Integrated timetabling for section and suburban railway operations performance objectives and optimality measures

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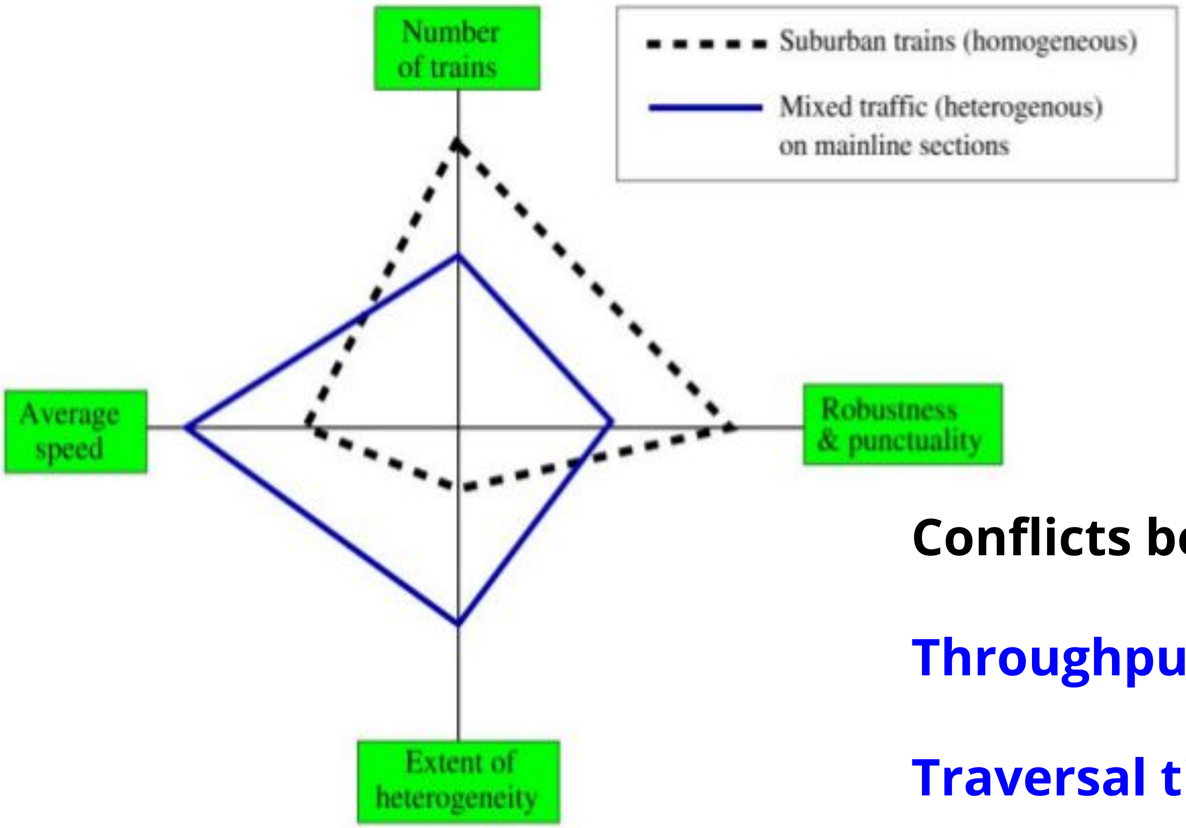
Overview

1. Some principles of rail-traffic timetabling
2. Capacity utilization of sections handling mixed traffic
3. Analysis of factors that affect congestion
4. Junction congestion analysis
5. Typical performance objectives: guidelines
6. Rolling stock management: standardization and impact on punctuality and rake utilization
7. Suburban railway planning

1. Some principles of rail-traffic timetabling

- UIC 406 document by the International Union of Railways
- A framework broadly applicable to many professional railway operating environments
- Four considerations in capacity assessment:
  - throughput (number of trains)
  - heterogeneity (mix of trains)
  - stability (robustness)
  - traversal time (service)

The balance of railway capacity (adapted from [Uic04])



Conflicts between:

