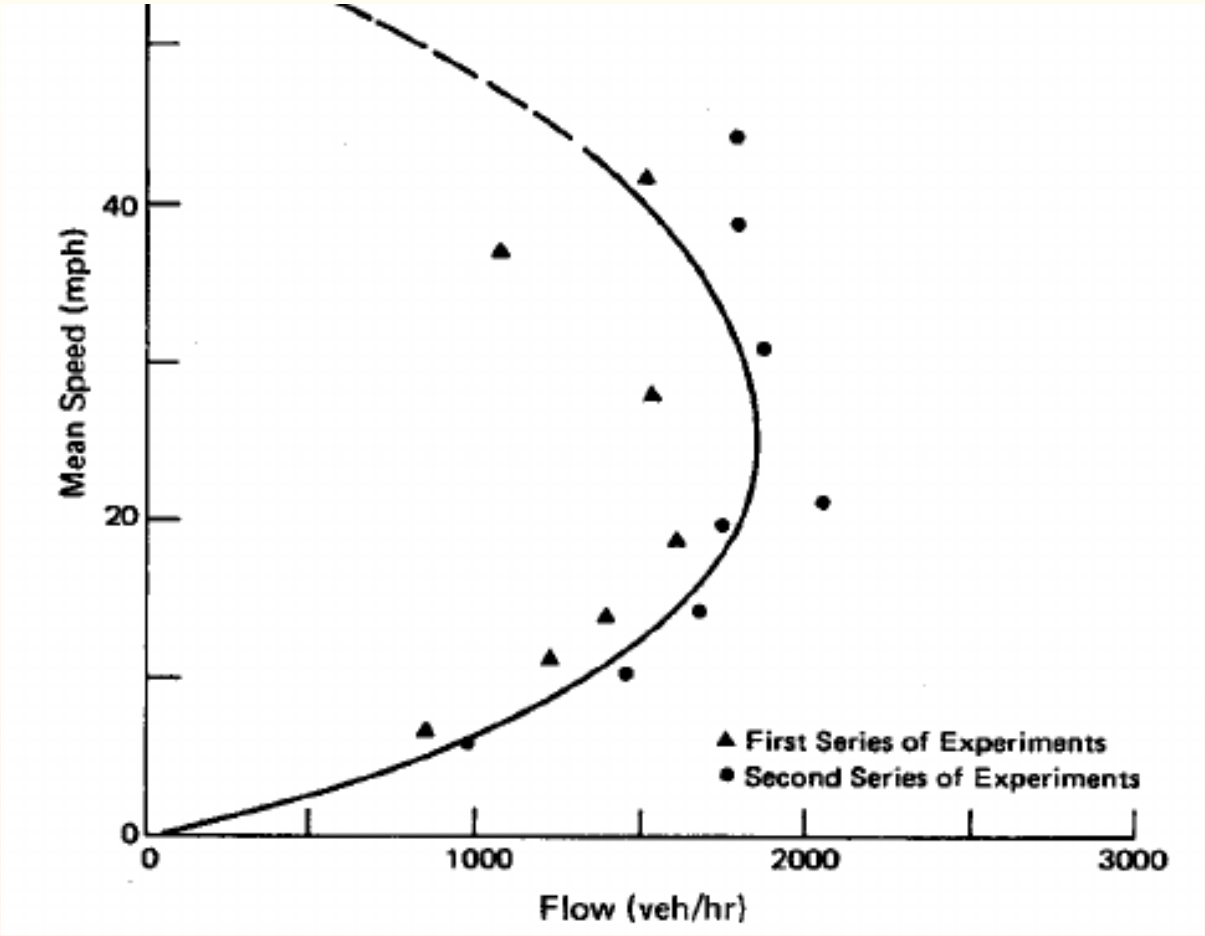

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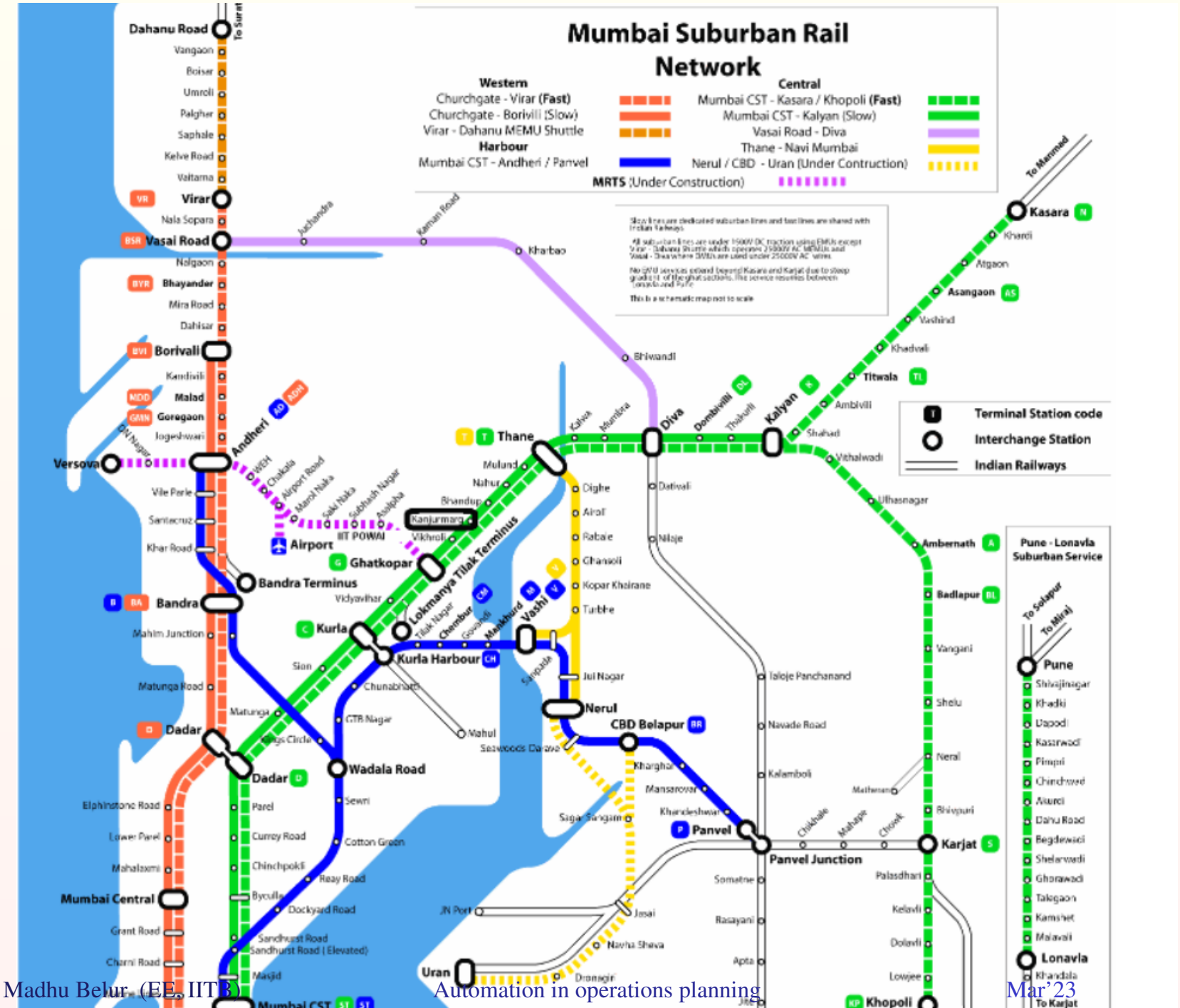
Bad for throughput: too low speed, also too high speed!


