Crew Planning Tool for Mumbai Suburban Railways

Naman Kasliwal*, Sudarshan P*
Madhu Belur*, Narayan Rangaraj**

*Department of Electrical Engineering, IIT Bombay
**Industrial Engineering and Operations Research, IIT Bombay

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Introduction - Mumbai Western Railways

- Western Railways uses 89 rakes - rolling stock units - to run 1355 services every day
- Crew Allotment - Each service requires a guard and motorman

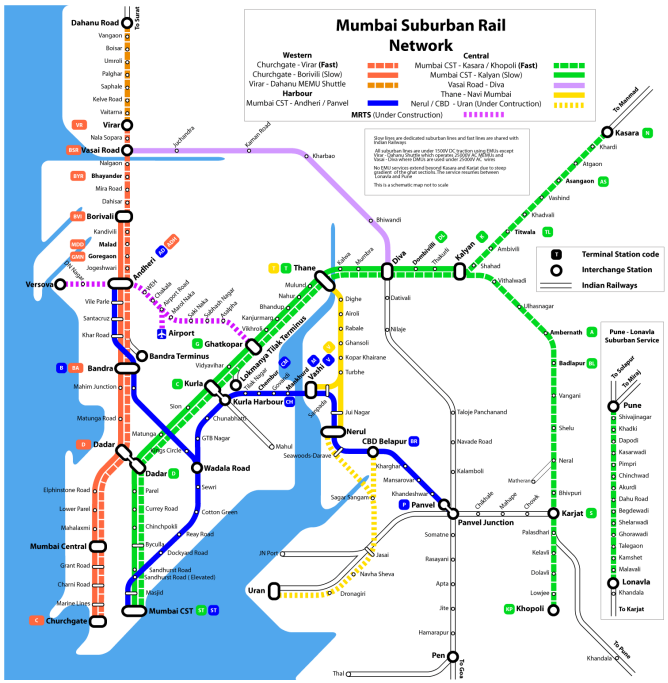

Figure 1: Suburban Railways Map

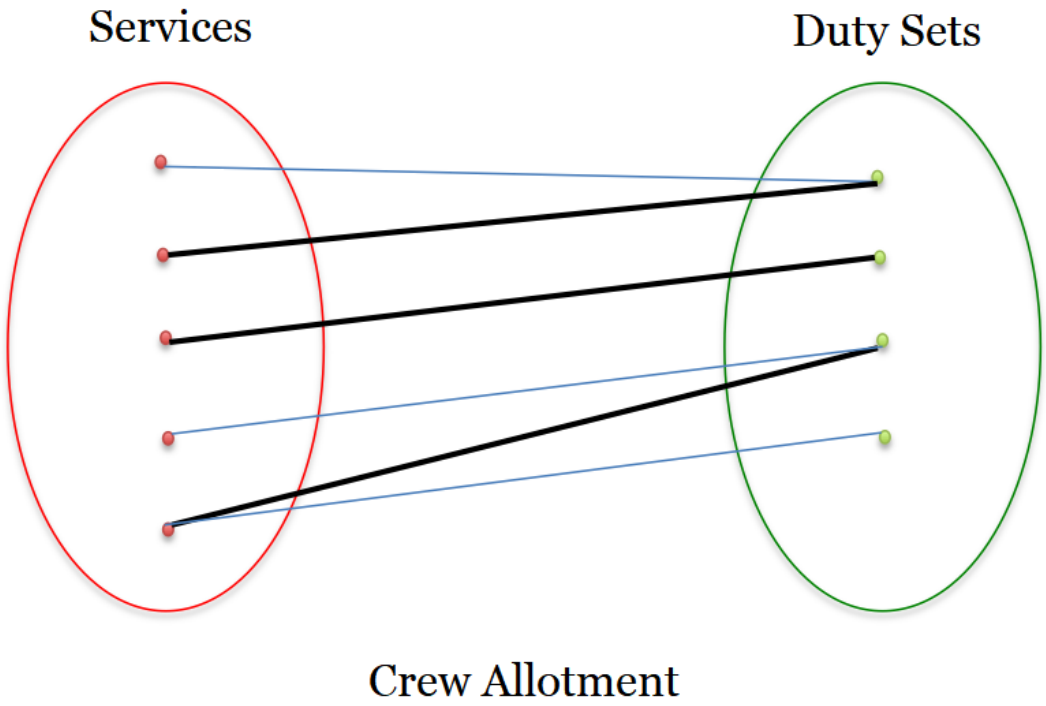

Figure 2: Matching Crew to Services

The Problem

- Shortage 132 guards, 90 motormen $\rightarrow$ Overtime is expensive, vulnerable
- Currently done manually, 2-3 month long process
- Difficult to manually determine an optimal set allocation

The Problem

- Shortage 132 guards, 90 motormen $\rightarrow$ Overtime is expensive, vulnerable
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- Need for an automatic and optimized crew planning tool to:
  - Reduce operating costs
  - Improve system efficiency
  - Provide better working conditions, safety

Work to be done by the tool

Train Timetable Book $\rightarrow$ Crew Schedule Book

Train Timetable Book

STATIONS		12926	VR	C. Rly.	BVI	BVI	VR	BVI
		ASR-BDTS Pashchim EXP.	90590 BQ 12 CAR	98744 AD 44	90592 BV 12 CAR	90594 CF 12 CAR	90596 R 12 CAR	90598 C 12 CAR
VIRAR	**A**		**1**				**3**	
	D	**13:25**	**13:25**				**13:29**	
Nalla Sopara		T	13:31				13:36	
