

Fleet management in rail transport: Petroleum rakes in Indian Railways

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Outline

Overview of petroleum sector in India

Understanding the problem

Proposed solution to deterministic problem

Proposed solution to anticipated problem

Current status

Future work

Overview of Petroleum Sector

- ▶ India's annual consumption of petroleum products 200 Million Tonnes
- ▶ Transport modes - Pipeline, Coastal Shipping, Rail, Road
- ▶ Movement of petroleum products by rail: 42 Million Tonnes
- ▶ Revenue from transportation of petroleum products by rail - USD 1 billion
- ▶ 30+ rail loading locations, 100+ unloading terminals
- ▶ current fleet size : 200 rakes - 10000 wagons run in Unit-trains of 50 wagons each

Understanding the problem

- ▶ Placement of indents (firm demands) from oil industry
- ▶ What to do with a petroleum rake once it gets empty
- ▶ Multiple products and rake compatibility - Diesel, Gasoline, Jet Fuel, Kerosene, Base oil and some intermediate products. For quality considerations, petroleum product loadability in a wagon depends on the previous product loaded
- ▶ Maintenance of rakes
- ▶ Terminal capacities
- ▶ Uncertain environment
- ▶ The current process is repetitive, time consuming and involves lot of man hours
- ▶ Passenger traffic gets higher priority than freight trains in Indian Railways

Empty Rake Flow - 1370 unique pairs

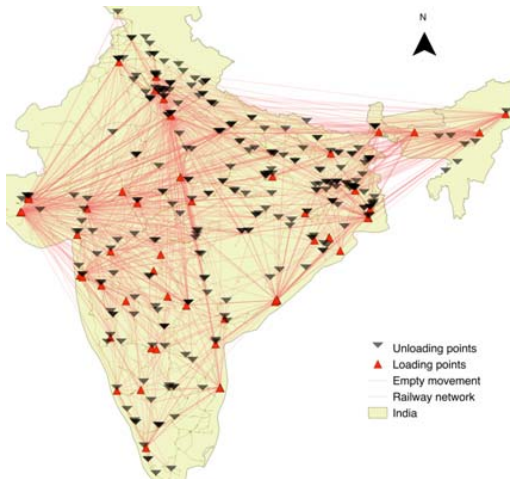


Figure 1: Vishal Rewari, Raja Gopalakrishnan, Narayan Rangaraj
Networks of Petroleum Terminals and Empty flows

Breaking up the problem in 2 parts

- ▶ 1st Part: Outstanding known indents in the system, deterministic
- ▶ 2nd Part: Prediction for future demand, anticipated

Proposed solution to deterministic problem

- ▶ Linear Programming model
- ▶ Input to model
 - ▶ Rake status, outstanding indents
 - ▶ Terminal points, decision matrix
 - ▶ Rake-indent compatibility based on product-loadability and maintenance constraints
- ▶ Output of model
 - ▶ Assignment of rakes to indents
 - ▶ Unassigned rakes and indents
- ▶ Objective:
 - ▶ Minimise empty running
 - ▶ Minimise difference between due date of indent and travel time
 - ▶ Prioritise indents
- ▶ Constraints:
 - ▶ A rake should be assigned to only 1 indent and vice versa
 - ▶ Terminal capacity constraints
 - ▶ Only assign compatible rakes

Entities used in model

<i>Rakes</i>	set of rakes in the system, including 1 dummy rake, which is allocated when no other rake can be allocated to the indent
<i>Indents</i>	set of outstanding indents, including 1 dummy indent, which is allocated when a rake is unassigned. It also depends on the planning horizon considered
<i>AvailableRakes</i>	set of rakes which can satisfy at least 1 indent, $AvailableRakes \subset Rakes$
<i>AvailableIndents</i>	set of indents which can be loaded in atleast 1 rake, $AvailableIndents \subset Indents$
<i>LoadingPoints</i>	set of points from where rake loads the petroleum product
<i>UnloadingPoints</i>	set of points where rake delivers the loaded product and becomes empty

$$\text{rakeCompatible}_{r,i} = \begin{cases} 1 & \text{rake } r \text{ can satisfy indent } i \\ 0 & \text{rake } r \text{ cannot satisfy indent } i \end{cases}$$

$$\forall r \in \text{Rakes}, i \in \text{Indents}$$

$$t_{(p1),(p2)} = \text{time to go from } p1 \text{ to } p2 \quad p1, p2 \in \text{TerminalPoints}$$

$$t\text{Extra}_r = \text{time required for the the loaded rake } r \text{ to reach its destination}$$

$$\text{location}_p = \text{terminal point of } p \quad \forall p \in \text{Rakes} \cup \text{Indents}$$

