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Effective Railway Planning Through Operations Research

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ABSTRACT

Railway transportation has been around for decades and has seen a massive shift in its paradigm in terms of planning and implementation of timetable and rules. Railways are a part of millions of people's everyday lives and this has seen a change from a few railway lines to large companies that deal with the planning and services of said railway. We have selected this topic not only to see how mathematical solutions compare far better than manual planning but to also observe the change in the intricacies of the working of railways through operations research. Operations Research is the application of scientific methods to problems arising from operations involving integrated systems of people, machines and materials. In a nut shell, it is the discipline of applying appropriate analytical methods to help make better decisions with the help of practitioners, researchers, educators, and students which have an ecosystem of strengths, weaknesses, opportunities and threats. Some areas OR can be applicable are Line capacity estimation, Strategic problems, Capacity planning (infrastructure), Tactical problems. It is also used in operational problems such as train control, dynamic scheduling & dynamic pricing. 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.In this paper we give an overview of state-of-the-art Operations Research models and techniques used in passenger railway transportation. For each planning phase (strategic, tactical and operational), we hope to describe the planningproblems arising there and discuss some models and algorithms to solve them. We not only consider classical, well-known topics such as timetabling, rolling stock scheduling and crew scheduling, but we will also discuss some recently developed topics such as shunting and reliability of timetables. Finally, we will focus on several practical aspects for each of these problems. There is a lot of scope for research in this field with real time data. Indian Railways can see massive change in their functioning and effectiveness if Operations Research methods are applied on a large scale. 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.

INTRODUCTION

[A common misconception held by many is that O.R. is a collection of mathematical tools. While it is true that it uses a variety of mathematical techniques, operations research has a much broader scope. It is in fact a systematic approach to solving problems, which uses one or more analytical tools in the process of analysis. OR is also referred to as Management Science (M.S.) in order to better reflect its role as a scientific approach to solving management problems. There is no clear consensus on a formal definition for O.R. For instance, C. W. Churchman who is considered one of the pioneers of O.R. defined it as the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to problems. The key here is that O.R. uses a methodology that is objective and clearly articulated, and is built around the philosophy that such an approach is superior to one that is based purely on subjectivity and the opinion of "experts," in that it will lead to better and more consistent decisions. However, O.R. does **not** preclude the use of human judgement or non-quantifiable reasoning; rather, the latter are viewed as being complementary to the analytical approach. One should thus view O.R. not as an absolute decision-making process, but as an ***aid*** to making good decisions. O.R. plays an advisory role by presenting a manager or a decision-maker with a set of sound, scientifically derived alternatives. However, the final decision is always left to the human being who has knowledge that cannot be exactly quantified, and who can assess the results of the analysis to arrive at a feasible decision.][1]

A. Brief History and Origin

While there is no clear date that marks the birth of O.R., it is generally accepted that the field **originated in England** during World War II. The cause for its origin was the development of radar defence systems for the Royal Air Force, and the first recorded use of the term Operations Research is attributed to a British Air Ministry official named A. P. Rowe who constituted teams to do "operational researches" on the communication system and the control room at a British radar station This new approach of picking an "operational" system and conducting "research" on how to make it run more efficiently soon started to expand into other arenas of the war.

O.R. began with Europe, but slowly made its way to the US. Its first presence in the U.S. was through the U.S. Navy’s Mine Warfare Operations Research Group; this eventually expanded into the Antisubmarine

[1] Mishra, Vinod. (2014). Encyclopedia of Business Analytics and Optimization. B.T. Kumaon Institute of Technology, India.

Warfare Operations Research Group that was led by Phillip Morse, which later became known simply as the Operations Research Group.

B. Scope of Operation Research

(i) National Planning and Budgeting

OR is used for the preparation of Five Year Plans, annual budgets, forecasting of income and expenditure, scheduling of major projects of national importance, estimation of GNP, GDP, population, employment and generation of agriculture yields etc.

(ii) Defence Services

Basically, formulation of OR started from USA army, so it has wide application in the areas such as: development of new technology, optimization of cost and time, tender evaluation, setting and layouts of defence projects, assessment of “Threat analysis”, strategy of battle, effective maintenance and replacement of equipment, inventory control, transportation and supply depots etc.

(iii) Industrial Establishment and Private Sector Units

OR can be effectively used in plant location and setting finance planning, product and process planning, facility planning and construction, production planning and control, purchasing, maintenance management and personnel management etc. to name a few.

(iv) R & D and Engineering

Research and development being the heart of technological growth, OR has wide scope for and can be applied in technology forecasting and evaluation, technology and project management, preparation of tender and negotiation, value engineering, work/method study and so on.

(v) Business Management and Competition

OR can help in taking business decisions under risk and uncertainty, capital investment and returns, business strategy formation, optimum advertisement outlay, optimum sales force and their distribution, market survey and analysis and market research techniques etc.