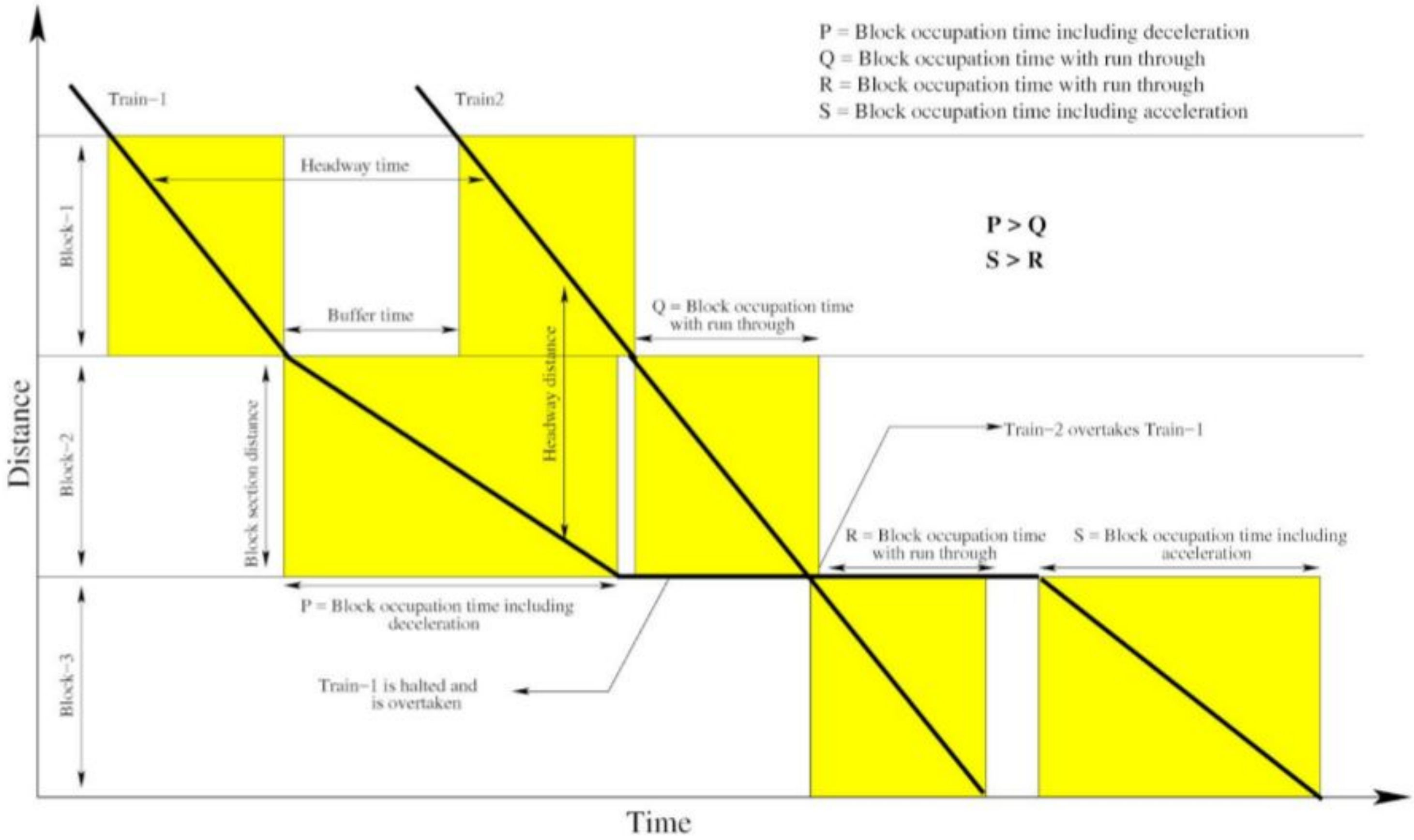
Throughput and heterogeneity

Traversal time and stability

The interaction effect between other pairs of performance measures

- Combined behaviour is less straightforward to quantify and depict
- Three factors on what they depend
  a. Traversal time
     - length of section, achievable speed, planned halts, time for accelerating and decelerating, explicit allowances
  b. Congestion and Overtaking
     - Methods of estimating congestion for single stream of traffic not relevant for mixed traffic
  c. Junction/Terminal Operations
     - Platform, running line resources, crossovers and track resources are bottleneck to throughput

Distance-time chart showing headway distance, headway time, and overtake of Train 1 by Train 2



Good quality paths for passenger trains

- High traversal speed between stations
- Low overtakes by other trains
- Halts only at scheduled stations (and not for just being overtaken by other trains)
- Punctuality of departure