Mumbai Suburban Rail Network
Western
Churchgate - Virar (Fast)
Churchgate - Borivili (Slow)
Virar - Dahanu MEMU Shuttle
Harbour
Mumbai CST - Andheri / Panvel
Central
Mumbai CST - Kasara / Khopoli (Fast)
Mumbai CST - Kalyan (Slow)
Vasai Road - Diva
Thane - Navi Mumbai
Nerul / CBD - Uran (Under Contruction)
MRTS (Under Construction)
Terminal Station code
Interchange Station
Indian Railways
Pune - Lonavla Suburban Service
Dahanu Road
To Surat
Vangaon
Boisar
Umroli
Palghar
Saphale
Kelve Road
Vaitarna
Virar
Nala Sopara
Vasai Road
Nalgaon
Bhayander
Mira Road
Dahisar
Borivali
Kandivili
Malad
Goregaon
Jogeshwari
Andheri
DN Nagar
Versova
Vile Parle
Santacruz
Khar Road
Bandra Terminus
Bandra
Mahim Junction
Matunga Road
Dadar
Elphinstone Road
Lower Parel
Mahalaxmi
Mumbai Central
Grant Road
Charni Road
Mumbai CST
Juchandra
Kaman Road
Kharbao
Bhiwandi
Airport
IIT POWAI
Ghatkopar
Kanjurmarg
Vikhroli
Bhandup
Mulund
Nahur
Thane
Kalwa
Mumbra
Diva
Dombivili
Thakurli
Kalyan
Titwala
Ambivli
Shahad
Vithalwadi
Ulhasnagar
Ambernath
Badlapur
Vangani
Shelu
Neral
Bhivpuri
Karjat
Kasara
Khardi
Atgaon
Asangaon
Vashind
Khadvali
To Manmad
Digha
Airoli
Rabale
Ghansoli
Kopar Khairane
Turbhe
Dativali
Nilaje
Lokmanya Tilak Terminus
Vidyavihar
Kurla
Kurla Harbour
Vashi
Sion
Chunabhatti
Tilak Nagar
Chembur
Govandi
Mankhurd
Sanpada
Jui Nagar
Nerul
CBD Belapur
Seawoods Darave
Kharghar
Mansarovar
Khandeshwar
Panvel
Panvel Junction
Taloje Panchanand
Navade Road
Kalamboli
Matheran
Palasdhari
Kelavli
Dolavli
Lowjee
Khopoli
Somatne
Rasayani
Apta
Jasai
Navha Sheva
JN Port
Uran
Dronagiri
Dadar
Parel
Currey Road
Chinchpokli
Reay Road
Cotton Green
Wadala Road
Sewri
Byculla
Dockyard Road
Sandhurst Road
Sandhurst Road (Elevated)
Masjid
Matunga
King's Circle
GTB Nagar
Mahul
Saiwoods Darave
Saga Sangam
Chikhale
Mahape
Chowk
Pune
Shivajinagar
Khadki
Dapodi
Kasarwadi
Pimpri
Chinchwad
Akurdi
Dehu Road
Begdewadi
Shelarwadi
Ghorawadi
Talegaon
Kamshet
Malavali
Lonavla
Khandala
To Karjat
To Solapur
To Miraj

