Zero Base Timetabling (ZBTT) on the Golden Quadrilateral + Diagonals (GQD)

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+ 18 students

at IITB

Together with
Railway Board
CRIS
12 Zonal Railways
In 2020

Objectives

New passenger timetable with many objectives

- Faster run times
  - More modern rolling stock available
- Rationalized halt pattern (many new trains added over the years)
- Changes in arrival-departure times
- Create sufficient time windows for maintenance activities
- Create freight corridors for efficient freight operations

Objectives meet customer goals as well as railway operator’s goals

What was achieved (on the GQD)

- De-novo timetabling (zero-base)
- Retimetabled trains at speeds allowed by upgraded tracks
- Compaction
- Got wider, uninterrupted freight corridors
- Transitioned GQD TT process to a software: allows new TT for GQD within 45 minutes (for 1650 daily paths across the GQD)
- Software allows priority-wise scheduling and resource-allocation

Timetabling

Timetable is the (combined) determination of a path in time-space of all the scheduled trains on a network

In sequential terms

- Determine route of a train (origin, destination, halt pattern)
- Determine starting time
- Compute inter-station running times (including speed restrictions)
- Add allowances (for more robustness and punctuality)
- Plan overtakes (precedences) for higher priority trains

If this has to be done for several trains and on many sections, need some support in visualizing and checking all constraints

Timetabling on a network

Indian Railway network is quite complex

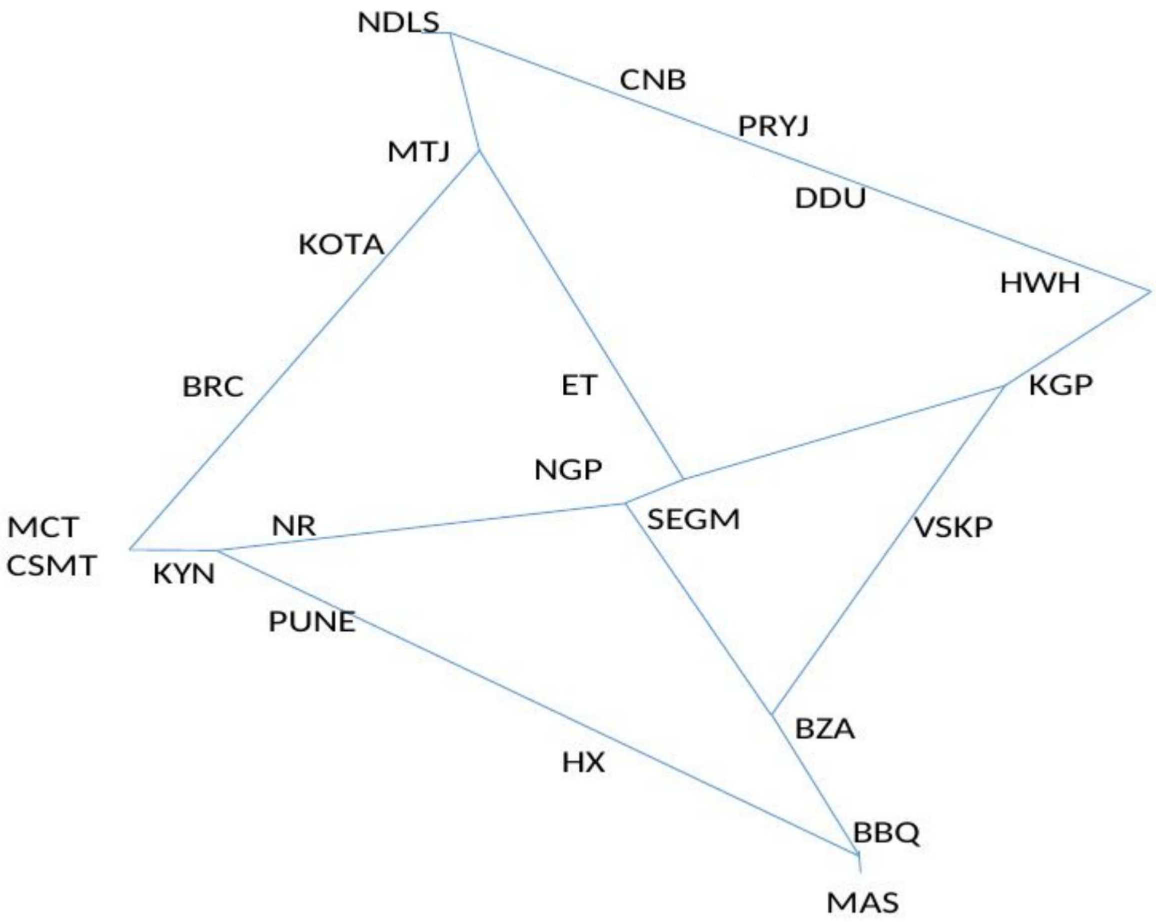
Simultaneous determination of all train timings requires co-ordination

Yearly timetabling conference involving all zonal railways and divisional timetabling personnel

Difficult to make large scale changes

In 2020, IR decided to try making significant changes through a de-novo timetabling effort

One major focused effort was the GQD (Golden Quadrilateral + Diagonals) - keeping in mind schedules on other parts of the network


NDLS
CNB
PRYJ
MTJ
DDU
KOTA
HWH
BRC
ET
KGP
NGP
SEGM
VSKP
MCT
CSMT
NR
KYN
PUNE
BZA
HX
BBQ
MAS

Inputs and Outputs

Inputs that IITB simulator uses

Section details

- Station list (interstation distances)
- Number of lines on each section
- MPS, PSR (from km to km, speed)
- Running lines at stations (loop entry velocity)
- Block working time - to account for IBH/Auto signaling

Train details

- Proposed start time
- Route of train
- Halt duration
- Max speed/acc/dec
- Priority
- Allowances (extent and distribution)

Major outputs

- Traversal details (section by section for each train)
- End to end travel times
- Satsang charts (including allowances)
- Reports
- Diagnosis charts
- Locally usable database of all inputs and also network level timetable