Vasai Road		**13:34**	**13:36**				**13:41**	
		T						
Naigaon			13:40				13:45	
Bhayandar		**13:44**	**13:46**				**13:51**	
Mira Road		T	13:51				13:56	
Dahisar			13:55				14:00	
BORIVALI	**A**	**13:57**						
	D	**14:00**	**14:01**		**14:01**	**14:04**	**14:05**	**14:08**
		8	**5/T**		**3**	**4**	**T**	**1**
Kandivli		ON STA			14:06	14:09		14:13
Malad		LINE BET			14:09	14:12		14:16
Goregaon		BVI-			14:12	14:15		14:19
Ram Mandir		BDTS			14:14			14:21
Jogeshwari					14:17	14:20		14:24
ANDHERI	**A**	**14:19**		**HB**				
	D	**14:22**	**14:17**	**14:20**	**14:22**	**14:25**	**14:21**	**14:28**
		BDTS ARRL. 14:45	**T**	**2**		**T**	**T**	
Vile Parle				14:24	14:25			14:31
Santa Cruz				14:27	14:28			14:34
Khar Road				14:30	14:31			14:37
BANDRA			**14:26**	**14:34**	**14:35**	**14:35**	**14:30**	**14:41**
			T			**T**	**T**	
Mahim Jn.				14:37	14:38			14:44
Matunga Road					14:41			14:47
DADAR	**A**							
	D		**14:32**		**14:45**	**14:41**	**14:36**	**14:51**
Prabhadevi					14:47			14:53
Lower Parel				**CSTM**	14:50			14:56
Mahalakshmi				**Arr**	14:53			14:59
M'BAI CENTRAL(L)			**14:39**	**15:04**	**14:56**	**14:48**	**14:43**	**15:02**
			T			**T**	**T**	
Grant Road			14:41		14:58	14:50	14:45	15:04
Charni Road			14:43		15:00	14:52	14:47	15:06
Marine Lines			14:46		15:03	14:55	14:50	15:09
CHURCHGATE	**A**		**14:50**		**15:07**	**14:58**	**14:54**	**15:13**
From CCG at			**15:55**		**15:10**	**15:02**	**14:58**	**15:16**
TRAIN NO.			**90729**		**90689**	**90677**	**90671**	**90691**