Complement priority of an indent

$$\text{comPriority}_i \quad \forall i \in \text{Indents}$$

Number of days left till indent's due date or expected loading date

$$\text{due}_i \quad \forall i \in \text{Indents}$$

$$\text{checkDay}_{d,r,i} = \begin{cases} 1 & \text{if Rake } r \text{ will reach Indent } i \text{ on Day } d \\ 0 & \text{otherwise} \end{cases}$$

$$\forall d \in \text{Days}, r \in \text{Rakes}, i \in \text{Indents}$$

An integer valued terminal capacity of a loading point.

$$\text{termCap}_{lp} \quad \forall lp \in \text{LoadingPoints}$$

List of indents which have similar loading point

$$\text{indentLoading}_{lp} \quad \forall lp \in \text{LoadingPoints}$$

Decision variable

$$\text{allocate}_{r,i} = \begin{cases} 1 & \text{if rake } r \text{ is allocated to an indent } i \\ 0 & \text{otherwise} \end{cases}$$
$$\forall r \in \text{Rakes}, i \in \text{Indents}$$

Objective 1:

Minimise empty running time

$$\sum_{r \in Rakes} \sum_{i \in Indents} t_{(location_r), (location_i)} * allocate_{r,i}$$

Objective 2:

Minimise the absolute difference between the delivery time of rake and due date of the indent

$$\sum_{r \in Rakes} \sum_{i \in Indents} |t_{(location_r), (location_i)} + tExtra_r - due_i| * allocate_{r,i}$$

Objective 3:

Prioritise old indents so that they don't get starved

$$\sum_{i \in Indents} \text{comPriority}_i * \left(\sum_{r \in Rakes} \text{allocate}_{r,i} \right)$$

Constraints

A rake can be assigned to only 1 indent

$$\sum_{i \in Indents} allocate_{r,i} + allocate_{r,di} = 1 \quad \forall r \in AvailableRakes \quad (1)$$

An indent is assigned only 1 rake

$$\sum_{r \in AvailableRakes} allocate_{r,i} + allocate_{dr,i} = 1 \quad \forall i \in Indents \quad (2)$$

$dr \in Rakes, dr \notin AvailableRakes, di \in Indents, di \notin AvailableIndents$

Restricting allocation to compatible rakes

$$allocate_{r,i} \leq rakeCompatible_{r,i} \quad \forall r \in Rakes, i \in Indents \quad (3)$$

Terminal loading capacity

$$\sum_{i \in indentLoading_{lp}} \sum_{r \in AvailableRakes} checkDay_{d,r,i} * allocate_{r,i} \leq termCap_{lp} \quad (4)$$