The above points are clearly motivated by the fact that railways is a service

Good quality paths for freight trains

- Most freight trains in India do not run on timetabled paths
- Rail movement of freight has significant benefits in energy use, environmental impact and safety
- A good quality freight path:
    - High traversal speed between stations
    - Low overtakes by other trains and few halts at locations other than where they need to

Robustness and punctuality

- Railway system is subject to uncertainties and delays
- Primary delays - delays directly caused by disturbances
- Secondary delays - The delays caused to a train due to primary delays of other trains
- Some of the major causes are:
    - Planning
    - Infrastructural failures
    - Human factors
    - Weather and environmental conditions

Major causes of secondary delays

- High capacity utilization and thus smaller headways
- When a train reaches a terminal station with a delay, the subsequent train in the rake link could be delayed
- When a train reaches late, the planned crew at the interchange point also gets late leading to delay of subsequent train
- Late running trains (or early trains) occupying resources that on-time trains are unable to use
- (Early arrival: too much allowance/slack: makes station resource unavailable for other trains: this harm is under-estimated.)

Criteria for a “quality timetable” for mixed rail traffic scenario

Ensure higher throughput, better quality paths for passenger and freight trains, and thus better usage of rail-infrastructure by:

A. Low traversal times (time spent in the system)
B. Enable high running speeds of trains
C. Minimizing overtakes between trains
D. Punctuality of departure at stations with scheduled halts
E. Punctuality of arrival at stations with scheduled halts
F. Resilience/robustness of the timetable due to unanticipated disruptions

2. Capacity utilization of sections handling mixed traffic

- Maximum number of trains per day a section can accommodate
- Throughput is compared with the capacity to obtain efficiency of the timetabling process or operation
- Different definitions of capacity and capacity utilization
  - Mixed-traffic-ideal-grouping notion of capacity
  - Distance-time-chart-occupied notion of capacity utilization
  - Bottleneck section: slowest-train-based notion of capacity
  - Bottleneck section: fastest-train-based notion of capacity

Brief explanation of capacity calculation

1. Time to travel the bottleneck block (longest block) in a section is calculated
2. Actual time utilized : Sum of travel time by trains, prior and later headway for each train and time for overtakes
3. Out of 1440 minutes (minutes per day), available time: 840 minutes

   (after excluding 240 minutes (i.e. 4 hours) for maintenance and say 70% efficiency)

4. Capacity utilization is the ratio of actual time utilized to available time

3. Analysis of factors that affect congestion

Maintenance block considerations

- Significant impact on available capacity
- In future, with preventive maintenance and condition based maintenance with sensors and other inputs, this may need revision
- Improper balancing of maintenance and traffic goals can lead to congestion
- Speed restriction after maintenance work

Slacks and allowances

Timetable needs to absorb small disturbances

- The allowance can be calculated in two ways:
    a. by scheduling trains at speeds lower than technically achievable (slack)
    b. by keeping scheduled running times longer than the technically minimum running time (allowance)
- Slacks are planned keeping in mind driver behaviour and equipment performance in safe regimes
- For allowances, there are two steps that need to be followed to have punctuality in the operations of a timetable
    a. Determination of total allocation to be allocated to a train throughout its journey
    b. Optimal distribution of the total allowance to all stations throughout the journey

Grouping of trains based on speeds

- Schedule trains of similar running characteristics in a bunch rather than interlace them
- Leads to minimum overtakes and thus less traversal time
- Sometimes cannot be done to the desired level due to requirement of passenger convenience of timings
- The principle of grouping should be followed to the extent possible
- Should be a major consideration at the time of preparing timetables

4. Junction congestion analysis

- Different from that of a section on a network
- Combinations of simultaneous movements are possible and resources have to be shared carefully
- The relationship between capacity, delays encountered and resource utilization is not as clear as it is for sections
- Currently no well-defined frameworks or planning tools to assess junction resources
- Resource-to-resource hindrance analysis
- The case of Allahabad junction (ALD) with 19 lines (both up and down) and 10 platforms

Planning of freight trains at a junction

1. Plan a time of day dependent variable freight halt to get a realistic picture of waiting/movements at large junctions
2. Backtrack the freight trains and start them from source station such that they experience small amounts of hindrance due to other train movements while entering/exiting congested junction

5. Typical performance objectives: guidelines

Arise from a combination of tools and analyses performed from the data that was used for railway related studies conducted by our group

This area deserves an extensive and continuously updated efforts on the part of IR

- Capacity-utilization
- Bottleneck-scheduling
- Junction-analysis
- Slack-and-allowance-distribution