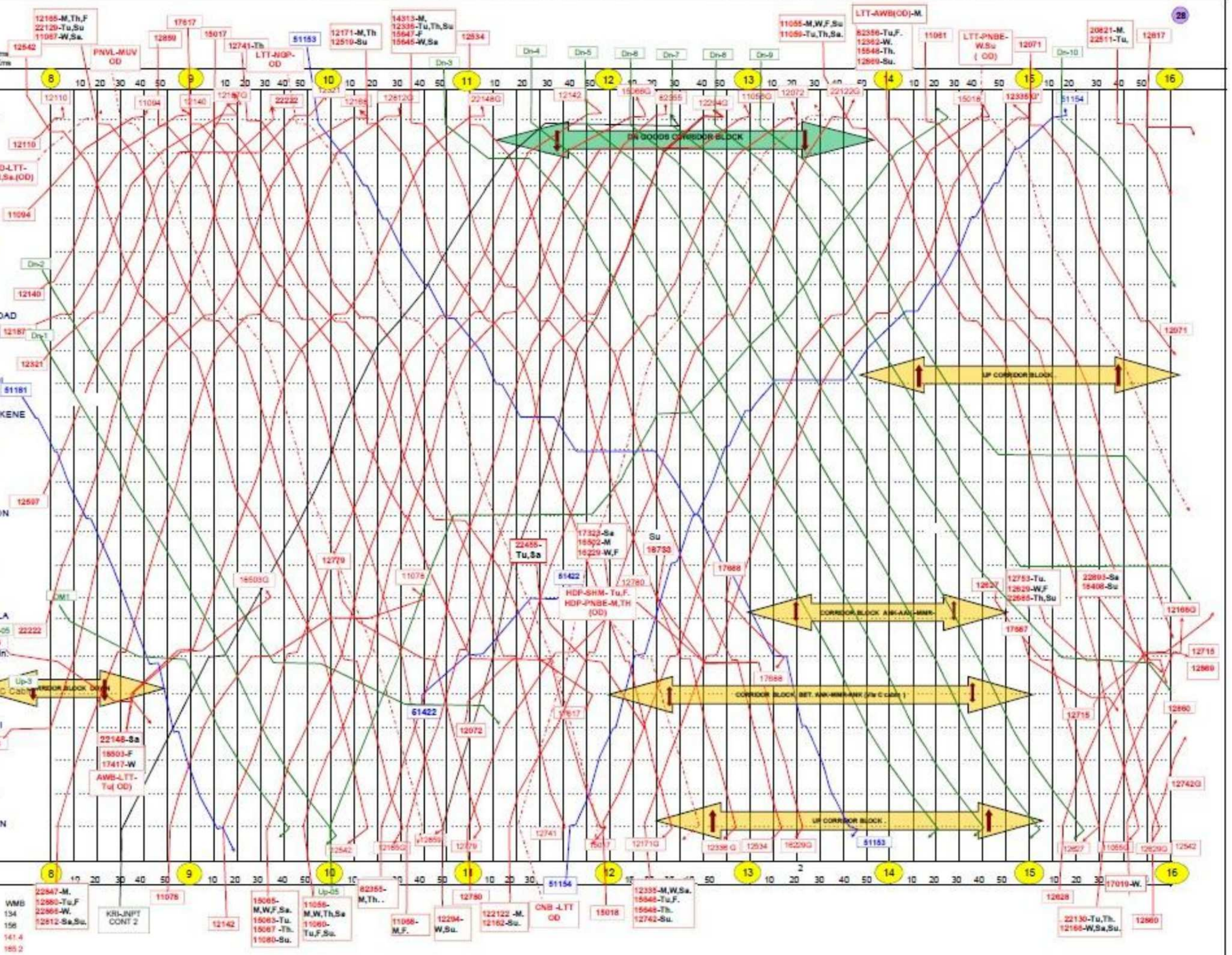
W.E.F. 2020 P8R

IGATPURI - NANDGAON - IGATPURI ZBTT

BHUSAVAL DIVISION Update 14/09/20

LENGTH		148.76 KMS	
SIGNALLING		MACLS	
DOUBLE LINE		IGP - NGN	
BANKING SECTION - NIL			
RULING GRADIENT			
DN	GO - AV	1/110	1.75Kms
UP	MMR-SUM	1/132	5.55Kms

DISTANCE FROM CSTM	STN to STN	
136.51	...	IGATPURI
141.96		IBH
145.75	9.24	GHOTI
150.42		IBH
155.10	9.35	PADLI
161.47	6.37	ASVALI
165.30		IBH
170.19	8.72	LAHAVIT
181.41	11.22	DEVLALI
187.08	5.67	NASHIK ROAD
194.16		IBH
198.60	11.52	ODHA
205.84	7.24	KHERWADI
212.41	6.57	KASBE-SUKENE
218.51	6.10	NIPHAD
225.53	7.02	UGAON
235.38	9.85	LASALGAON
240.81	5.43	IBH
249.28	8.47	SUMMIT
		ANKAI
		ANKAI KILLA
260.18	10.90	MANMAD Jn.
		ANKAI via C Cabin
265.30	5.12	PANEWADI
273.49	8.19	HISVAL
278.81	5.32	PANJHAN
285.27	6.46	NANDGAON



SECTION CAPACITY

		WYOMB	WMB
2013-2014	IGP-MMR	111.7	134
	MMR-NGN	130.8	156
2014-2015	IGP-MMR	117.8	141.4
(Projected)	MMR-NGN	138.5	165.2

Route Classification : 'A'

track circuits,fromSurat to Bharuch.
2) Double Line :- Surat-Bharuch

Distance		Train number		16733	16502	12431	22413	22633	12955	12939
From CCG Kms.	Intermediate Kms.	STATIONS		RMM-OKHA Exp.	YPR-ADI Weekly Exp..	TVC-NZM Raj. Exp.	MAO-NZM GOA Raj.	TVC-NZM S.F Exp.	MMCT-JP S.F Exp.	PUNE-JP S.F Exp.
		From page no		-- --	-- --	-- --	-- --	-- --	-- --	-- --
		Days of operation		Su	M	W,F,SA	SU,M	TH	DAILY	SU,W
		Maximum permissible Speed		110	110	120	110	110	110	110
		Normal/Max. Load		23/24	21/21	18/20	18/20	22/24	24/24	21/22
				H.M.	H.M.	H.M.	H.M.	H.M.	H.M.	H.M.
266.62		Surat(Spl).(ST)(IIIR) (Tapty Br. No. 452 Km. 269/8-9) सूरत (जं)	a	22:10	22:10	P	22:25	22:23	22:40	22:55
	3.69		d	22:15	22:15	22:28	22:28	22:28	22:45	23:00
						+1 TR				
270.31		Utran(Spl)(URN)(III) उत्राण	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	3.3		d	22:22	22:22	22:35	22:35	22:35	22:52	23:07
273.61		Kosad(Spl)(KSE)(IIIR) कोसाड़	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	3.55		d	22:24	22:24	22:37	22:37	22:37	22:54	23:09
277.16		Gothangam (Spl) (GTX) (IIIR) गोठानगाम	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	3.09		d	22:26	22:26	22:38	22:39	22:39	22:56	23:11
280.25		Sayan (Spl) (SYN) (IIIR) सायन	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	6.9		d	22:28	22:28	22:40	22:41	22:41	22:58	23:13
287.15		Kudsad (D)(KDSD) कुडसद	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	2.96		d	-- --	-- --	-- --	-- --	-- --	-- --	-- --
290.11		Kim (Spl)(KIM (IIIR) (Br.478, Km. 292 / 12-13) कीम	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	7.78		d	22:34	22:34	22:45	22:47	22:47	23:04	23:19
				+5 TR	+5 TR					
297.89		Kosamba Jn.(Spl) (KSB) (IIIR) कोसम्बा (जं)	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	4.33		d	22:44	22:44	22:51	22:52	22:52	23:09	23:24
302.22		Hathuran(D) (HAT) हथुरण	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	3.86		d	-- --	-- --	-- --	-- --	-- --	-- --	-- --
306.08		Panoli(Spl) (PAO) (IIIR) पानोली	a	P-22413 22:50	P-22413 22:50	-- --	-- --	-- --	-- --	-- --
	10.24		d	23:00	23:00	22:55	22:57	22:57	23:14	23:29
316.32		Ankleshwar Jn.(Spl)(AKV) (IIIR) (Br. 502. Km. 323 /10-to 325/3-4)अंकलेश्वर (जं)	a	-- --	23:09	-- --	-- --	-- --	23:21	-- --
	9.24		d	23:07	23:11	23:00	23:02	23:02	23:23	23:34
				+3+5	+3	+3	+3	+3	+3	+3
325.56		Bharuch Jn. (Spl) (IIIR) भरुच (जं)	a	-- --	-- --	-- --	-- --	-- --	-- --	-- --
			d	23:23	23:23	23:09	23:13	23:13	23:33	23:45
Engineering Allowance Provided				3	3	3	3	3	3	3
Traffic Recovery time Provided				5	0	1	0	0	0	0
Staggering Time				0	0	0	0	0	0	0
To Page No.				49	49	48	49	49	49	49

Details matter!

- Inter-station running times rounded up to minutes will cause an average of 45 minutes increase in running time on the Mumbai - Delhi route (often more) for all trains
- More detailed sectional running times not possible to maintain unless the data about speed restrictions and train characteristics is accurately captured
- Loop lines at stations need to be accounted for in detail when planning precedences
- Allowances need to be planned carefully
    - Selectively applied for commuter trains and high priority trains

IITB mixed-rail traffic simulator

- Helps capacity planning and identifying bottle-necks
- Multiple trains with different priorities, different running characteristics
- Signals: multiple aspects possible (usually 3 or 4), automatic block signalling
- Station/block infrastructure: running lines, station speed restrictions, main-line, loop-line speed restrictions
- Permanent Speed Restrictions, block section MPS, maintenance blocks, gradients
- Train MPS, acceleration, deceleration, length parameters, source/destination/halt-patterns/halt-durations

Simulator logic

- Travel-advance, Greedy-heuristic with "asynchronous train movement"
- First, high priority trains are scheduled (simulated) from first to last stations
- Next simulate lower priority trains, train by train w.r.t. proposed schedule
- Ensure occupancy information of higher priority trains are respected

Thus: simulator output: a timetable guaranteed to be:

- feasible (train-running/infrastructure constraints-wise)

- conflict-free (multiple trains avail same resource: at **different** times)

Network-related challenges

- Classification of infrastructure into up/down: difficulty for a **network**
- Multiple zero-mileposts inevitable (since **not** a linear network)
- Often need to **jump** milepost-distances (at merging junctions)
- Reversals are typical (but train journey has to move only forward)
- Trains “vanish” from GQD and re-appear elsewhere
    - These sub-routes have to be linked with some time-gap, **not** independent simulations
- Need to focus on high-impact part of network (else can start GQD only after **rest of IR** is completely modelled!!)

How was compaction achieved?