Figure 3: Each column in the timetable book represents a service (total 1355)

Crew Schedule Book

Services are grouped into duty sets which define a motorman's daily work

- ON duty time and station, OFF duty time and station
- All services to be worked by motorman during duty time
- Rest hours (rest given after completing that day's work)
- A set that completes late at night at a location other than the lobby and which require a night halt is called Halting set
- Additional constraints on timings of halting sets

Pairs of sets

SET NO. 1 — **ADH-4**

ON DUTY :	16:35	CCG	KMS :	166.09
OFF DUTY:	23:00	ADH	HRS :	06:25

90781	CCG-VR	(F)	16:55	18:19
	BCL-DDR-BA-ADH-BVI			
90912	VR-CCG	(F)	18:30	19:52
	BVI-ADH-BA-DDR-BCL-CCG			
91067	CCG-BVI		20:52	21:59
91092	BVI -ADH		22:10	22:32
	PRT T. NO. **91139** SET NO.**251**			

REST HRS: 05:50

SET NO. 2

ON DUTY :	04:50	ADH	KMS :	125.39
OFF DUTY:	09:55	CCG	HRS :	05:05

	R/O SET NO **251** PF NO. **3**			
90034	ADH- CCG		05:10	05:56
90121	CCG -BVI		06:32	07:36
	SAME RAKE			
90141	BVI- BSR	(F)	07:40	08:07
	BVI-BSR			
90260	BSR-CCG	(F)	08:18	09:33
	BVI-ADH-BA-DDR-BCL			

REST HRS: 21:50

SET NO. 3

ON DUTY :	07:45	CCG	KMS :	111.62
OFF DUTY:	13:45	CCG	HRS :	06:00

90223	CCG-ADH	08:07	08:53
	PRT T NO **90252** OF SET NO.**103** & WORK O/L PF NO.**2** R/O SET NO. **227**		
90304	ADH-CCG	09:36	10:23
90437	CCG -BVI	11:00	12:05
90498	BVI- CCG	12:15	13:22

REST HRS: 24:45

SET NO. 4

ON DUTY :	14:30	ADH	KMS :	150.00
OFF DUTY:	22:30	CCG	HRS :	08:00

PRT T NO 90646 OF SET NO. 353
THEN TAP TO CCG BY 90646
SHUNTING DUTY / WAITING DUTY

REST HRS: 18:50

130

Types of Sets

- Working sets:
  - **Day working sets**
  - **Halting working sets** - Always in pairs, short rest at night
    Required for morning services
  - **Night sets** - On-duty time after 22:00
    Required for unassigned night services, shunting and morning services
- Waiting duty and shunting duty sets:
  - Emergency work
  - Taking rake to/from stabling depots

Problem Formulation

The overall problem has been decomposed into the following 2 stages:

1. **Set Generation Stage**
   To group services into work days → Daily work
2. **Set Linking Stage**
   To arrange work days into a sequence → Monthly work

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Objectives (decreasing order of importance):

- Tight packing of services → Maximizes average working hours, kms
- Tight linking of sets → No unnecessary rest
- Sets should start/end close to headquarters - Churchgate, Borivali
- Minimize TAP (Travel as a passenger) between services
- 2:3 ratio of number of sets for Churchgate and Borivali headquarter

Set Generation Constraints - 1

- Total working hours in a set $\leq$ 8 hours
- No unnecessary breaks between services, Break $\leq$ 30 minutes
- About 40 minutes break for meals
- Protection and work overlap for services that:
  - Require rake to navigate in opposite direction
  - Run during peak timings $\rightarrow$ 7:00 to 11:00 and 17:00 to 22:00