Capacity utilization

An indicator of congestion and high values are used to justify additional investments and to provide more traffic allowances in timetabling

- Capacity measure itself needs significant refinement and consensus in use before any valid claim can be made in mixed traffic sections
- Decisions about additional investments must be backed by a simulation based study

Bottleneck-scheduling

- The maximal throughput strategy on the bottleneck resource should drive the schedule on the rest of the network
- If a section appears to be a bottleneck then the traffic on this section should be:
  - Streamlined, with as few overtakes as possible
  - Also as ideal grouping as possible, so as to achieve maximum throughput and overall traversal time performance

Junction-analysis

- The impact of junction movements is significant and causes significant cascading impacts on sectional running
- This area of analysis in is a very challenging one worldwide and proper tools and techniques need to be developed

Slack-and-allowance-distribution

- Divisional measures of punctuality needs reworking: more continuous unit of measurement and based on the resources available
- The current practice of loading all allowances at the end of a section before interchange is detrimental to punctuality of operation
- Only reasonable amounts of allowance should be provided for section congestion
- For guarding against junction congestion, given the occupancy pattern of platforms at junctions, additional halt times at junctions be explored

6. Rolling stock management: standardization and impact on punctuality and rake utilization

- The quantity of rolling stock required for providing adequate levels of service should be carefully determined
- Efficient rake links will lead to effective utilization of coaches by minimizing the number of rakes required
- One factor that hampers efficient rake linking is difference in composition of rakes
- Network flow modelling and vertex colouring approaches can be used

Benefits of standardization

- A direct benefit of standardization is the possibility of needing lesser number of rakes for running a given set of services
- Improvement in rake utilization due to pooling effect
- Robustness of operations
  - Improvement in punctuality of services
  - Delay propagation stays in control even for fairly large values of delays
  - The system is able to recover fast from the effect of big-disruptions