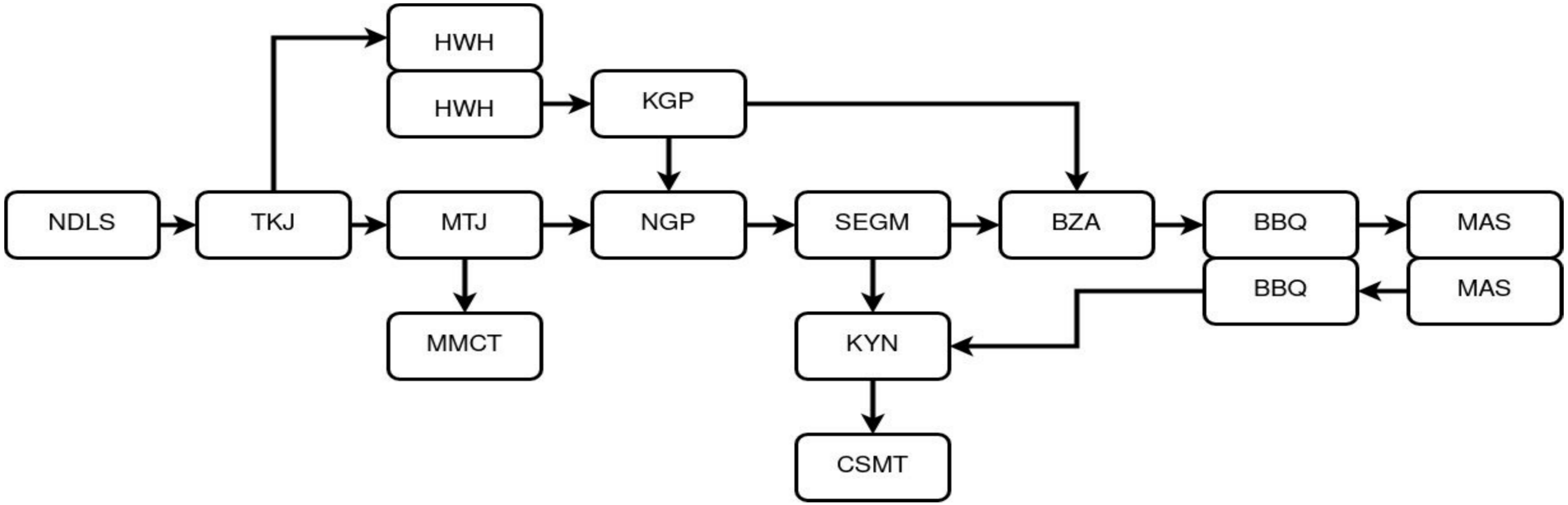
- Compaction consists of (a) canceling/truncating train runs that are not viable - an exercise that must be done from time to time, (b) speeding up of trains (running trains at higher speed because of rolling stock), (c) reducing halts and duration of halts and (d) grouping of trains
- Better grouping of fast and slow trains results in freeing up capacity. (Fast/slow trains mixed or interlaced causes more overtakes: **bad**)
- Grouping happens by appropriate and careful choosing of the start-time at the start-station.
- IITB Simulation currently does **not choose** start-time. That is decided by end-user: ZR-origin and ZR-destination (e.g. to ensure no "un-earthly" hour and no suburban-train interference)
- Once start-timings are fixed and priorities are given, then slack can get removed by IITB simulator, which **aggressively schedules trains** (priority-wise) as soon as resource is available (with due provision of allowances for robust timetabling)

IITB participation in ZBTT: for GQD

- During Jan 2020 to Dec 2020, IITB simulator was used for ZBTT on GQD
- Freight path scheduling (after coaching train timetabling)
- Input was taken from CRIS' database in CRIS format
- Output was given in a format that CRIS could import into the Satsang database
- Diagnostics tool was also developed for ZR self-usage
- All software was using FOSS (Free and Open Source Software): runs on any laptop/desktop: no internet/cloud needed

Several challenges

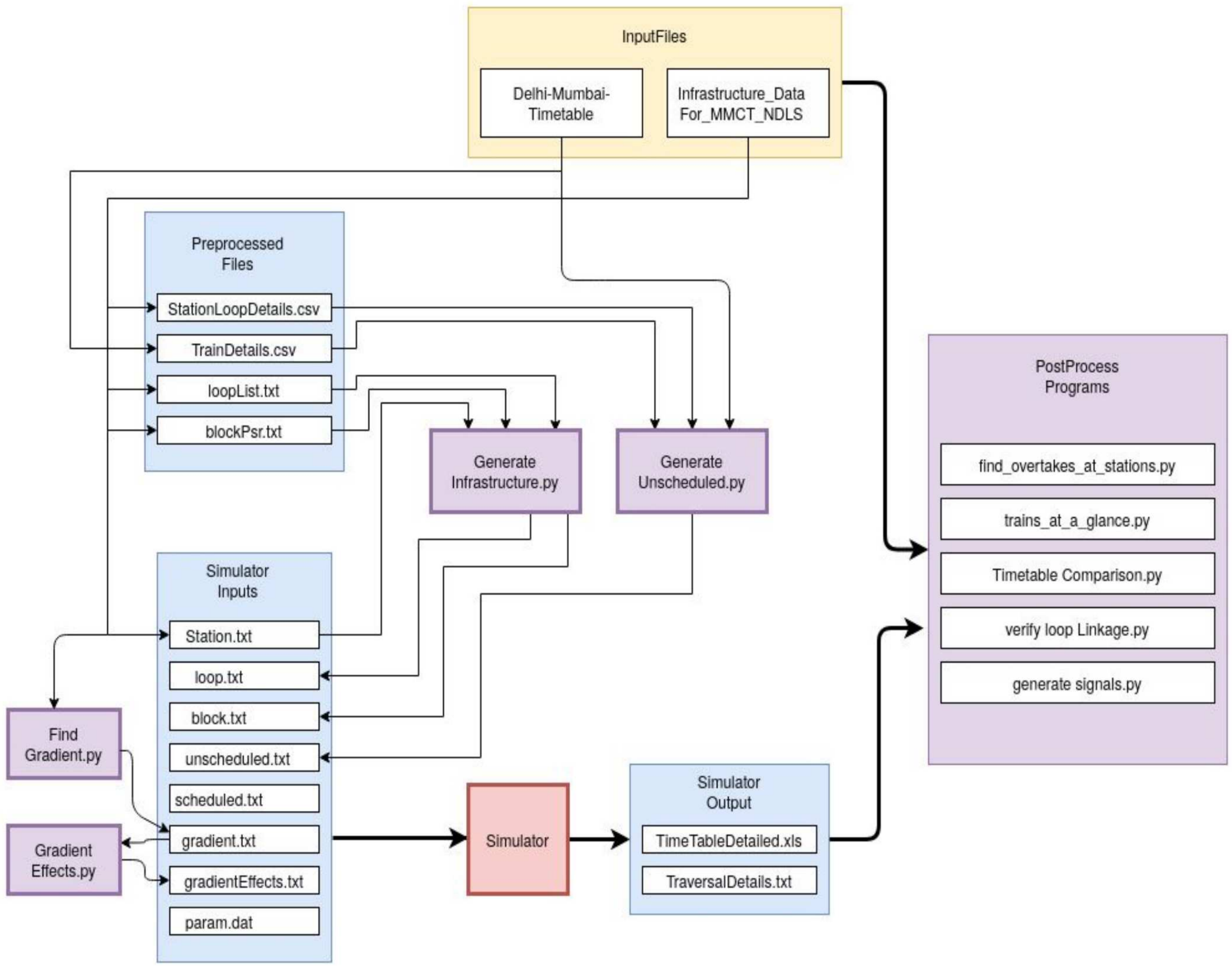
Network Simulation : Problems faced



- Simulator was designed for linear networks.
- Needed capability to find path from one station to other.
- Simulator is direction specific and train can only travel in one direction (**<u>reversals</u>** handled using multiple iterations)

Major challenges

- Some trains leave on day 1, and can remain in GQD until day 3
- Conflicts between trains can happen over 5 days: need to simulate for trains **<u>starting</u>** on 5 consecutive days
- About 1600 daily paths: 1600 X 5 = 8000 trains need simulation (one by one): priority-wise
- Suburban/Local-train constraints at Mumbai, Howrah
- Allowance strategy (EA + TA)
- Shifted to seconds (from erstwhile minutes/quarter-minute) accounting
- Routes have significant overlap at terminals and also HWH-KGP, NDLS-MTJ and SEGM-NGP: cannot **<u>independently</u>** schedule and then merge
- Some trains leave GQD (e.g. BSL) and enter again elsewhere (ET/PCOI)



- CRIS data processing
- Allowance allocation
- Simulator inputs/outputs
- Processing back for CRIS/ZR-CPTM feedback
- Satsang import

- Huge software exercise: Java and Python skills
- IITB project students involved: learning railways terminology

Freight pathing: in the presence of coaching trains

CC-point: Crew-Change-Point

For each of 6 routes, and each direction up/down

- Some “section” trains: CC-point to the **next** CC-point
- Some “crack” trains (i.e. **skipping** one CC-point)
- 2 end-to-end trains (like TKD-BSR, AJJ-KYN)