$$\forall d \in Days, lp \in LoadingPoints$$

Size of the problem

Number of rakes 200

Number of indents 50

Number of loading points 50

Horizon for indents 7

Decision variables $200 \times 50 = 10000$

Assignment constraint 50

Indent constraint 200

Compatibility constraint $200 \times 50 = 10000$

Terminal capacity constraint $50 \times 7 = 350$

Total number of constraints $200 + 50 + 10000 + 350 = 10600$

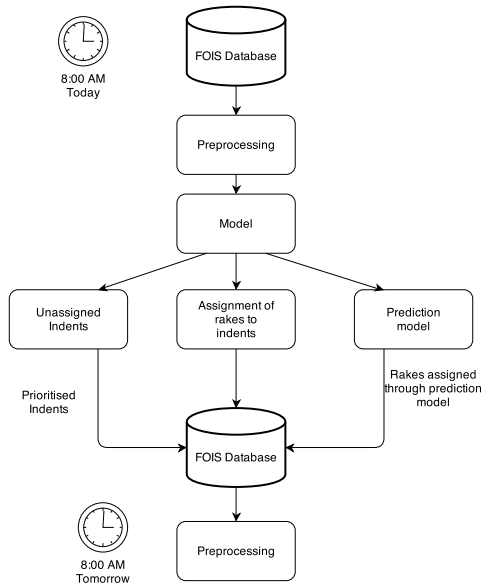


Figure 2 : Overall flow diagram for daily decisions

Model architecture explanation

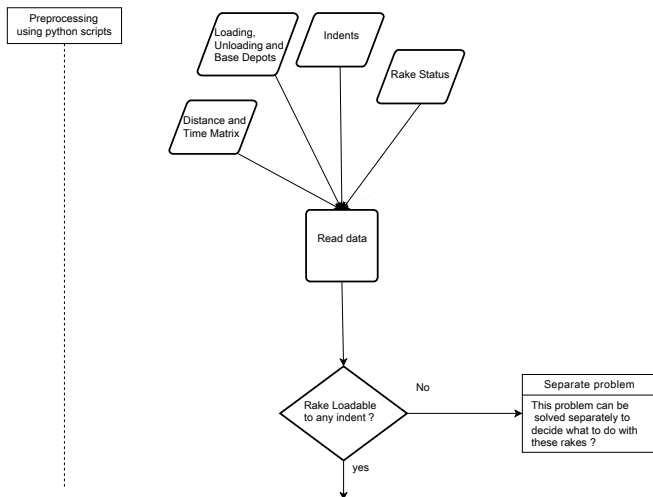


Figure 3 : Model architecture 1/2

Model architecture explanation

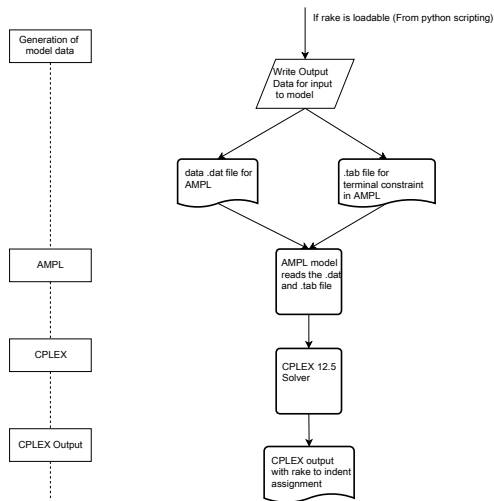


Figure 4 : Model architecture 2/2

Compatibility and extension

- ▶ Compatibility of the model:
 - ▶ Current system is compatible with the data already collected by Indian Railways
 - ▶ The input can be used by the model with very little preprocessing for the file formats required
 - ▶ The output is text based representation of assignments which can be then transformed to any format required
- ▶ Extension to the model:
 - ▶ The objective functions can be combined together and be given weights
 - ▶ For example: Objective functions o_1 , o_2 , weights w_1 , w_2
 - ▶ Sample objective: $w_1*o_1 + w_2*o_2$

Performance

Environment Software

- ▶ 2.4 GHz Intel Core i5 CPU
- ▶ 4 GB RAM

Optimization Algorithm

- ▶ IIT Bombay Optimus Server
- ▶ AMPL + CPLEX 12.5
- ▶ OS: Fedora 14 Intel X4300 M3, Quad core Xeon E5506, 64GB RAM
- ▶ Post graduate - 4GB
- ▶ Database - SQLite

Setup

1. Connecting to Database
2. Writing the files in the concerned format
3. approx. 3 seconds

Optimization running time

1. Running the model on solver
2. approx. 1 second

Proposed solution to anticipated problem

- ▶ Uses history of empty rake movement across the network
- ▶ Concept of virtual node - nodes where empty rakes have more than one assignable outward direction
- ▶ A network of nodes of loading, unloading, maintenance points and virtual points
- ▶ Use of monthly planning meet with petroleum industry for estimating demand

Entities used in model

G	Network of petroleum traffic
N	Set of nodes in the petroleum network, consists of loading, unloading, maintenance and virtual points.
A	Set of arcs in the petroleum network, connects 2 distinct nodes in the network
VP	Set of milestone yards or virtual points
LP	Set of loading points
ULP	Set of unloading points
TXR	Set of maintenance points

Entities used in model

n_i	Adjacency list of node i , represents the other nodes in the network connected to node i
p_i	Probability vector for node i
$p_{i,j}$	Probability value for adjacent outgoing node j of a node i in the p_i vector
q_i	Probability vector for anticipated indents for node i
$q_{i,j}$	Probability value for adjacent outgoing node j of a node i in the q_i vector
d_j	Vector of demand in number of rakes at loading point j for next 3 days
$lp_{i,j}$	Set of loading points we can go from node i through adjacent node j , $j \in n_i$
$cum_{i,j}$	Cumulative demand of all loading points that can be reached from node i through node j

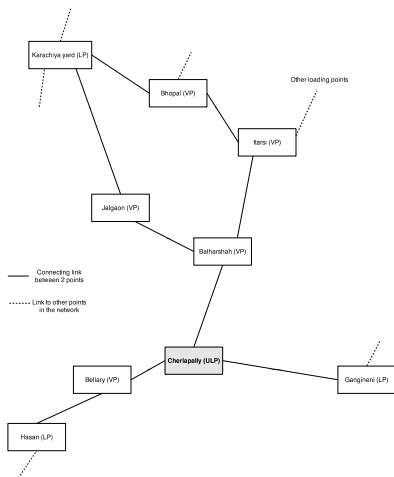


Figure 5 : Network of Petroleum Locations and Virtual Points

Transformation

$$cum_{i,j} = \sum_{x \in lp_{i,j}} d_x \forall j \in n_i$$

$$q_{i,j} = \frac{cum_{i,j}}{\sum_j cum_{i,j}}$$

$$p_{i,j}^1 = \alpha p_{i,j} + (1 - \alpha) q_{i,j}$$

Current status

- ▶ Under integration with IR's Freight Operations Information System
- ▶ Further refinement of the prediction model

Future work

- ▶ Extending the model for other railway commodities (primarily coal)
- ▶ Facility location decision for train maintenance
- ▶ Better forecasting models for arrival time of freight trains
- ▶ Fleet Sizing

Thank you!