  Change of crew as same crew cannot continue running the same rake
- Halting sets:
  - Rest between parts $\geq$ $max(5, \frac{2}{3}$ * working hours of first part) hours
  - Total working hours for pair $\leq$ 14 hours
  - Second part should be lighter

Set Generation Constraints - 2

- The on-duty and off-duty time should be at least 15 minutes before and after work
- Sets need to be allotted to Churchgate and Borivali lobby
- For halting pairs, crew must not be rested at that crew's assigned lobby
- No relief to be provided en-route for any train
- Night sets should also be utilized for shunting duty

Set Linking Constraints

- Total working hours for last 14 days $\leq$ 104 hours
- Rest between sets $\geq$ 12 hours (except between halting pairs)
- Rest after night duty $\geq$ 30 hours
- A night must not be linked in succession to another night set. Similarly, for the pair of halting sets.
- Allocate sets for waiting duties and shunting duties:
  - Number at such sets predefined
  - Required only at Churchgate, Bhayandar, Bandra, Borivali stations
  - In time slots of 7:00 to 15:00, 15:00 to 23:00 and 23:00 to 7:00

  Most movements to/from stabling depots happen at night
- All the sets not in sequence can be kept as out of rotation sets

Constraints based on Field Expertise - 1

- Churchgate, Dadar, Bandra, Andheri, Borivali, Bhayandar and Virar are the 7 major stations to start and end the sets
- Car sheds and scrap yard constraints
- Rest after night duty $\geq$ 30 hours
- In a set, at least 1 break of 30 minutes is required, preferably at Churchgate
- For the morning part of a pair of halting sets, a 35 minutes break must necessarily be given when the crew reaches Churchgate
- The working hours in the morning part of a halting pair should be capped at 5 hours 30 minutes

Constraints based on Field Expertise - 2

- The evening part of a pair of halting sets should start as late as possible, certainly after 15:00
- After the utilization of shunting sets, the stabling work will be given to a working set
- Beds limited $\rightarrow$ Each pair of halting sets requires 2 beds
- The night sets must not be given a large number of services, 2 is preferred
- Geographical information about the stations and platforms