Constraints

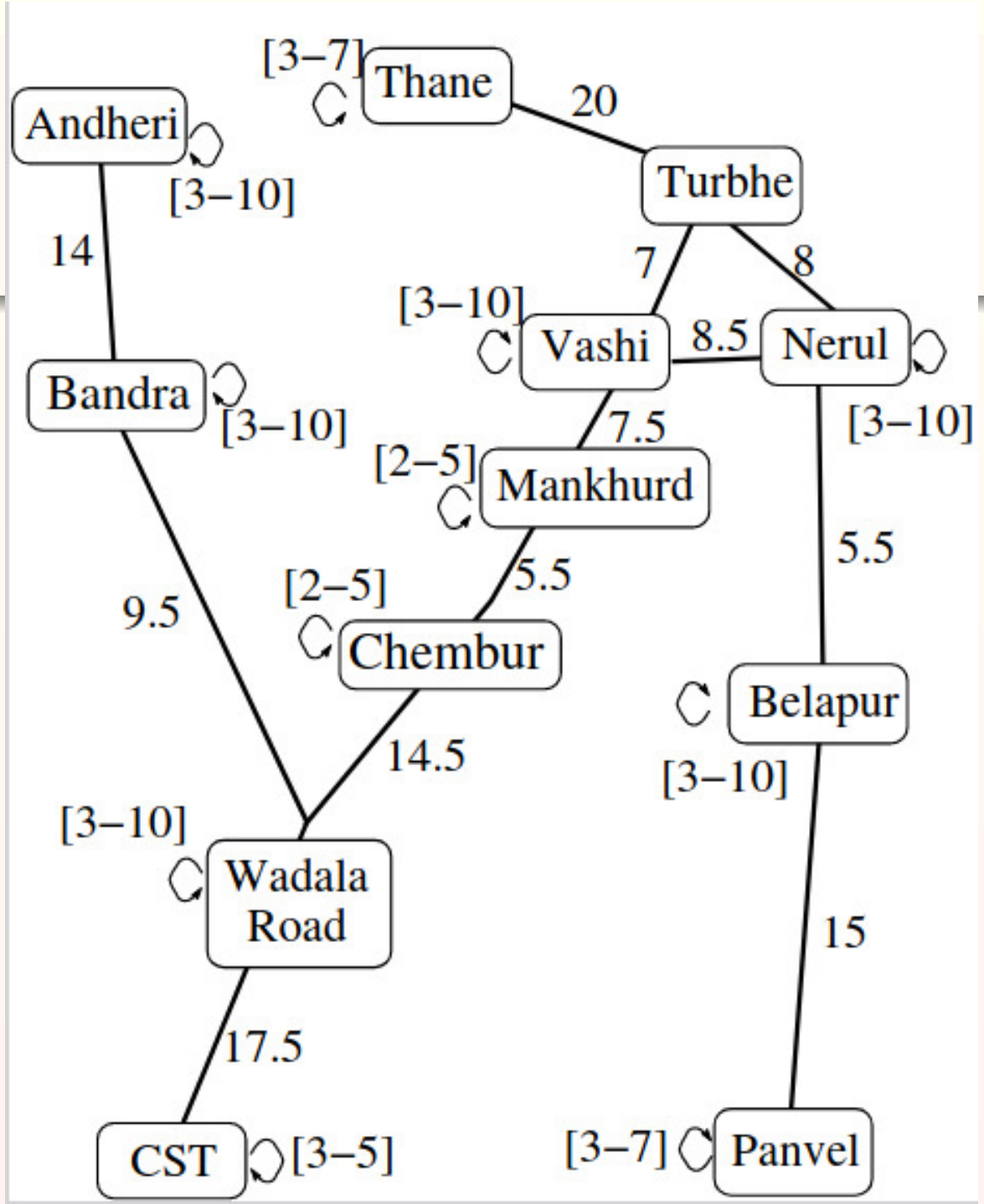
Hard constraints:

- Headway: safety
- Frequency of service: demands: origin/destination services
- Traversal times
- Turn-around constraints: ‘rake linking’
- Platform dwell/occupancy constraints

Soft constraints:

- Spacing between consecutive ‘similar’ services

Mumbai harbour-line



Constraints tightest at CSTM ("VT")

Platform vacating constraints:
An exit (from platform 2) hinders consecutive two entries

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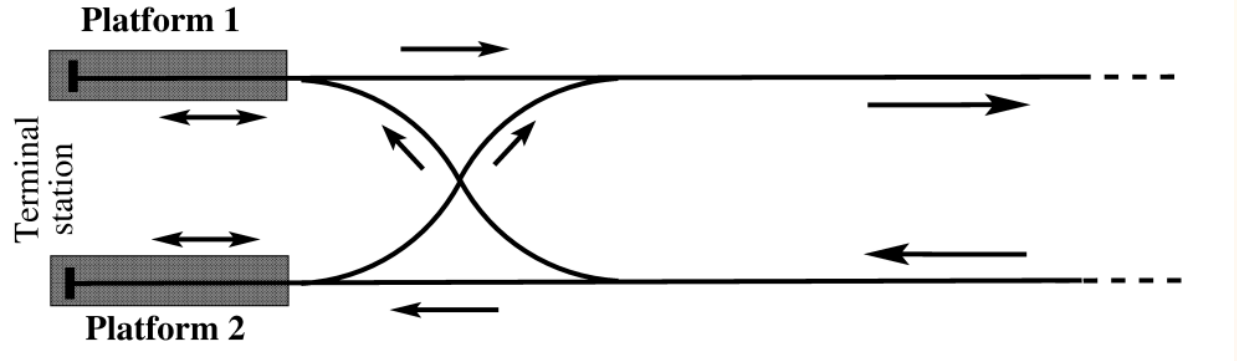
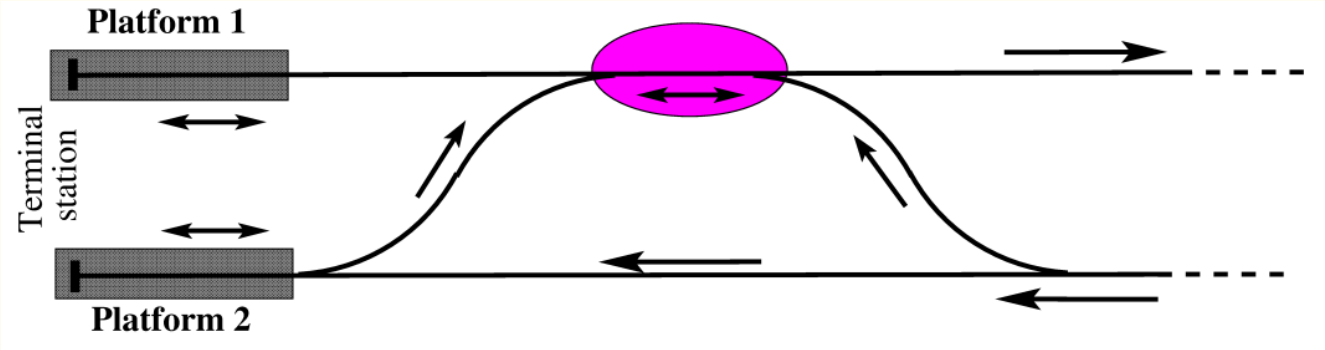