Section and crack each have 100 kmph, 75 kmph and 60 kmph (in 20:30:50 ratio, and with appropriate acc/dec characteristics)

Procedure:

- Reserved paths for coaching train and fired freight trains in the extracted freight-corridors
- Experimented with limited number of freight trains of higher priority

Freight trains-End to End and crack paths Trains (NDLS-MMCT)

Train No	Time-of-Run (minutes)	Speed (kmph)	Section
11031201	1161.29	68	TKD - BSR (1315 km)
11031202	1355.07	58.28	TKD-to-BSR
11031101	1169.14	67.55	BSR-to-TKD
11031102	1179.94	66.93	BSR-to-TKD
11031501	190.3	91.59	KOTA-to-BTE (290.5 km)
11031502	194.58	89.57	KOTA-to-BTE
11031602	233.67	74.59	BTE-to-KOTA
11031601	237.18	73.48	BTE-to-KOTA

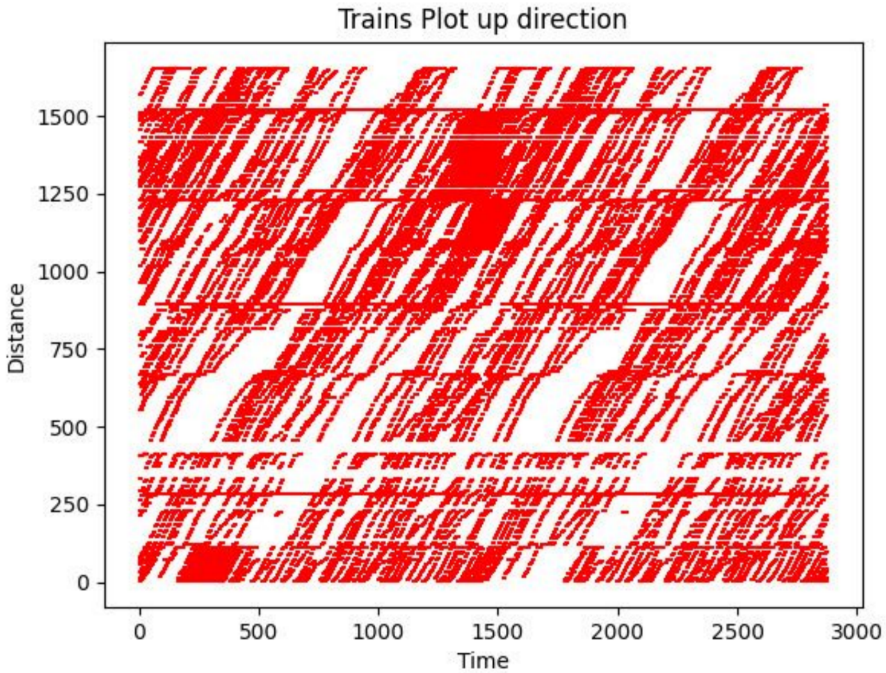
Route 1: Freight trains - Sectional Trains (NDLS-MMCT)

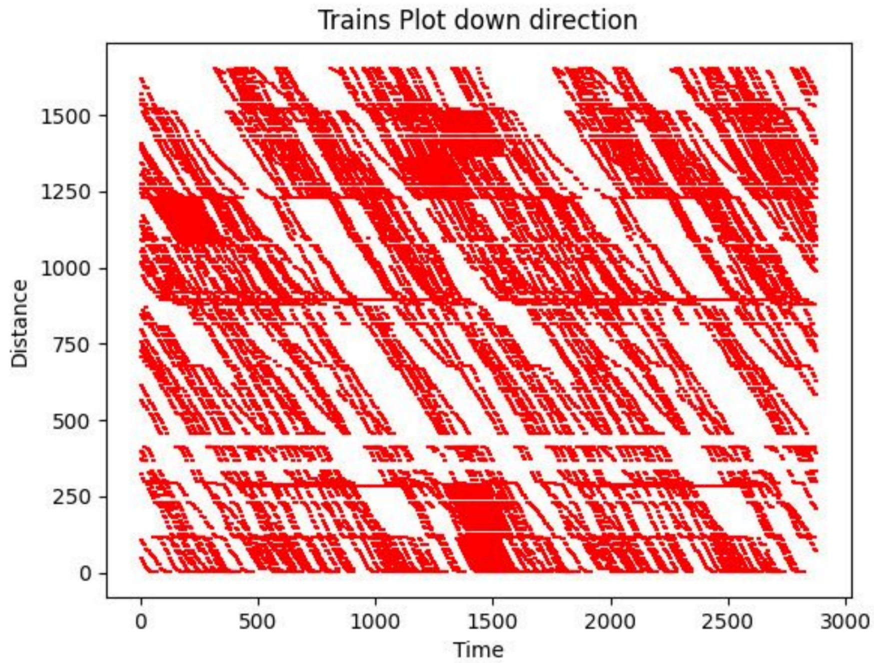
Train No	Time of Run (min)	Speed (kmph)	Section (Distance = 182.72 km)
11031308	150.9	72.65	SWM - BTE
11031301	154.48	70.97	SWM - BTE
11031404	130.33	84.12	BTE - SWM
11031409	150.95	72.63	BTE - SWM

Freight running target

- Average speed 50 kmph
  - Good for customers
  - Good for rolling stock utilization
  - Good for crew utilization
- Target run between crew change points - 300 km (at least 250 km)
  - Currently closer to 150-200 km, except for a few crack paths on some sections
- A major cause of low end to end speeds is enroute detention of freight trains because of priorities (overtaken by passenger)
- Freight corridors will allow smoother running of freight
  - Caution: Too many trains in a freight corridor will require many holding lines and crew for balancing the requirement

Preliminary coaching train plots for HWH-MAS (R3)





Example of details in timetabling: Allowance: incorporation into the simulator

- 3 main steps: 1:pre-process CRIS data, 2:simulate, 3:post-process back to CRIS format (and human readable)
- Allowance: not part of simulation. We created halts before Inter-Change-point (IC-point): halt-duration+AC-loss+DC-loss = allowance. Sometimes 2 or 3 halts before IC point
- Simulator creates halt and then in post-process, we "absorb" halt into running.
- We also show halt-duration+AC-loss+DC-loss as EA and TA
- Much book-keeping in creating halt, halt-duration, and then absorbing back and report in Satsang as EA and TA

Allowance: incorporation by iitb-sim

- Allowance "consumption": usually anywhere within the division, and not "just before IC-point"
- Extreme-case: all allowances consumed **just befor**e IC-point (since we did not need earlier)
- Then block-section would show two trains simultaneously in same block section (or overtake)
- We found this in WTT: overtake within block-section (just before IC-point)
- We **had** reported allowance-based-halt **as halt**: caused confusion
- (In above extreme case, halt one train and send another: simulation was done assuming this anyway.)
-

ance	TRAIN NO
Inter medi- ate Kms	STATIONS
	From Page No.
	Days of operation on section
	Normal/Max. Load
	Max. Permissible Speed (Kmph)

59024	12910	12215	12952
BL- MMCT Valsad Fast Pass.	NZM- BDTS Garib- rath Exp.	DEE- BDTS Garib- rath Exp.	Mumbai Rajdhani Exp.
....	96	96	96
Daily	M,Th,Sa	Tu,W,F,Su	Daily
18/22	21/21	21/21	20/21
100	120	120	130

					-- --	-- --	-- --	--
134.86		Gholvad (Spl) III (GVD)	a	+2 ..	06 05	+2 EA	+2 EA	+[illegible] A
	11.08	घोलवड	d	05 4[illegible] 4	06 06	06 08 1/2	06 08 1/2	06 [illegible] 1/4
123.78		Dahanu Road (Spl.) III (DRD) डहाणूरोड	a	3+4 3[illegible]T ..	5+1TR 06 22	+3 EA	+3 EA	+[illegible] A
			d	05	06 24	06 17 1/4	06 17 1/4	0[illegible] 7

129[illegible]	12215	59024	12952	14707	93004	93006	12954	
NZM-BDTS Garib-rath Exp.	DEE-BDTS Garib-rath Exp.	BL-MMCT Valsad Fast Pass.	Mumbai Rajdhani Exp.	BKN-BDTS Ranak-pur Exp.	DRD-VR EMU	DRD-CCG EMU	August Kranti Rajdhani Exp.	STN. CODE
120	120	120	120	121	....	....	121	
M,Th,Sa	Tu,W,F,Su	Daily	Daily	Daily	Daily	Daily	Daily	
21/21	21/21	18/22	20/21	23/24	12-12	12-12	20/21	
120	120	100	130	110	110	110	130	
110	110	[illegible]	[illegible]	10	110	110	110	
H.M.	H.M.	H.M.	H.M.	.M.	H.M.	H.M.	H.M.	
.. ..	.. ..	06 22	.. ..	..	–	–	.. ..	DRD
06 17 1/4	06 17 1	06 24	06 27	56	07 05	07 15	07 42	डहाणूरोड
		+7 TR						N/S(118/17)
.. ..	.. ..	06 42	.. ..	..	07 20	07 30	.. ..	VGN
06 23 1/2	06 23 1	06 43	06 33 1/4	07 3 3/4	07 20 1/2	07 30 1/2	07 48 1/4	वाणगांव

