Applying Operations Research to Railway Operations

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Operations Research or Operational Research (OR) is the use of advanced analytical techniques to improve decision making. OR's history can be traced back to World War II. The Allied forces deployed a group of scientists and mathematicians to solve their complex wartime problems. After the war the attention was turned to possibility of applying same principles to business problems and civilian use.

Some OR methods and techniques are,

- Computer simulation for testing ideas for improvement before going for field trials.
- Optimization is choosing the best, optimal solution when many feasible options are available.
- Probability and statistics helps in measuring risk, and make reliable forecasts.
- Problem structuring for complex decisions
- Linear programming, Dynamic programming, network analysis
- Queuing models
- Inventory models

Ravindran et al (2001) have explained why the OR professional has to be aware of several limitations like,

- Building a complicated model when a simple one will suffice.

- Moulding the problem to fit the technique
- Validation of model before implementation
- Taking the model too literally
- A model cannot be better than the information that goes into it.

The authors have given ten principles by which the OR user and developer can exercise caution.

Researchers and practitioners alike have applied many techniques in Transportation sector, for both tactical as well as operational issues. There is still tremendous scope for application of OR techniques to optimize the Railway Operations. The broad areas identified by OR professionals are;

1. Line capacity estimation
2. Strategic problems
3. Capacity planning (infrastructure)
4. Tactical problems
    a. Timetabling
    b. Fleet planning
    c. Crew scheduling
5. Operational problems
    a. Train control
    b. Dynamic scheduling
    c. Dynamic pricing (revenue management)

Rangaraj et al (2005) have identified areas in Indian Railways having potential for optimization;

1. Definition of capacity on railway section
2. Capturing congestion effects and broad scheduling strategies

3. Medium term capacity investments in signalling
4. Trade off between throughput (number of trains) handled and transit time (average)
5. Strategic decisions (railways)
6. Robust capacity: capacity in the presence of failure
7. Signaling failures modeled and impact on train running quantified
8. Quantify the trade-off between achievable headway and service measures (such as punctuality and average delays suffered by trains) under a given pattern of failure
9. Railways (capacity analysis)
    a. Terminal capacity
    b. Capability of handling trains at terminals
10. Routing possibilities: Look-ahead period and a routing algorithm applied on an appropriate time-space network
11. Timetabling
12. Master chart preparation tool for railway planning
13. Rake linking
14. Long distance trains
    a. Coaching stock utilization (integrated with maintenance schedules at terminals)
    b. Timetables as an input
15. Suburban trains
    a. Integrated with timetables
    b. Maintenance schedules as an input
16. Long distance rake linking
17. Terminal maintenance line charts (pit lines and washing lines - also considering constraints on line length and time for maintenance)
18. Rake link table (constraints on length of run between two maintenance points and rake compatibility)

19. Typical patterns of rake linking (self linking, interchange of day trains)
20. Marketing and Pricing models
    a. Network based models for pricing (based on second shortest distance)
    b. Marketing and service planning
21. Containers/Trucking: Fleet utilization and locational imbalance based pricing model
22. Supply chain view of transport operations: Freight supply chains on Indian Railways

The airline industry has been integrating the different modules of the scheduling process to extract more efficiency out of the system. There has been a lot of research in the area of recovery models and algorithms for real-time railway disturbance and disruption management. Currently these decisions are taken manually without the support of Intelligent Support Systems. The problem of rescheduling is basically,

- Timetable rescheduling

- Rolling stock rescheduling

- Crew rescheduling

The techniques used are Alternative Graph Model, Branch and Bound Algorithm, Mixed Integer Programming, Job Shop Scheduling Method, Heuristic Greedy Approach, Fix and Regenerate Algorithm, Genetic Algorithm, Artificial Neural Network.