- Ideal: 'Scissor' crossing
- Fastest exit and least 'hindrance' to following entries
- Curves are on only a small distance: hence smaller distance of low-speed constraints
- Pretty expensive (but not exorbitant)

Platform-asymmetric layouts at a terminal

Not-too-bad layout:



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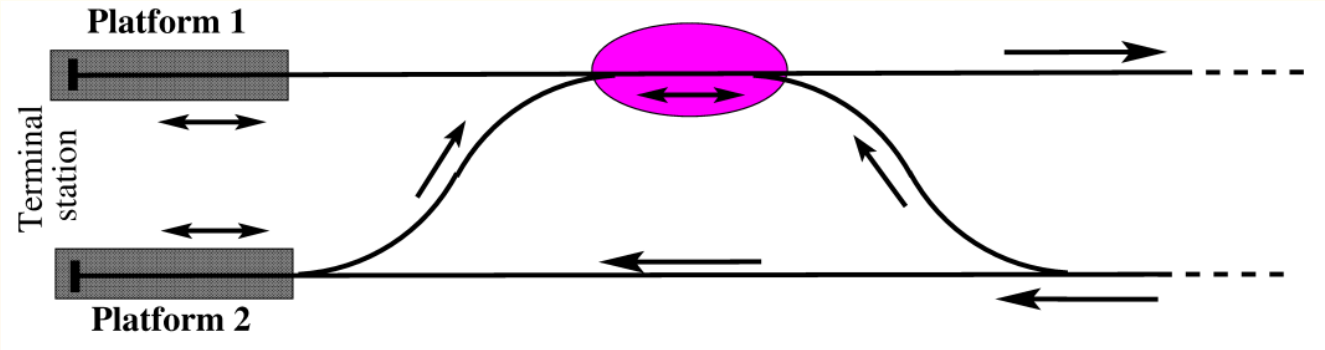

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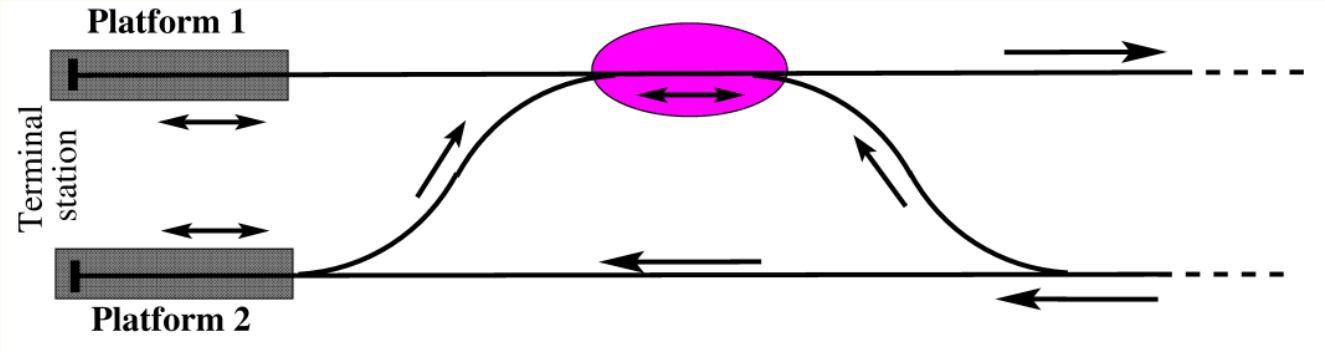

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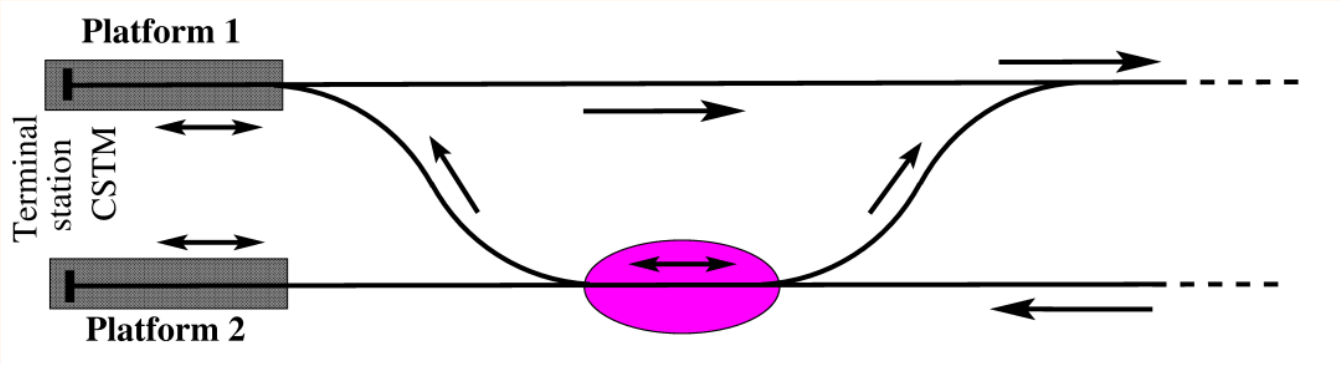