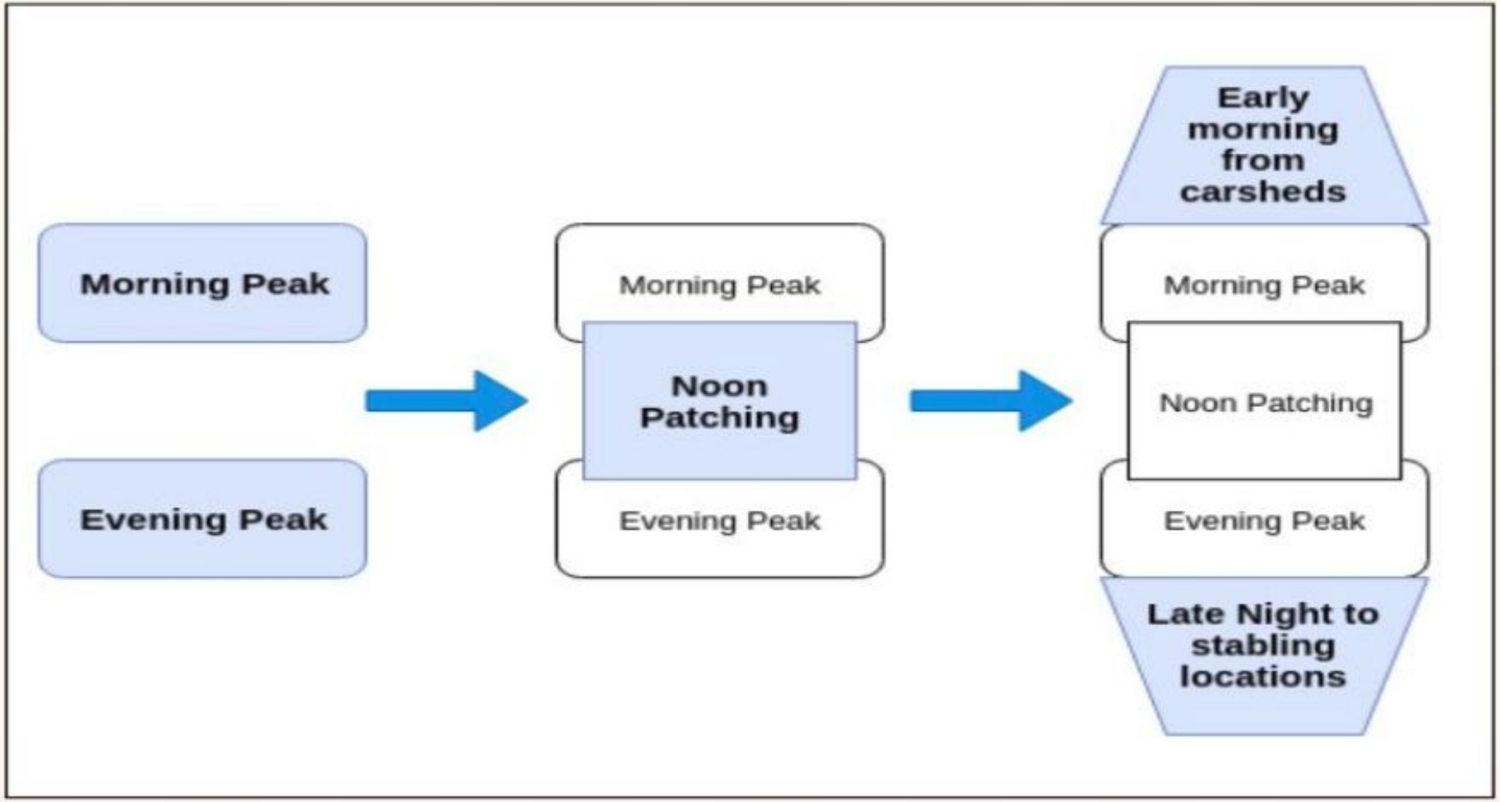
7. Suburban railway planning

- Suburban rail services in urban or regional geographies generally comprise of homogeneous services which are run at high density
- High throughput is desired
- The stages of planning required in suburban timetabling include:
    - Line planning
    - Timetabling of services
    - Rake linking (vehicle planning)
    - Crew scheduling

Timetabling and Rakelinking

- Timetabling in India is presently done manually with some computer based visualization and decision support
- An iterative procedure which starts by modifying the already existing timetable
- Existing approach completely ignores any sort of optimization that one might use while designing such timetables
- This calls for an optimizer tool to generate timetable
- Our approach uses a constraint representation and then solution of a Mixed-integer linear programing
- The final output - Arrival and departure event values and also the rake cycles