Train Number	Train Name	Traversal Time between DDU-PRYJ -GQD(Minutes)	Traversal Time between DDU-PRYJ-IIT B (Minutes)	Extra allowance based Halts AT STATIONS (Minutes)
12301	HWH -NDLS **Rajdhani**	112 mins	120.72 mins	KCN=4.12 PCOI=4.12 NYN=4.15
12313	SDAH -NDLS **Rajdhani**	112	122	KCN=4.12 PCOI=4.12 NYN=4.15
12309	PATNA **RAJDHANI**	112	128.78	BEP=4.50 KCN=4.51 PCOI=4.50 NYN=4.54
12423	Guwahati **RAJDHANI** EXPRESS	112	138.58	BEP=4.51 KCN=4.50 PCOI=4.50 NYN=4.53

Allowance incorporation: IITB-implementation

Before Interchange point (IC-point):

- 2 or 3 block sections: distribute total allowance amount X seconds
- Calculate amount per station y seconds per station
- Halt duration = y - 0.7* accln-loss - 0.7*decln loss
- Actually accln-loss and decln-loss is more than what was subtracted
- Each train actually gets more allowance (because of 0.7 factor) (unless indeed decln/accln was not from MPS, due to PSR for example, or small-block-section)

How to **timetable** consumption of EA+ TA?

Allowance can be given in block-section only

- this causes decrease of overall “throughput” (even if automatic signalling is considered for those blocks)
- For block-precedence/conflict to not be detected, need exact signal locations for automatic block signalling blocks
- Halt addition/removal may or may not “cascade” to create new conflicts, but EA+TA is 15 to 20% of the traversal duration: so adding EA/TA can cascade to create new conflicts.
- Concentrating EA+TA to just few block sections can further cause cascading.
- Since blocks are **more scarce** resource than loops, throughput is higher if allowance is **timetabled** to be consumed in loops (as halts) (We assumed more loops just before inter-change points.)

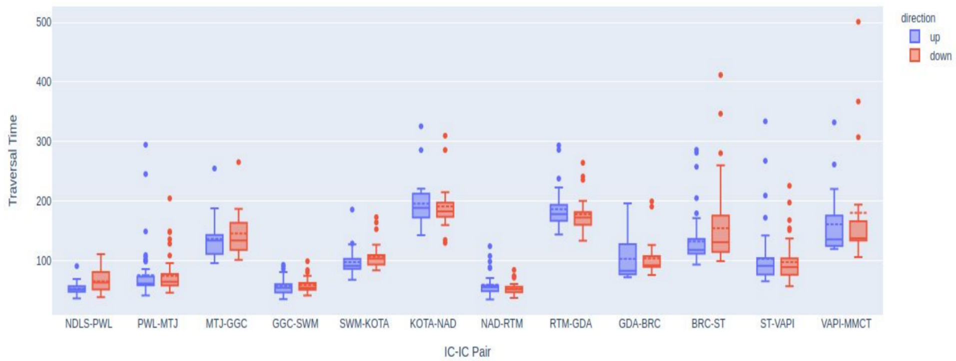
Diagnostic tool

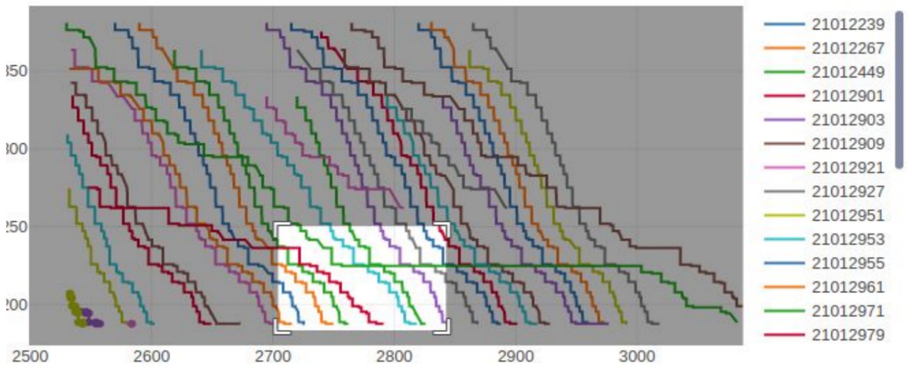
- This is for each ZR usage, no data can get edited accidentally.
- Only train simulation data kept available: still sensitive due to ZBTT exercise (and hence there is a login/password).
- Each TT/divisional level personnel can use for following purposes
- Analyze excessively long halts
- Hosted on a server by IITB through CRIS help
- Complements Satsang in some ways, but is independent effort done by IITB for self-usage (for diagnosis) since Satsang is far more integrated (and hence is better not touched/edited hastily)

Database for simulation analysis

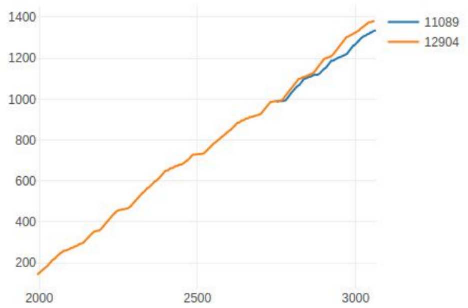
- Simulation inputs & outputs stored in a single database
- Permits complex queries that link trains, stations, traversals etc.
- We use it internally for analyzing GQD + simulation data
- Uses:
  - Identifying freight corridors from train traversals visuals
  - Adjustment of maintenance blocks
  - Find better firing times, replanning allowance allocations for efficiency
  - Identify problematic interchange-interchange sections
  - Pinpoint causes for longer train running time
- Requires only a web browser
- This tool made available to the Zonal Railway TTICs on 1st Oct