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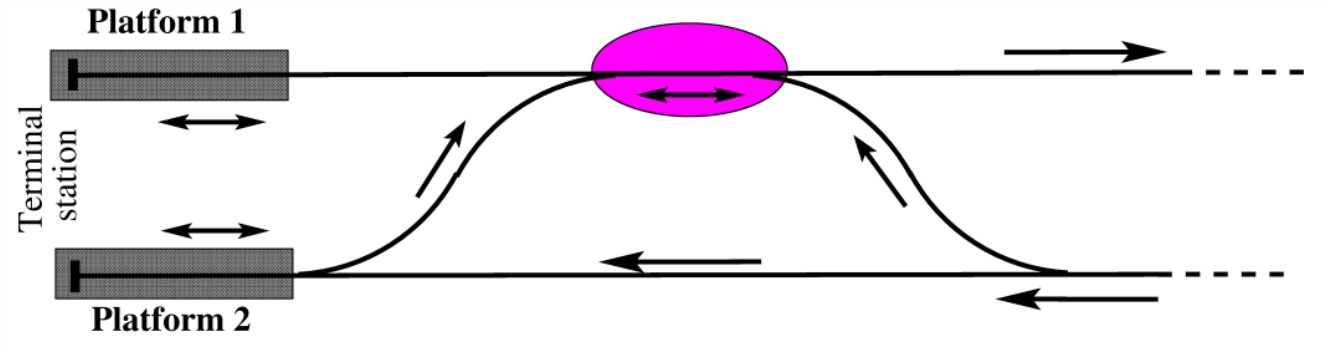

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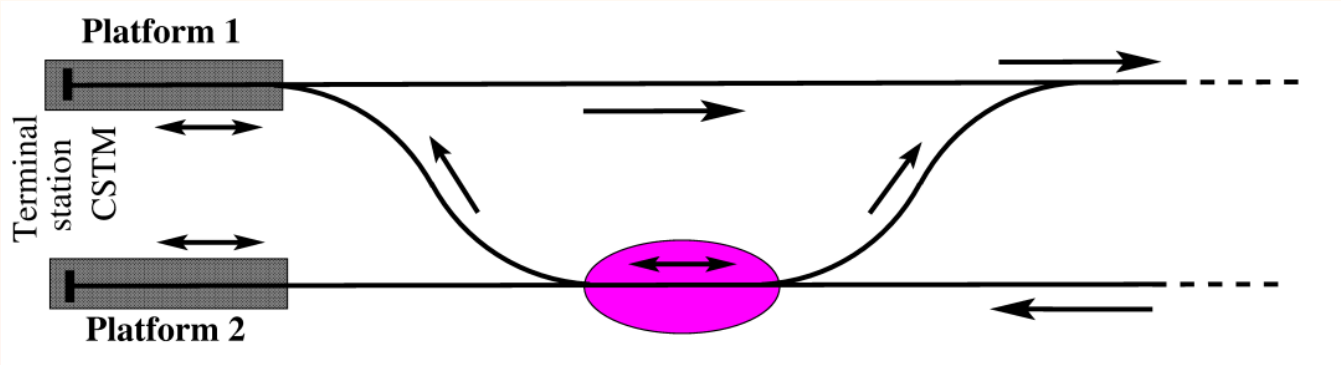

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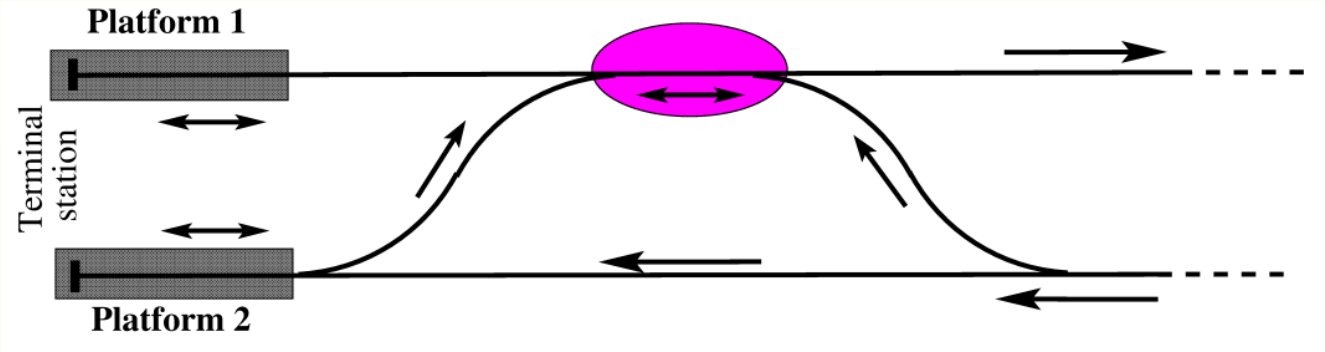

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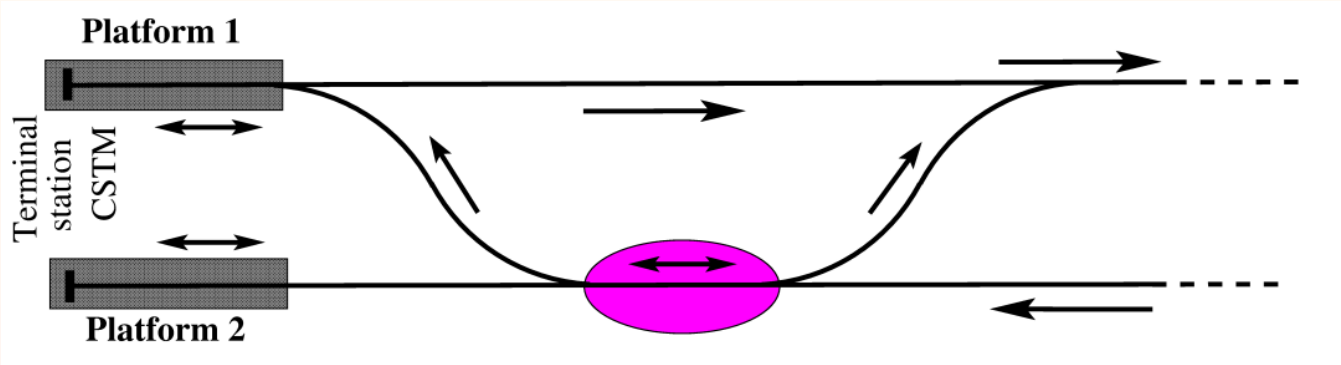