Constraints based on Field Expertise - 3

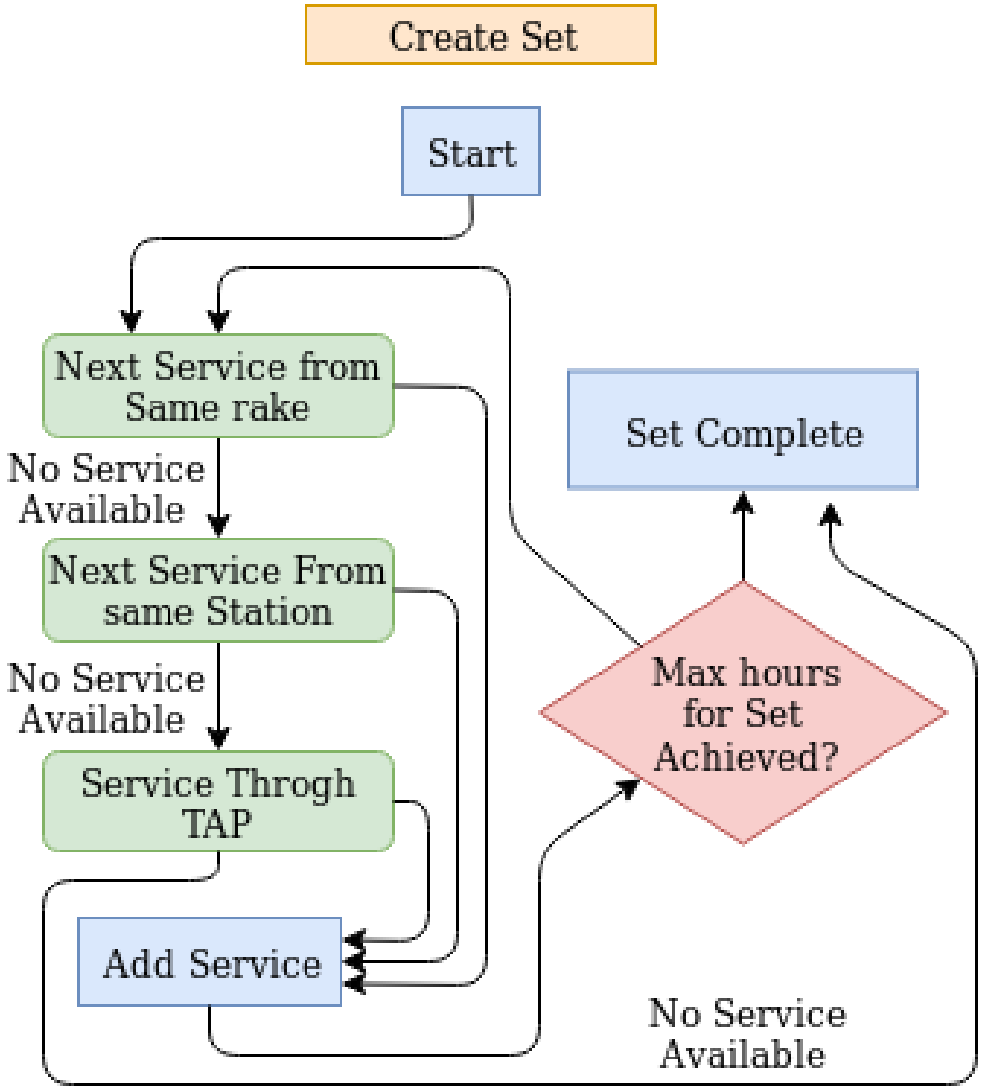
- The maximum allowable number of services in a set is 5, preferably no more than 4
- For a night set, the off-duty time should be at or after the start of the first morning service from the set's end station
- No normal set should start early morning
- A long service that goes all the way between Dahanu Road and Churchgate needs to broken at Virar (resulting in 2 services)

Allocation Scheme

Creation of a large collection of possible solutions with a hope of finding a **good quality solution**

1. Efficient, flexible and quick heuristic
2. Modelled 30+ constraints into the algorithm
3. Resource allocation done constructively
4. Time weighted probabilistic function to create multiple allocations
5. Work load balancing function to further improve the results
6. Iterative approach of creating work duties
7. Largely greedy initially with a self-correcting mechanism