Database for simulation analysis: via browser

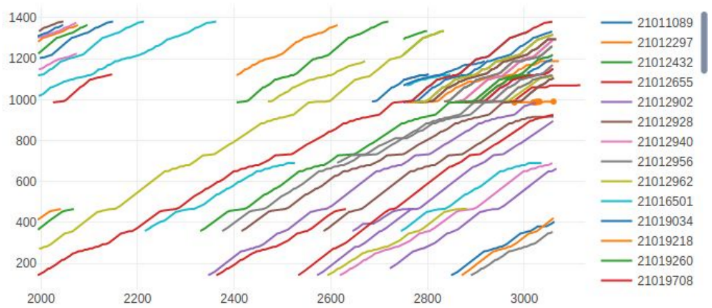




ETE Traversal

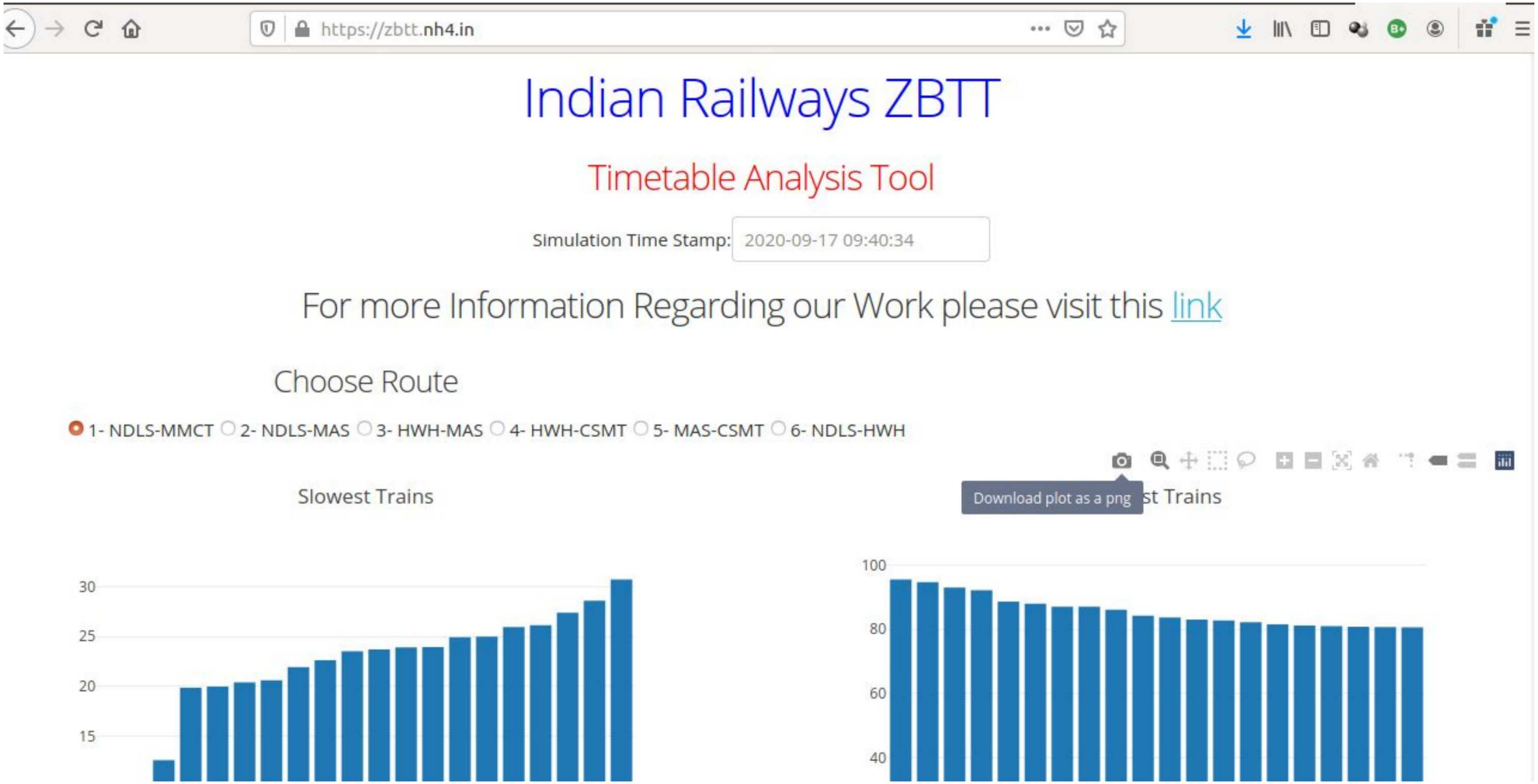


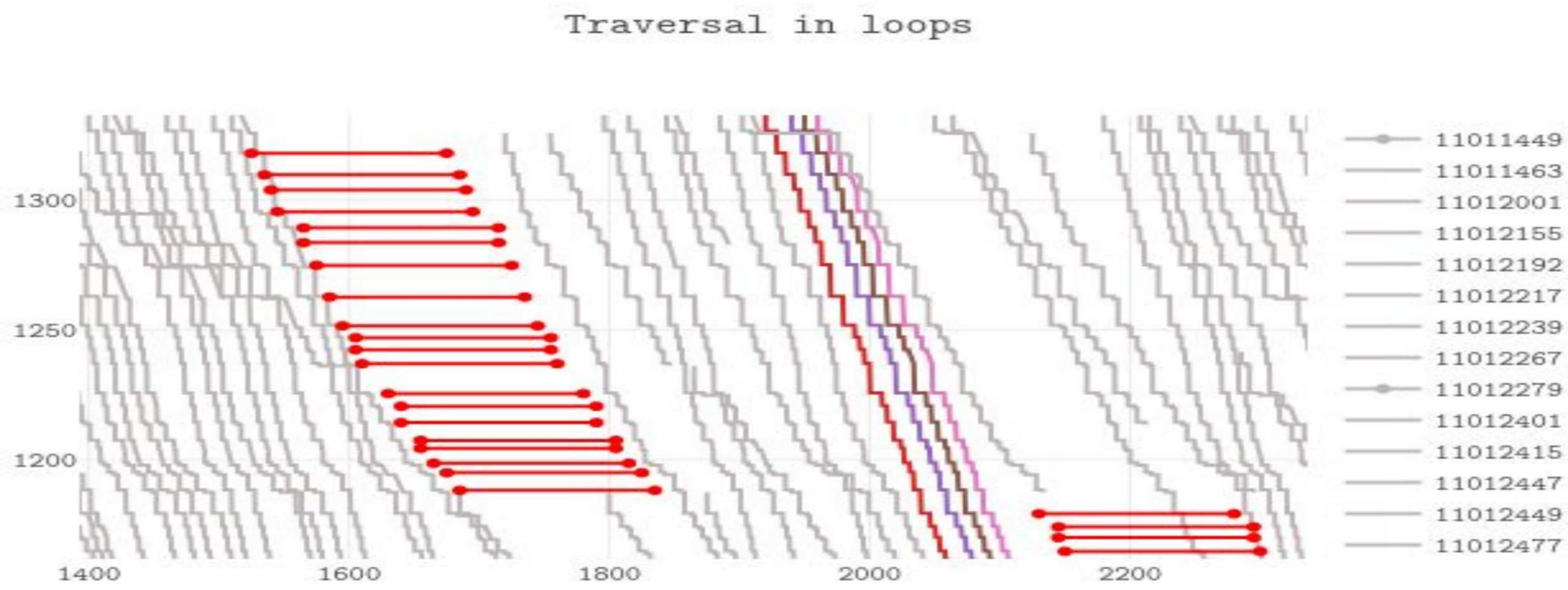
All Trains in this Region



Diagnostic tool features

- String charts with hover details (much like Satsang) for full train lengths
- Overlays maintenance blocks to optimize for conflicts
- Compare simulations IITB simulation times with original GQD schedules
- Zoom into specific loops to analyze long halts across zones
- Zone-wise view as well as view of full network
- Main utility:
  - Bird's eye view of simulation results without Satsang
  - String charts for visual inspection of pain points
  - Fine-tune schedules for trains at zonal level for improving timetables


https://zbtt.nh4.in
Indian Railways ZBTT
Timetable Analysis Tool
Simulation Time Stamp: 2020-09-17 09:40:34
For more Information Regarding our Work please visit this link
Choose Route
1- NDLS-MMCT 2- NDLS-MAS 3- HWH-MAS 4- HWH-CSMT 5- MAS-CSMT 6- NDLS-HWH
Download plot as a png
Slowest Trains
st Trains
30
25
20
15
100
80
60
40

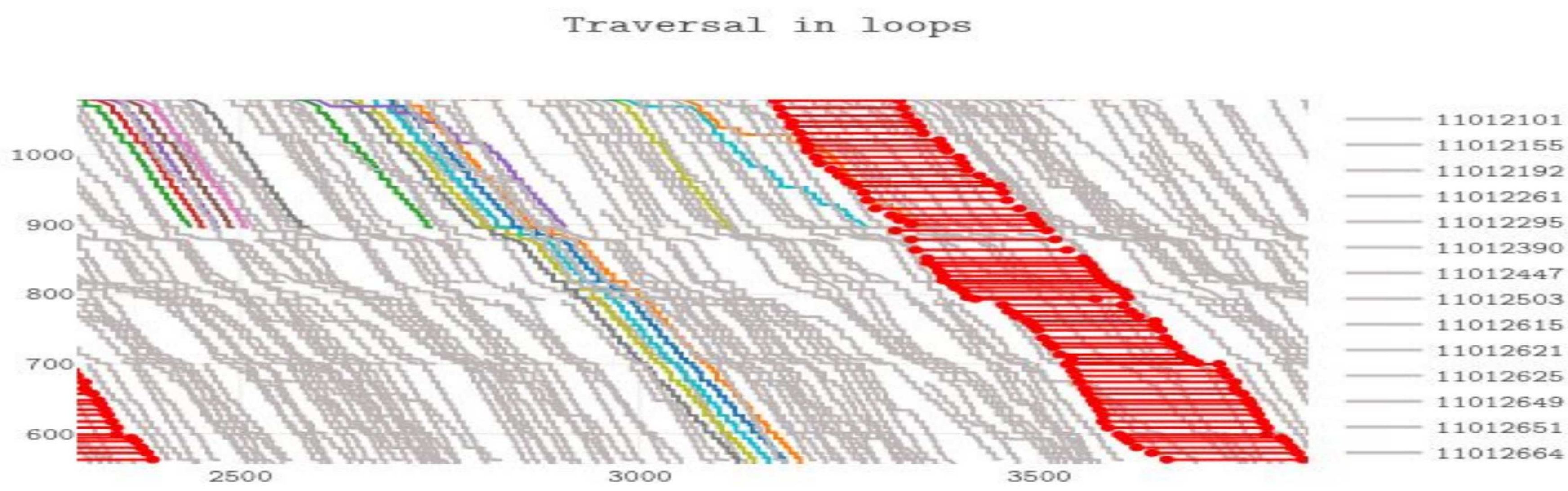


Above plot: Route 1: down: MMCT to NDLS: only end to end (BSR to TKD) visible here

