Crew Planning Tool
for Mumbai Suburban Railways

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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 → **Overtime is expensive, vulnerable**
- Currently done manually, **2-3 month** long process
- Difficult to manually determine an optimal set allocation
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- Currently done manually, 2-3 month long process
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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 → Crew Schedule Book
### Figure 3: Each column in the timetable book represents a service (total 1355)
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

<table>
<thead>
<tr>
<th>ON DUTY</th>
<th>16:35</th>
<th>CCG</th>
<th>KMS</th>
<th>166.09</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF DUTY</td>
<td>23:00</td>
<td>ADH</td>
<td>HRS</td>
<td>06:25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>90781</th>
<th>CCG-VR</th>
<th>16:55</th>
<th>18:19</th>
</tr>
</thead>
<tbody>
<tr>
<td>90912</td>
<td>VR-CCG</td>
<td>18:30</td>
<td>19:52</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>91067</th>
<th>CCG-BVI</th>
<th>20:52</th>
<th>21:59</th>
</tr>
</thead>
<tbody>
<tr>
<td>91092</td>
<td>BVI-ADH</td>
<td>22:10</td>
<td>22:32</td>
</tr>
</tbody>
</table>

PRT T. NO. 91139 SET NO.251

| REST HRS | 05:50 |

#### SET NO. 2

<table>
<thead>
<tr>
<th>ON DUTY</th>
<th>04:50</th>
<th>ADH</th>
<th>KMS</th>
<th>125.39</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF DUTY</td>
<td>09:55</td>
<td>CCG</td>
<td>HRS</td>
<td>05:05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>90034</th>
<th>ADH-CCG</th>
<th>05:10</th>
<th>05:56</th>
</tr>
</thead>
<tbody>
<tr>
<td>90121</td>
<td>CCG-BVI</td>
<td>06:32</td>
<td>07:36</td>
</tr>
</tbody>
</table>

SAME RAKE

<table>
<thead>
<tr>
<th>90141</th>
<th>BVI-BSR</th>
<th>07:40</th>
<th>08:07</th>
</tr>
</thead>
<tbody>
<tr>
<td>90260</td>
<td>BSR-CCG</td>
<td>08:18</td>
<td>09:33</td>
</tr>
</tbody>
</table>

BVI-BSR

BVI-ADH-BA-DDR-BCL

REST HRS: 21:50

#### SET NO. 3

<table>
<thead>
<tr>
<th>ON DUTY</th>
<th>07:45</th>
<th>CCG</th>
<th>KMS</th>
<th>111.62</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF DUTY</td>
<td>13:45</td>
<td>CCG</td>
<td>HRS</td>
<td>06:00</td>
</tr>
</tbody>
</table>

| 90223     | CCG-ADH | 08:07 | 08:53 |

PRT T NO. 90262 OF SET NO. 103 & WORK O/L

PF NO. 2 R/O SET NO. 227

<table>
<thead>
<tr>
<th>90304</th>
<th>ADH-CCG</th>
<th>09:36</th>
<th>10:23</th>
</tr>
</thead>
<tbody>
<tr>
<td>90437</td>
<td>CCG-BVI</td>
<td>11:00</td>
<td>12:05</td>
</tr>
<tr>
<td>90498</td>
<td>BVI-CCG</td>
<td>12:15</td>
<td>13:22</td>
</tr>
</tbody>
</table>

REST HRS: 24:45

#### SET NO. 4

<table>
<thead>
<tr>
<th>ON DUTY</th>
<th>14:30</th>
<th>ADH</th>
<th>KMS</th>
<th>150.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF DUTY</td>
<td>22:30</td>
<td>CCG</td>
<td>HRS</td>
<td>08:00</td>
</tr>
</tbody>
</table>

PRT T NO. 90646 OF SET NO. 353

THEN TAP TO CCG BY 90646

SHUNTING DUTY / WAITING DUTY

REST HRS: 18:50
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

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 headquarters
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Objectives (decreasing order of importance):
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- 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 \( \geq max(5, \frac{2}{3} \times \text{working hours of first part}) \) hours
  - Total working hours for pair \( \leq 14 \) hours
  - Second part should be lighter
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
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.
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 be broken at Virar (resulting in 2 services).
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

Start

Create Set

Set Complete

Max hours for Set Achieved?

No Service Available

Next Service from Same rake

Next Service From same Station

No Service Available

Service Throgh TAP

Add Service

No Service Available
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

Day-1 | Day-2 | Day-3 | Day-4 | Day-5
---|---|---|---|---
Crew-1 | A | B | C | D
Crew-2 | D | A | B | C
Crew-3 | D | A | B | C
Crew-4 | C | D | A | B
Extra Crew | B | C | D | A
Linking scheme

1. Start with Random link of sets
2. Check if all constraints are satisfied?
   - If Yes: Update lower limit of fortnight constraints
   - If No: Filter out sets to follow constraints
3. Split into Out of rotation Sets and Linked Sets
4. Combine Sets Greedily
   - If all constraints satisfied, go back to step 2

Diagram: [Flowchart showing the linking scheme process]
Crew Duty Generation Tool
Easy-to-use tool for generation of efficient crew duty sets

<table>
<thead>
<tr>
<th>STATISTIC</th>
<th>ALGORITHM</th>
<th>MANUAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Halting Sets</td>
<td>129</td>
<td>192</td>
</tr>
<tr>
<td>Number of Day Working Sets</td>
<td>209</td>
<td>161</td>
</tr>
<tr>
<td>Number of Night Working Sets</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>Total Sets</td>
<td>368</td>
<td>382</td>
</tr>
<tr>
<td>Average Kms</td>
<td>135 kms</td>
<td>125 kms</td>
</tr>
<tr>
<td>Average Working Hours</td>
<td>6:29</td>
<td>6:16 (CCG DEPOT) 6:23 (BVI DEPOT)</td>
</tr>
</tbody>
</table>

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 → 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 straightforward, less than 0.4 seconds to execute.

- 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

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