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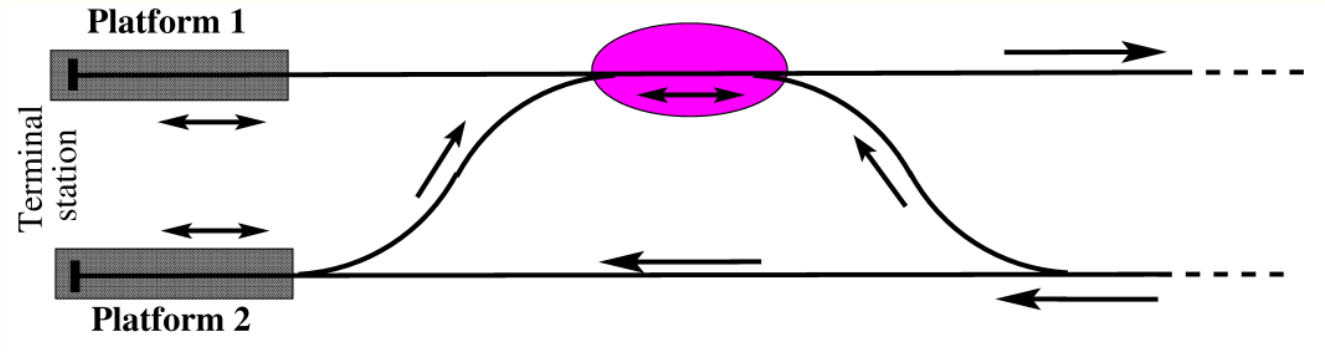

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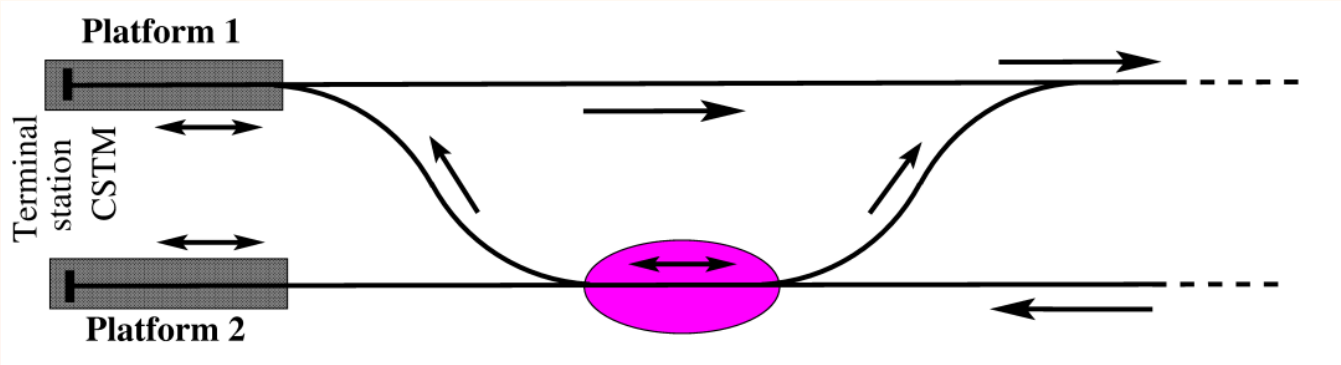

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- Exit from platform 2 delays entry into platform 1
- Higher hindrance in the lower layout
- Lower layout: curve after bottleneck portion: slower exit

Inputs to the tool

Inputs: different infrastructural parameters:

- Stations, network layout
- Passenger demands, traversal times
- Turnaround times at terminals

Output: timetable meeting all constraints with least number of rakes

Case Study: Harbour Line Network

Current Status: Mumbai Harbour line network

- 12 major stations
- 49 rakes in service in peak time - 38 for Harbour and 11 for Trans Harbour

For a 3 hour peak timetable, about:

- 750 Departure-Arrival Events
- 40500 Headway Variables (Integer or Binary)
- 10000 Linkage Variables (Integer or Binary)
- 6500 Platform Variables (Integer or Binary)
- 3200 Precedence Variables for Platform Allocation (Binary)