Allocation Scheme



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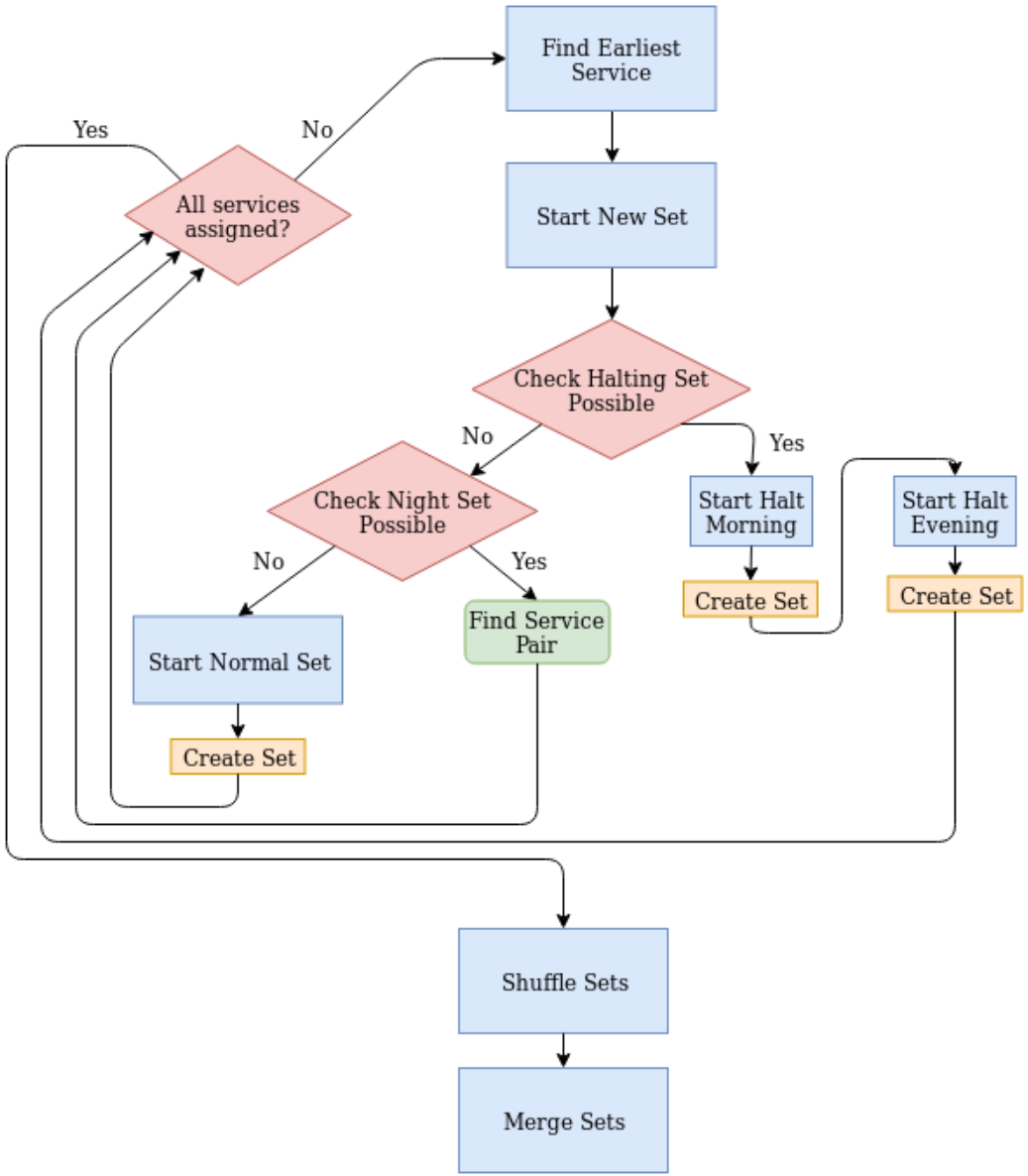


Allocation Scheme - some improvements

Shuffle and Merge

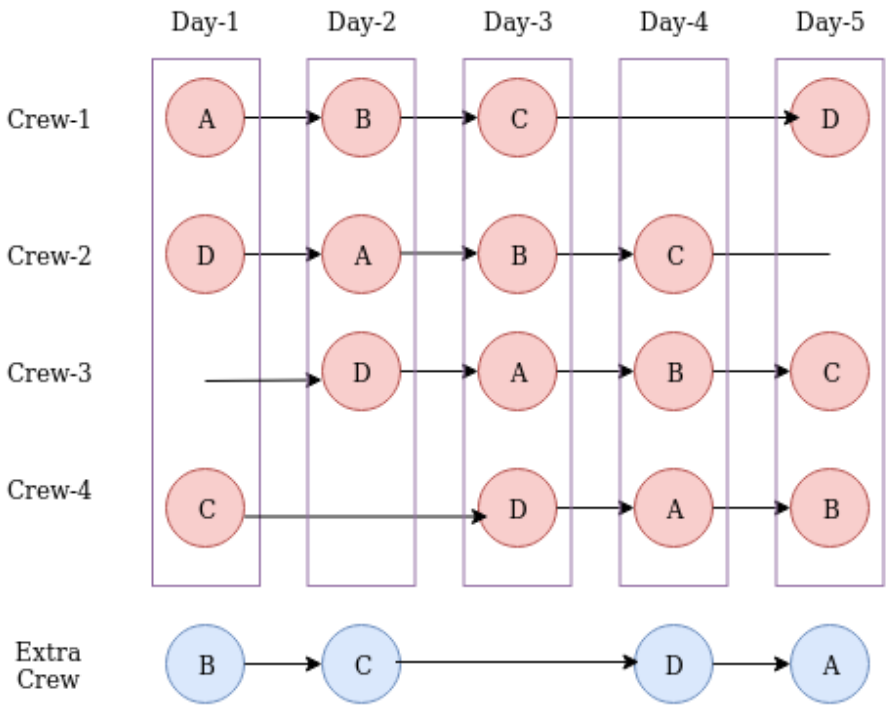
1. Break the larger set into smaller blocks of duties and combine them with other smaller sets
2. Work load balancing - Evens out the duty hours among all sets which were constructed greedily