Horizontal axis: time, vertical axis: loop numbers (roughly stations)

Red line: maintenance block, grey faint lines: passenger trains

All other colour curves: freight trains



Above plot: Route 3: down: MAS to HWH: shows end-to-end (TNP to KGP),

crack (BZA to DVD) and section (BZA to RJY)

Horizontal axis: time, vertical axis: loop numbers (roughly stations)

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Performance measures that are useful in semi-automated timetabling

Single train

BRT excessively high on some section → PSR mis-specified, Block length (slightly) improper

Multiple train

Slow traversal on a block → small blocks in auto signaling territory can indicate congestion - rare

Long halt at station → (a) for low priority train, examine whether a better start time is warranted, (b) for high priority train, examine whether block working can be reduced as warranted, (c) examine number of loop lines at subsequent station

Minimum headway → points to areas where BWT can be reduced

Freight statistics

Mumbai Delhi

End to end : BSR - TKD (1315 km), Container trains, crew halts at ST, RTM and KOTA, 4 in each direction (end to end)

Max speed 100 kmph, Acc: 0.08 m/s^2, Dec: 0.1 m/s^2 (for loaded)

and 0.15 for **unloaded**

Sectional trains: RTM-KOTA (263 km)

Examples of Re-Timetabling suggestions

	Current Timetable		ZBTT Time		IIT B Simulation	
Train Number	Start time	End Time	Start time	End Time	Start time	End Time
12615	19:15	06:30	18:50:00	06:35:00	18:50:00	03:21:31
12616	18:40	06:20	16:10:00	04:55:00	16:10:00	01:13:59
12840	23:45	04:00	19:15:00	23:10:00	19:15:00	22:06:20
12839	23:45	03:50	23:45:00	03:15:00	23:45:00	2:54:23

Trains ** Can be considered for earlier start from origin and therefore arrival on the previous night at destination. Some more examples are possible on Central Railway at Mumbai

Some timetabling possibilities - arising from simulation

Grand Trunk Express - Given the saving in time suggested by simulation, it can be made a 1 night journey in one or boths sides of the run - new timings can be evaluated end to end - time saving suggested by simulation for consideration of zonal railways - new time can be evaluated

Chennai Howrah Mail can be made 27 hours in each direction and can be a single night journey both ways - new timings can be evaluated end to end - time saving suggested by simulation for consideration of zonal railways - new time can be evaluated

If VSKP - LTT express has to have the same arrival timings at LTT to continue platform turn around, 3 hour saving on run time can be retained with fixed departure-arrival times by changing the route from BZA-WADI (via GNT-GTL instead of WL-SC) - this will provide new connectivity - time saving suggested by simulation for consideration of zonal railways - route to be evaluated by SCR (part that is not on GQD)

Maintenance blocks and freight corridors

Block	Start time of MB	End time of MB	Duration of MB	Train(s) bursting the bloc	Start of FC-1	End of FC-1	Start of FC-2	End of FC-2
RLK-MEP	22:10	01:10	03:00	{'11012951'}	02:36	04:27	05:42	07:26
RLK-NAD	23:50	02:50	03:00	{'11012926'}	03:49	05:10	05:18	06:27
NAD-RLK	22:04	01:04	03:00	{'11012951'}	02:32	04:18	05:39	07:17
NAD-BRNA	09:40	14:34	04:53	No train bursts this block	03:54	05:24	01:32	03:01
BRNA-NAD	15:41	20:31	04:50	No train bursts this block	08:12	09:50	10:53	12:29
BRNA-KUH	09:43	14:38	04:55	No train bursts this block	03:57	05:31	01:35	03:08
KUH-BRNA	15:30	20:20	04:50	No train bursts this block	10:40	12:19	08:01	09:39
KUH-RNH	09:49	14:42	04:52	No train bursts this block	04:03	05:37	01:46	03:11

Maintenance blocks (MB)

Freight corridors (FC) (of duration 1 hour and more)

On every block section, available maintenance blocks of 3 hours or more are identified. In some cases, the present timetable has a small number of trains that burst these blocks and may need adjustment.

Freight corridors of one hour or more during the day are also identified.

Suggestions for going forward, after this effort

- Systematic analysis of available freight and maintenance corridors on each route
  - Already clear that some bottleneck sections should use maintenance and freight corridors in a flexible manner, depending on requirement
- Bottleneck section on each route to be identified (together by ZRs) and passenger timings reworked using ZR suggestion.
  - Identification of some trains whose timings, if reworked, could lead to significant improvement freight corridor availability overall
- ZR/RB suggestions of speeding up of passenger trains (from rake utilization point of view, for example): can be checked in an hour or two.
- Integrate this tool with CRIS database
- Tool runs on standalone laptop: just FOSS packages
- Transition to systematic tool: **inevitable** in the long run: turbulence of transition almost over.

Some achievements

- Proposed timetable can be checked for feasibility on the entire network
  - New proposed timings for one or more train can be checked quickly
- Diagnostic tool for sectional running times and other performance parameters
  - Statistics on running can be extracted easily (including global statistics)
- Bottleneck sections can be identified
  - Long waits for lower priority trains
- Freight corridors and maintenance blocks can be identified
- Freight paths can be created and feasibility of crack paths examined

Future possibilities - many interesting options

Two examples

- Network analysis of traffic
  - Possible that NCR (DDU-Kanpur) and WCR (Bina-Jhansi) sections of the GQD (and overall IR network) are bottleneck sections and need to drive the end to end timetables
  - These are dynamic changes over the years and require periodic review
  - Similar analysis at zonal levels
- Rake utilization and planning can drive timetabling to a larger extent, where warranted - options are now easier to explore

ZBTT (contd) & tool development challenges

- Key challenges faced within ZBTT from a tool-development viewpoint
- Need to provide ZBTT solution: but also make effort more useful for later years (tool ought to survive)
- Separation of tool from infrastructural/train-specific details
- End-user should not need to know tool-details
- Just data-in and data-out perfect for tool-**users**
- Real-life problems (IR) still far too large for computer-solutions
- This full talk, and contact details will be available, and also at:

www.ee.iitb.ac.in/%7Ebelur/talks 99874 66 279

Summary of key challenges

- Need for heuristics (rather than global optimum)
- Recall that in TT, “search space” is just too large. Cannot manage without heuristics. (“Optimize” is quite a buzzword.)
- Scheduling trains realistically needs “simulating” train’s acceleration/running/deceleration **anticipating** signal location (more soon)
- Volume of data (train diversity, route-diversity, multiple paths between OD)
- Put a **time-out** for badly proposed train-paths (and proceed further)

Multiple expertises, need team-trust

- End-user’s clear formulation of requirements: with priority of what is more important
- Domain know-how
- Operations Research skills (underlying academic know-how)
- Software skills (coding, data-handling)
- More permanent “home” for the developed tool (End-user’s sister)
- Inevitable to have diversity within each sub-team. (Not assembly-line)
- Famous example: Kroon “et al” paper on Dutch timetabling

De-novo timetabling elsewhere:

The new Dutch timetable: the OR revolution, 2009 paper in “Interfaces” journal

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

2009 paper about new Dutch timetable: author affiliations

Authors: Kroon, Huisman, Abbink, Fioole, Ybema, Maroti, Schrijver, Steenbeek, Fischetti

Affiliations: railway personnel/software-firm/academia

- Department of Logistics, Netherlands Railways:
  - Kroon, Huisman, Abbink, Fioole, Ybema
- Rotterdam School of Management, Erasmus University: Kroon, Maroti
- Econometric Institute, Erasmus University Rotterdam: Huisman
- CWI and University of Amsterdam: Schrijver
- Safiro Software Solutions: Steenbeek
- University of Padova Italy: Fischetti

Separation of IITB/ZR/RB/CRIS roles in ZBTT: now/later

What IITB is providing

- End to end timings of proposed trains
- Daily paths - as of now, based on Tuesday timetable
- Grouping of all trains that use Tuesday paths
- Can include other paths as required on other days
- Freight corridors
- Maintenance corridor suggestions
- Analysis of overall network capacity
- Provide charting tool and analysis to ZRs through CRIS

What zonal railways can do

- Propose **starting times** of trains in consultation with each other
- Firm up Interchange point to Interchange point timings
- Allocate allowances internally
- Group daily trains - to make maximum use of daily paths
- Identify freight paths that make good use of crew times - e.g. crew change points that are 300 km or more apart, so as to achieve good speeds

What Railway Board can do

- Set overall norms for speeds, allowances and punctuality, and Maintenance norms
- Provide more realistic locomotive parameters from footplate experiments.
- Co-ordinate useful end to end freight paths where there is traffic

What CRIS can do

- Host the overall timetable, including charting tools
- Integrate timetable with Rolling Stock management system (ICMS) and COA