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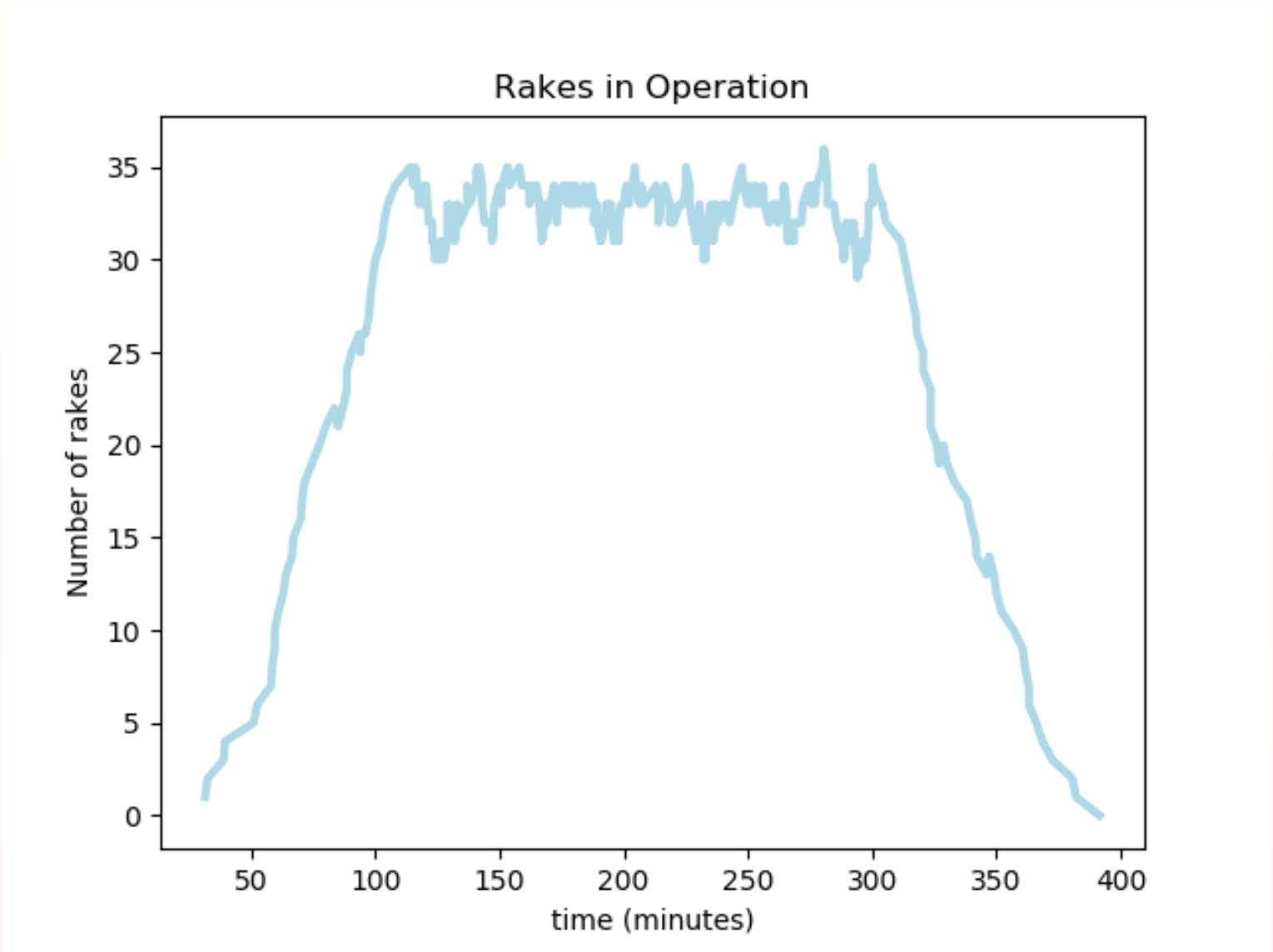
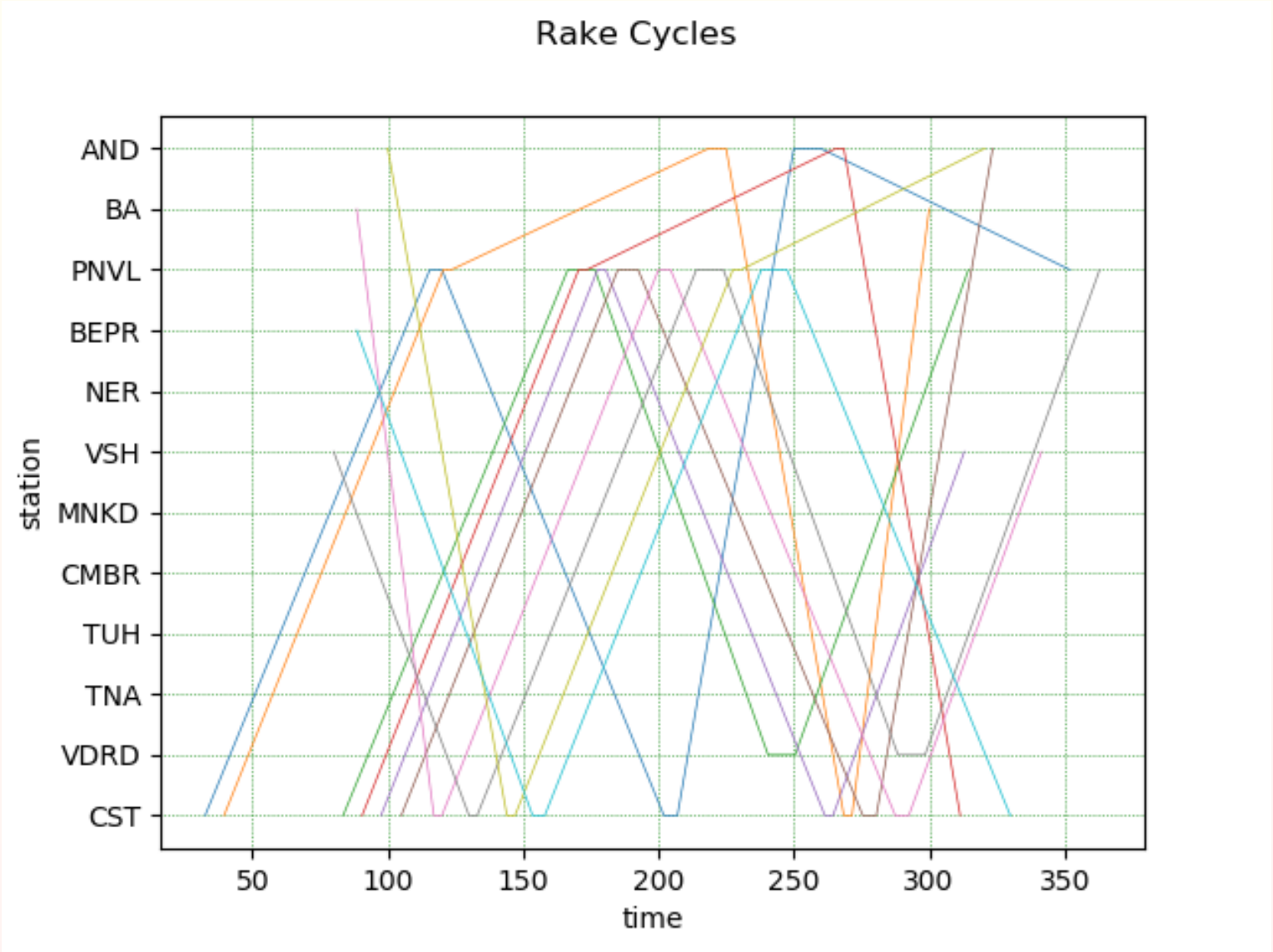
Case Study: Platform Allocation at CST