Linking Scheme

Rosters the generated solution sets to optimize work duration of crews

1. Breaks greater than 24 hrs results in additional crew requirement.
2. Algorithm's objective is to maximize average working hours, which reduces larger breaks, so lowers additional crew required.
3. Heuristic based on Traveling Salesman Problem.
4. Arranges the duty sets in a sequence which are separated by periods of rest.
5. Starts with randomised allocation, which is then constructively improved.

Linking scheme



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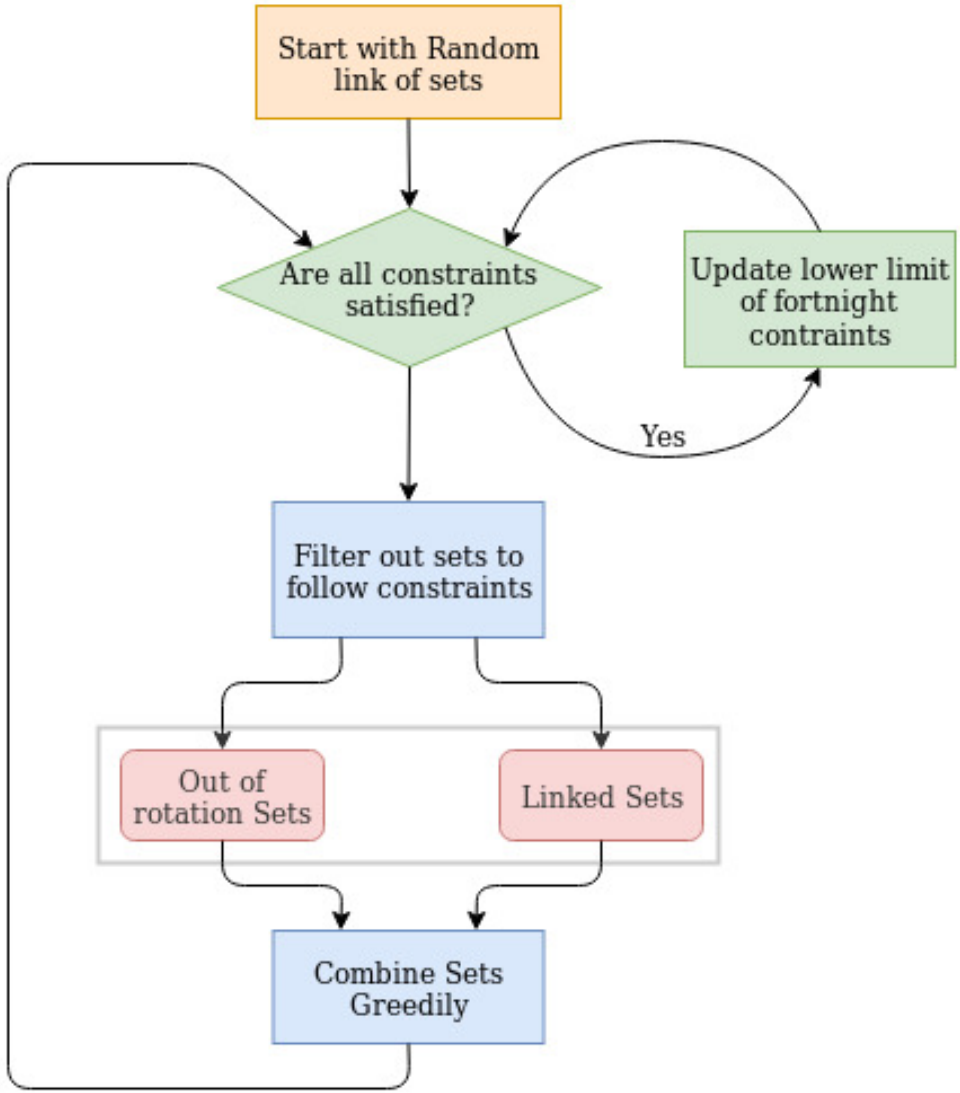