However the issues which are most important for Indian Railways are

1. LOCOMOTIVE ASSIGNMENT PROBLEM

2. OPTIMAL DESIGN OF TIME TABLES

3. DYNAMIC PRICING OF SERVICES

LOCOMOTIVE ASSIGNMENT PROBLEM

This issue is a very complex one and researchers all over the world have been grappling with the problem. The extent of the problem has been highlighted in a problem solved by Ahuja et al. (2005). They used a mixed integer programming (MIP) formulation of the problem that contained about 197 thousand integer variables and 67 thousand constraints. An MIP of this size could not be solved to optimality or near-optimality in acceptable running times using commercially available software. Using problem decomposition, integer programming, and very large-scale neighborhood search, they developed a solution technique to solve the problem of CSX Transportation, a major US railroad company, within 30 minutes of computation time on a Pentium III computer. As compared to the software in-house developed by CSX, there was an estimated a savings of over 400 locomotives, which translated into savings of over one hundred million dollars annually. CSX Transportation problem was Locomotive assignment for 538 trains, with different weekly frequencies, 119 stations and 5 types of locomotives. In a week the total number of trains which differed in a running day was 3324 and the resulting weekly space-time network consists of 8798 nodes (events) and 30134 arcs (train trips).

The 2011-12 yearbook of Indian Railways mentions

Asset	Total number
Locomotives	9569
Passenger Service Vehicles	55339
Other Coaching Vehicles	6560
Wagons	239321

Number of passenger trains run daily in 2011-12			
Type of trains	Broad Gauge	Metre Gauge	Total (incl.NG)
EMU	4,644	0	4,644
Mail/Express	3,042	29	3,071
Ordinary Passenger Trains and Mixed Trains	4,172	311	4,620
Total	11,858	340	12,335

The freight trains run about 390 million km annually on IR network carrying almost a billion tonnes.

The size of the problem can be gauged by these statistics. This kind of problem has been attempted with iterative partitioning. Ahuja (2002) mentions for solving such problems heuristic (approximation) algorithms have to be employed that can find nearly optimal solutions within a

reasonable amount of computation time. An improvement algorithm is a heuristic algorithm that starts with a feasible solution and iteratively tries to obtain a better solution. Neighbourhood search algorithms (alternatively called local search algorithms) are a wide class of improvement algorithms where, after every iteration an improved solution is found by searching the "neighbourhood" of the current solution.

The increased computational power has given hope to OR specialists to approximate the real systems in a better manner now. There is also a debate on tonnage based versus schedule based approach to freight train operations. Some research has shown that schedule based strategy especially in Canadian Railways has been more profitable. The availability of advanced computing power and OR software has enabled many Railways to adopt this strategy.

The traditional objectives for Locomotive assignment problem are minimization of operating costs or minimization of fleet size. Large scale complex freight train operations cannot be handled by present day software owing to the number of parameters and enormous time taken for the calculations. Thus in a way a sub optimal solution is imposed as the problem has to be sub divided into planning, scheduling and routing and then being dealt separately. Thus an integrated model has to be the goal of the OR specialist.

OPTIMAL DESIGN OF TIME TABLES

This is basically a train scheduling problem. It can be classified into static and dynamic scheduling. In static scheduling, there is information of all the trains beforehand. But in dynamic it is available sometimes only when it enters the network. Even the static time table can have two dimensions, off-line timetabling and real time dispatching. Researchers have used

Integer Programming solved by Langrangian relaxation. Lagrangian relaxation is a technique well suited for problems where the constraints can be divided into two sets,

- "good" constraints, with which the problem is solvable very easily
- "bad" constraints that make it very hard to solve.

Techniques like Simulated Annealing also have been applied to operational scheduling. It has been named so because it mimics the process undergone by misplaced atoms in a metal when it is heated and then slowly cooled. Genetic Algorithms have also been tried. But in all cases they focus on small networks, although it does serve the purpose of giving a benchmark for larger networks.

There are several decision variables and constraints in scheduling of trains.

Decision Variables on Trains
- Origin, destination and routes of trains
- days of operation and train times
- Trip plans for all stock
- Locomotive assignment
- Crew assignment

Constraints are
- Yard capacity
- Line capacity
- Train capacity
- Rules and norms for operations

Timetabling has been considered as a job shop problem and a heuristic combination of insertion, backtracking and dynamic route selection mechanisms by Burdett and Kozan (2010). Many models have been developed and the IR's Centre for Railway Information System (CRIS) is developing Software Aided Train Scheduling and Network Governance (SATSaNG). This project is entrusted with the task of building software tools to aid the planning process. The entire resource allocation process will now be aided by the tool leading to more efficient allocations and robust time tables.