	ODD-Arrival-dep-events				EVEN-Arrival-dep-events	
Prev-Departure	Next-odd-Arrival	OccupiedFor		Prev-Departure	Next-even-Arrival	OccupiedFor
5:00	5:04	4.0 minutes		5:03	5:07	4.0 minutes
5:07	5:10	3.0 minutes		5:10	5:14	4.0 minutes
5:13	5:18	5.0 minutes		5:17	5:24	7.0 minutes
5:21	5:27	6.0 minutes		5:27	5:33.5	6.5 minutes
5:30	5:39	9.0 minutes		5:38	5:42	4.0 minutes
5:42	5:45	3.0 minutes		5:45	5:49	4.0 minutes
5:48.5	5:53	4.5 minutes		5:52	5:59	7.0 minutes
5:58	6:02	4.0 minutes		6:04	6:08	4.0 minutes
6:07	6:11	4.0 minutes		6:11	6:15	4.0 minutes
6:14	6:18	4.0 minutes		6:18	6:22	4.0 minutes
6:21	6:28	7.0 minutes		6:27	6:34	7.0 minutes
6:33	6:40	7.0 minutes		6:39	6:44	5.0 minutes
6:45	6:48	3.0 minutes		6:48	6:53	5.0 minutes
6:53	6:56	3.0 minutes		6:57	7:01	4.0 minutes

Case Study: Rakes in Operation vs time



Case Study: Rake Cycles vs time



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- Input: services/frequencies
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Constrained programming based solvers:

- Gets a good feasible solution
- Helps to have spreadsheet based validators/checkers

(Though solvers have ensured satisfaction of constraints, one can validate by introducing 'test-flaws')

Periodic and Aperiodic Versions

Periodic Version:

- Tough integer programming problem: but fewer variables (just one period)
- Needs identical situations at end of every time period
- Very compact description of timetable
- Makes crew-scheduling easier

Aperiodic Version:

- Allows customization of services (peak 3-hour timetable need not have all service-counts as multiple of 3)
- Many more event arrival/departure variables

Have tried both versions in Mumbai suburban, but detailed case study is the aperiodic version

Delhi Metro Train Frequency

Line 1 (Dilshad Garden to Rithala)
- Peak Hours : 3 min
- Lean Hours : Upto 12 min

Line 2 (Jahangirpuri to HUDA City Cent)
- Peak Hours : 3 min
- Lean Hours : Upto 12 min

Line 3 (Noida City Cent to Dwarka Sec. 21)
- Peak Hours : 3 min
- Lean Hours : Upto 12 min

Line 4 (Yamuna Bank - Anand Vihar(ISBT))
- Peak Hours : 6 min.
- Lean Hours : Upto 12 min.

(Central Secretariat - Badarpur)
- Peak Hours : 4 min.
- Lean Hours : Upto 12 min.

(Inderlok - Mundka)
- Frequency : Upto 10 min.

Last trains from Inder lok

Towards Dilshad Garden
23:18 hrs

Towards Rithala
23:27 hrs

Towards Jahangirpuri
23:33 hrs

Towards Huda City Centre
22:51 hrs

Towards Anand Vihar
22:27 hrs

Towards Vishwavidyalaya
23:33 hrs

Towards Noida City Centre
22:39 hrs

Towards Mundka
23:30 hrs

Towards Dwarka
22:51 hrs

Towards Sarita Vihar
22:51 hrs

Rangaraj, Suburban Timetabling 1

Delhi metro timetable: example

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- Can use 'VLOOKUP' to quickly merge data across sheets
- "Advanced and mature usage of spreadsheets for large data: pivot-tables": data analysis (summary)
- However, spreadsheet:
  - insufficient for complex allocations/constraint validation
  - has limited ability as a 'solver'
  - no 'while' loop, no jumping from one solution to another
  - not OK for automation, nor for large data
  - semi-automatic, at best

Large data problems: crew allotment

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  Decision-support tools: can be visual

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  - optimize crew allotment
  - choose start-timings to get 'better and better' grouping at congested section

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- Problem specifications: from our own ‘shop-floor’: operations personnel
- Railways/Academia/Software-agency: combination inevitable

Zero-base TT efforts elsewhere: example

The New Dutch Timetable: The OR Revolution, 2009 paper in *Interfaces*

Paper abstract

In December 2006, Netherlands Railways introduced a completely new timetable. Its objective was to facilitate the growth of passenger and freight transport on a highly utilized railway network, and improve the robustness of the timetable resulting in less train delays in the operation. Further adjusting the existing timetable constructed in 1970 was not option anymore, because further growth would then require significant investments in the rail infrastructure.

Constructing a railway timetable from scratch for about 5,500 daily trains was a complex problem. To support this process, we generated several timetables using sophisticated operations research techniques, and finally selected and implemented one of these timetables. Furthermore, because rolling-stock and crew costs are principal components of the cost of a passenger railway operator, we used innovative operations research tools to devise efficient schedules for these two resources.

The new resource schedules and the increased number of passengers resulted

Authors/affiliations (of the famous paper in Interfaces)

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Authors: Kroon, Huisman, Abbink, Fioole, Ybema, Maroti, Schrijver, Steenbeek, Fischetti
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- Department of Logistics, Netherlands Railways: Kroon, Huisman, Abbink, Fioole, Ybema
- Rotterdam School of Management, Erasmus University: Kroon, Maroti
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Similar efforts in Germany: Narayan Rangaraj's collaborators

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Contact details

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  `www.ee.iitb.ac.in/%7Ebelur/railways/workshop`
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