Crew Duty Generation Tool

Easy-to-use tool for generation of efficient crew duty sets

STATISTIC	ALGORITHM	MANUAL
Number of Halting Sets	129	192
Number of Day Working Sets	209	161
Number of Night Working Sets	30	29
Total Sets	**368**	382
Average Kms	**135 kms**	125 kms
Average Working Hours	**6:29**	6:16 (CCG DEPOT) 6:23 (BVI DEPOT)

Comparison of duty sets generated by the tool vs manual preparation

Technical Details

- Python 3 programming language used
- Compatible with Linux and Windows
- 30+ constraints included in the construction of feasible sets and linking
- Efficient, flexible and quick
- Single runs takes less than 0.4 seconds to create 1 set allocation $\rightarrow$ allows for generating multiple allocations

HOER - Hours of employment rules, policies and on-field expertise built into the tool to automatically generate work duties that are operationally feasible

Set generation vs set linking

- Set generation followed by set linking
- In both, the idea is to pack nicely - high utilization implies low crew requirement
- Set generation seems more important, at least for Western Railway - duties in a set are performed tightly
- Large number of sets, so linking seems possible to minimize 24+ hour rests - requires considerable effort to automate, though
- Lot of delays, so anyway extra crew and standbys are needed, so linking is not taken as seriously - handled dynamically

Some comments

- Is Math Programming possible for this crew allocation problem? Describing all the constraints (including the preferences of the planners) in a way that permits a characterization of feasible collection of sets seems difficult.
- However, given an ordered list of duties, construction of a collection of sets using the rules is straighforward, less than 0.4 seconds to exectute
- Small number of options in some cases, especially with regard to halting sets/night duties - not clear whether these make a significant difference
- So our search space is transformed to ordered lists of all duties i.e. each ordered list — one final solution (or small set of solutions) with some quality
- Random search on these lists is possible and is what we have tried - can be improved

Conclusions

- Services and their station/timing details as input
  - Took many months!
- Crew work duties in desired format as output
- Preparation of work duties within minutes
- Customizable and flexible tool that can easily adapt to changes in:
  - Services
  - Lobby locations
  - Any other parameters within the policy/constraints
- Analysis before making changes in policy, operations, infrastructure
  For example, introducing Virar station as a third headquarter in WR
- Tool under preparation for 1 year, currently under final review
  - Improvements possible in solution quality

Associations

Department

- Western Railway Mumbai Division

People

- Ms. Suhani Mishra, Senior Divisional Operations Manager
- Mr. Shamit Monga, Divisional Operations Manager
- Mr. Abhishek
- Mr. Rajvir
- Mr. SG Sagar
- Mr. PK Majumdar

Contact

- Prof. Madhu Belur - belur@iitb.ac.in
- Prof. Narayan Rangaraj - narayan.rangaraj@iitb.ac.in