Steps to construct complete day timetable

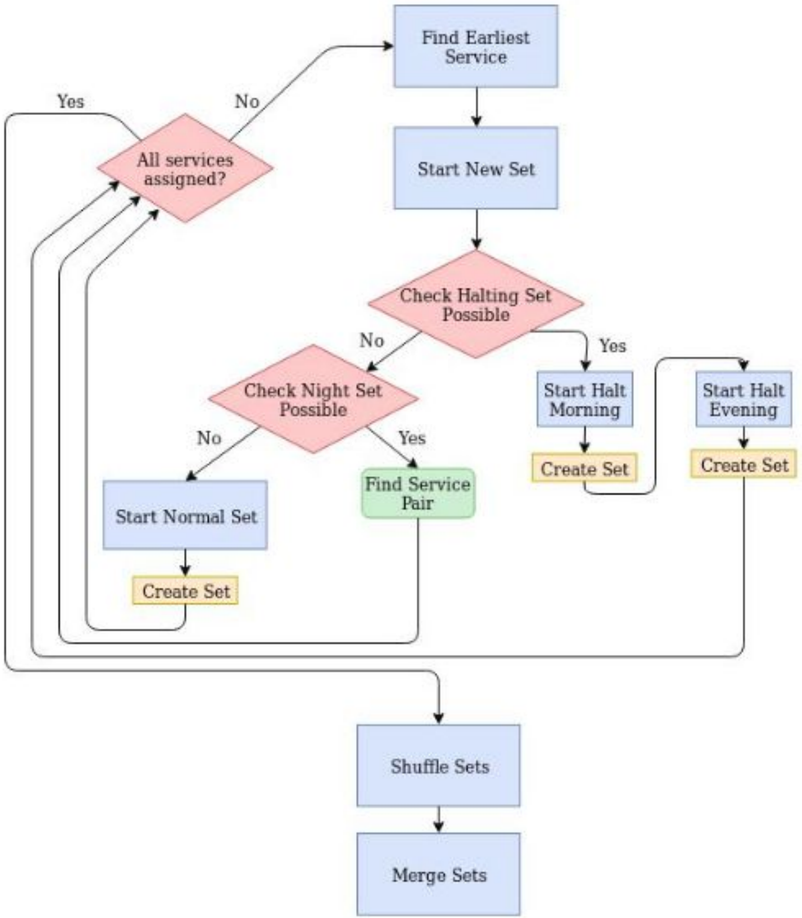


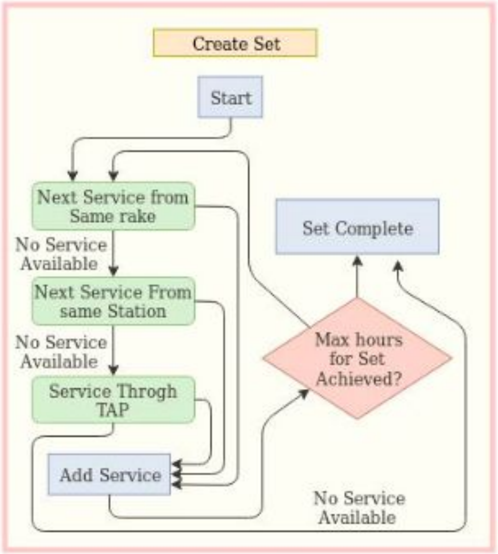
Crew scheduling

- For suburban services is a detailed planning activity which in practice takes 2-3 months to plan
- Crew scheduling optimization involves finding the correct services to group in a set for a day’s work of a crew member
- The overall problem has been decomposed into the following 2 stages:
    - Set generation - Services are grouped into set of duties which are less than 8 hours. The objective is to minimize the number of sets generated
    - Set linking - Organizes the sets in sequence in specific order

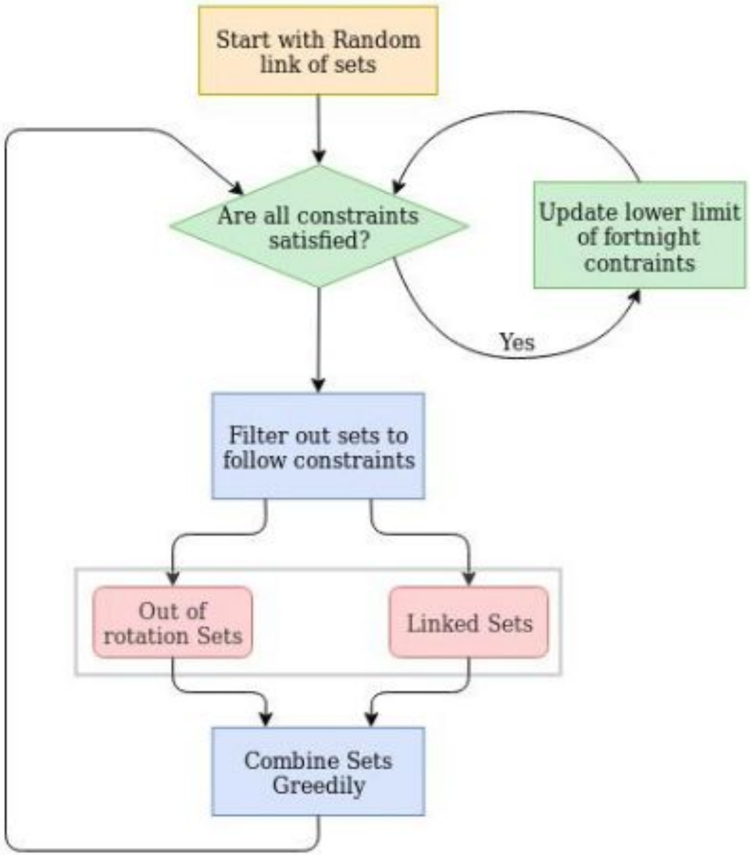
The above problem has been solved using a flexible and efficient heuristic - using python scripts

Flow chart of set generation





Flowchart of set linking



Conclusions

- Need for data-based input and evidence-based decision making possible in timetabling
- Worldwide, railway organizations make use of tools ranging from optimization and operations research to machine learning and data analysis to improve operations
- IR should be the leader in this area, given the complexity and volume of services that it offers its customers

Conclusions (Cont...) and the way forward

- Use of optimization techniques can aid in the activities of timetabling, rake linking and crew scheduling
- Complete revamp of the Netherlands Railway timetable by many years of cooperative work between railway personnel, academics and software professionals
- Ecosystem and skills for such a concerted effort for much larger railway system in India exists and should be cultivated, as the impact can be significant
- Need constant engagement between Academia & Railways

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