Summary of ZBTT tool

- IITB simulator cannot “replace” ZR (end-user) timetabling.
- Can complement ZR TT expertise by providing a tool (for faster iterations)

  ZR/divisional TT gets **network** level overview on their own PC (to gauge feasibility across zones before proposing)

- Provides benchmark BRT (can compare with field-trials)
- All agree that too much slack while timetabling is “self-goal”!!
- With track upgradation, changing user-patterns, tool helps in quickly re-timetabling: zone-wise, network-wide

  (TT is always ongoing exercise)

- All data (including PSR) in one central place, *uniform* format!
- Approximate when needed (else we won’t reach anywhere)

Managing Suburban constraints (with ZBTT)

- The new Timetable needs to take in account suburban railway operations in the metro areas of
  - Mumbai metropolian region (CSMT-KSRA, CSMT-KJT, MMCT-VR)
  - Chennai - (MAS-AJJ)
  - Howrah - (HWH-BWN and HWH-KGP)
- The speeding up of trains in the IITB simulator can result in more trains needing resources during the Peak operation period of suburban railway network.
- The compaction of timetable also may result in trains arriving at inconvenient hours.
- Wholesale re-timetimabling of suburban network (during ZBTT exercise): not recommended

Proposed solutions : Suburban constraints

- Maintain fixed number of slots for long distance train paths in the suburban timetable.
  - Slots themselves need not be rigid and can be tweaked a little based on local constraints.
- Adjust trains arriving at the cusp of transition periods from off-peak to peak and vice-versa by modifying their departure.
  - Might be an iterative process.
- Example: 16332 : TVC-CSMT SUF arrives at 19:05 at CSMT. Delayed departure can be suggested.
- Some trains arrive at very inconvenient times after speeding up (in proposed GQD timings and definitely so in simulated results).
  - 12702: Hussain Sagar Express : Arrives at CSMT 03:07
  - 11028 : Chennai - Mumbai Mail : Arrives at CSMT 03:16

Sections where multiple lines **are** considered

List of multiple lines in simulator

NDLS-PWL	4 lines
PWL-MTJ	3 lines
NEWC-JTHT	4 lines
STN-SKG	4 lines
KSRA-IGP	3 lines
KJT-LNL	3 lines

More lines can be added if required.
In most other cases, additional lines are for freight, suburban traffic, bankers and for additional local flexibility (have little impact on overall GQD schedule)

Simulator decides which of the multiple lines to use

General rule: use main UP and DN line when available, and additional lines when **unav**ailable

Zonal railways can retain the flexibility

If specific trains **must use** additional lines, this can be incorporated by IITB

Figure 1: Typical tractive effort vs speed (source: AREMA 2012)

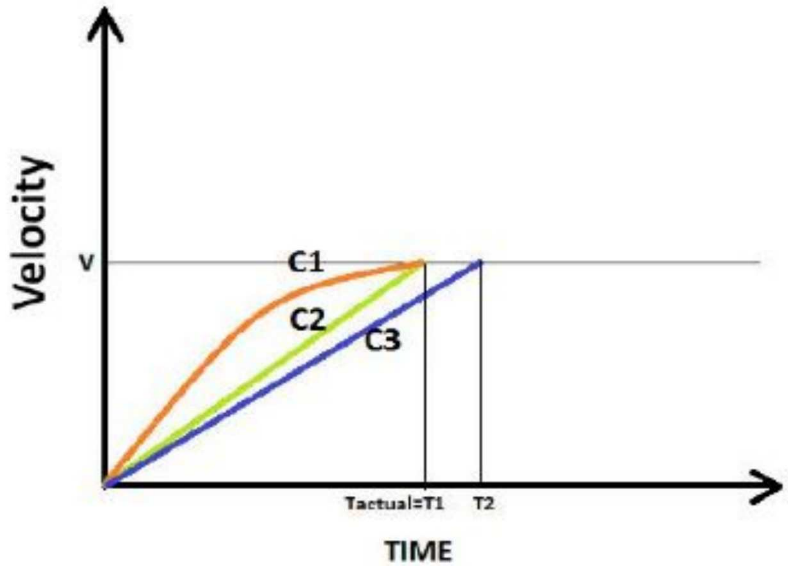


Figure 2: Speed vs time curves: C1: actual speed, C2, C3: constant-acceleration based curves

Force (vertical axis) vs speed (horizontal axis):

Schematic for typical locos

Velocity vs time:

C1: higher **slope** for **lower speeds**

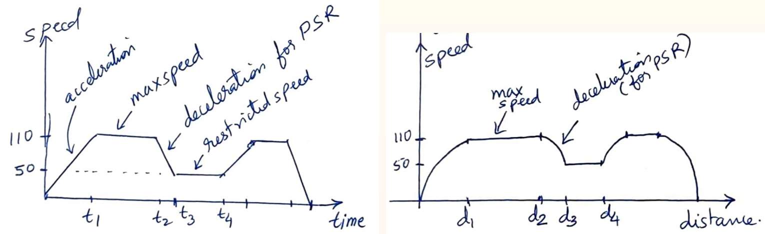
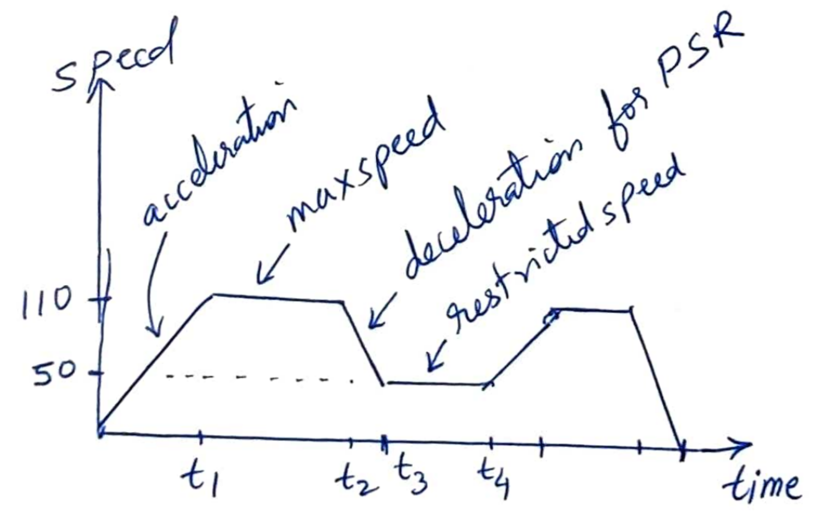


Figure: Speed vs time (more intuitive), and vs distance (for timetabling)



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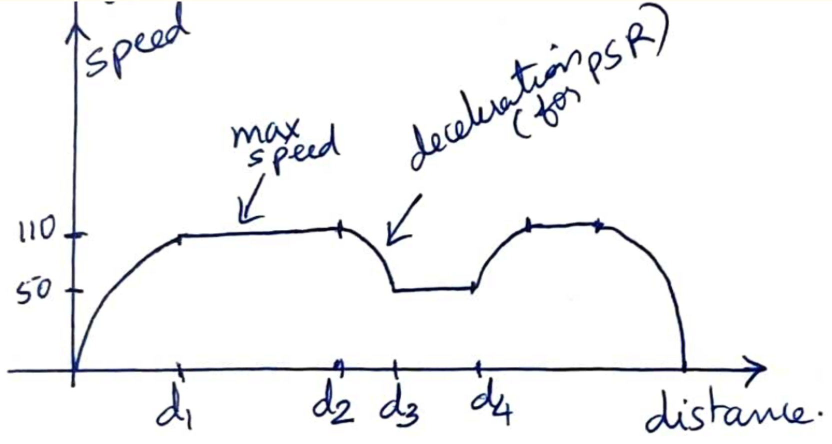

Figure: Speed vs distance (less intuitive, for timetabling)

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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 (intuitive, user-proposed) 'test-flaws')

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- Often, indepth study difficult due to the need for data
- Realistic studies would inevitably require elaborate details
- No shortcuts or ‘low-hanging-fruits’ remaining
- A continuous/long-term engagement needed for any fruitful outcome
- IR too complex for ready-made off-the-shelf solutions

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  often computationally easy to jump (rather than exhaustively search) (Similar to 'simulated annealing')
  - optimize crew allotment
  - choose start-timings at origin to get 'better and better' grouping at congested section

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

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- Need to shift to modern tools for
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  - system productivity/efficiency
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Questions, contact details

Questions ?

Thank you

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This talk currently at
www.ee.iitb.ac.in/%7Ebelur/talks

Suburban (WR) crew-allotment conference paper
http://www.ee.iitb.ac.in/%7Ebelur/pdfs/c19or-dresden.pdf
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Workshop on suburban-railways/metro operations planning (Jun 2019)
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