DYNAMIC PRICING OF SERVICES

In the interim budget speech by Railway Minister in Feb 2014, it was mentioned that an independent Rail Tariff Authority is being set up to rationalize fares and there was a proposal to expand dynamic pricing of tickets in line with the airline industry. Indian Railways introduced several premium trains with dynamic ticket pricing on IRCTC that can only be reserved online. The dynamic fare pattern is similar to the one used by airlines going up with demand. The fare applicable to each day/transaction is indicated at the time of booking on the IRCTC's e-ticketing website.

As reported during Christmas time in 2013, it sold one-way AC Tier-III tickets at up to Rs 12,000 and AC Tier-II up to Rs 17,000 - six to seven times higher than the ordinary Rajdhani Express fare on Delhi-Mumbai route.

In 2006, IR decided to introduce a Dynamic Pricing Policy for freight as well as passenger, for peak and non-peak seasons, premium and non-premium services, and for busy and non-busy routes. As per this policy the rates for non-peak season, non-premium service and empty flow directions would be less than the general rates and the rates for peak

season and premium services could be higher than normal. For the freight the non-peak season would be 1st July to 31st October. For the passenger segment this period would be 15th January to 15th April and 15th July to 15th September.

Now the key issue is how to decide the tariffs?

The tricky issue in dynamic pricing is to figure out how high the tariff can go and to what extent a passenger will pay higher rail tariffs, given that one can get an air-ticket at around the same price. A smart-pricing formula has been developed to compete with airways and increase fares in as per the demand curve. The formula has a floor price equivalent or more than the Tatkal Rajdhani/Mail tariff. The price will further increase in tune with the demand curve - the rate at which the tickets are booked. The prices of air tickets at that time will be monitored and thus keep the ticket price for premium trains lower than airfares.

Research in the field of dynamic pricing contains two distinct strands

- dynamic pricing strategy under social learning and
- pricing with strategic consumers

Social learning is the customers observing the trend or other customer's behaviour. This has a direct bearing on pricing and perceived utility of the product. Different strategies have to be adopted for both kinds of situations. McAfee and Te Velde (2006) have defined dynamic pricing, which is also known as yield management or revenue management, as a set of pricing strategies aimed at increasing profits. The techniques are most useful when two product characteristics co-exist. First, the product expires at a point in time, like hotel rooms, airline flights, generated electricity, or time-dated ("sell before") products. Second, capacity is fixed well in

advance and can be augmented only at a relatively high marginal cost. It will be worthwhile to analyze the strategies adopted by airlines industry and hotel/hospitality industry. Predictive analytics is being used by companies to determine best price for product. Perhaps it can be applied to the ticketing scenario also to determine base price and price cap for passenger services.

RESEARCH

There are a few organizations and institutions which are actively involved in this field. Many journals carry research papers on the Railway Operations. Few of them are,

Railway Applications Section (RAS) of INFORMS, USA, https://www.informs.org/Community/RAS

International Association of Railway Operations Research (IAROR), http://www.iaror.org/

Journal of Rail Transport Planning & Management, http://www.journals.elsevier.com/journal-of-rail-transport-planning-and-management/

Transportation Research Part B: Methodological, ELSEVEIR, http://www.journals.elsevier.com/transportation-research-part-b-methodological/

Computers & Operations Research, ELSEVEIR, http://www.journals.elsevier.com/computers-and-operations-research/

OR Spectrum, An International Journal, SPRINGER, http://www.springer.com/business+%26+management/operations+research/journal/291

TRAIL Research School, Netherlands, http://rstrail.nl/

UIC's International Rail Research Board, http://www.railway-research.org/Introduction

The market leaders in proving tools and software for OR are

GUROBI (http://www.gurobi.com/resources/free-linear-programming-solvers),

CPLEX (http://www-01.ibm.com/software/commerce/optimization/cplex-optimizer/),

MATLAB (http://www.mathworks.in/products/matlab/index.html?sec=applications),

LINDO (http://www.lindo.com/),

GLPK (http://www.gnu.org/software/glpk/),

MOSEK (http://www.mosek.com/).

There is tremendous scope for research in this field with real time data. The OR methods have not been adopted by the Indian Railways in a big way till date. Optimization tools have improved with the increased computational power and it will now be possible to solve many problems which seemed difficult or impossible before.

June 2014, Vadodara, INDIA

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