(vi) Agriculture and Irrigation

In the area of agriculture and irrigation also OR can be useful for project management, construction of major dams at minimum cost, optimum allocation of supply and collection points for fertilizer/seeds and agriculture outputs and optimum mix of fertilizers for better yield.

(vii) Education and Training

OR can be used for obtaining optimum number of schools with their locations, optimum mix of students/teacher student ratio, optimum financial outlay and other relevant information in training of graduates to meet out the national requirements.

(viii) Transportation

Transportation models of OR can be applied to real life problems to forecast public transport requirements, optimum routing, forecasting of income and expenses, project management for railways, railway network distribution, etc. In the same way it can be useful in the field of communication.

(ix) Home Management and Budgeting

OR can be effectively used for control of expenses to maximize savings, time management, work study methods for all related works. Investment of surplus budget, appropriate insurance of life and properties and estimate of depreciation and optimum premium of insurance etc.

COMPONENTS OF A RAILWAY SYSTEM

A. Rolling Stock-

Rolling Stock refers to the coaches, wagons, locomotives and railroad cars on the railway. It's planning is needed to determine the number of locomotives and passenger carriages required and the best way to use them for trains. Since rolling stock constitutes a major part of the railways, it's included in all the components of railway planning problems namely Strategic, Tactical, Operational and Short term.

B. Strategic Planning for Rolling Stock

Strategic Planning is concerned with decision making several years and sometimes decades in advance and aims for target performance and service quality. Therefore, Strategic Planning for Rolling Stock requires formulation of appropriate long term demand forecasting models for rolling stock that can deal with the volatile demand for railway transportation. Some decisions in this planning include purchase, lease or sell new or existing units. Though Rolling Stock involves huge amounts of money and is a major player in service quality, it isn't focused much in Strategic Planning since long term demand forecasting of resources is quite difficult.It also includes railway maintenance planning which comes later in the paper.

C. Tactical Planning for Rolling Stock:

Tactical Planning includes plans for period ranging from 2 months to a year. Tactical planning includes Tactical timetabling upon which rolling stock has to be scheduled. The aim is to reduce operational costs by reducing carriage kilometer, seat shortages and improve service quality. Though Rolling Stock involves huge amounts of money and is a major player in service quality, it isn't focused much in Strategic Planning since long term demand forecasting of resources is quite difficult. Tactical Planning involves allocation of rolling stock units to line groups. Different Models are available for the same.

Alfieri describes an integer programming model to determine the circulation of rolling stock on a single train line and a single day.

Van Montfort presents a model for computing circulations of locomotive hauled railway carriages. The model deals with first and second class carriages. It's solved by commercial MIP solvers.

Abbink present an integer programming model for distributing the available rolling stock between the train lines. This does not determine an actual schedule but minimizes seat shortages in morning rush hours by allocating rolling stock units to the busiest time in morning.

D. Operational Planning for Rolling Stock:

Operational Planning makes plans for an even shorter period than Tactical Planning. The planning horizon ranges from 3 days to 2 months. The planning in Operations closely resembles that of Tactical. While Tactical planning gives result in form of a generic week plan, Operational caters to the specific demand of particular weeks. Also while Tactical planning objectives are minimizing Operational costs, Operational focuses on relatively short term plan adjustments and how such adjusted plans are to be carried out. Operational Rolling Stock Planning is concerned with handling the modifications in Tactical plans and focusing on infrastructure maintenance. The latter requires much more effort than the former.

E. Short Term Planning for Rolling Stock:

Short term planning is the last phase of Railway Planning limiting the planning period to 3 days at maximum. Since the time period of this phase is extremely short, it includes quick decision making in relation to the latest developments. Short term Planning does not concern itself with optimal solutions. At best, it results in feasible solutions which keep the railways functioning. Short Term Rolling Stock planning functions and modifies the solutions of Operational Planning. It assigns duties where Operational Planning decides the daily duties. Similar to its counterparts, Short term rolling stock planning is also focused on maintenance. Short Term Planning deals with maintenance routing, that is, modifying the operational rolling stock schedules to see which units need more urgent maintenance than others and allocating the units to the appropriate maintenance facility, provided the distance travelled, route taken and wear and tear of the rolling stock units.

F. Constraints:

The Primary objective of Rolling Stock Management (RSM) is to minimize the costs occurred by the rolling stock units by minimizing the number of units required along with the number of empty runs. Rolling Stock Management is a long term strategic planning process as its expected lifetime is typically several decades and ordering new rolling stock can take several years.

An optimal Rolling Stock Schedule is prepared by keeping in mind the following constraints:

1. Minimization of carriage Kilometres
2. Minimization the number of seat shortages
3. Minimization of Shunting Movements.
4. Maintenance of rolling stock units.
5. Cycling of Planning

G. Railway Maintenance Planning:

Rolling Stock Planning is done besides Railway Maintenance Planning. Maintenance is essential as it increases productivity and reduces cost. An intensive Maintenance Strategy results in reliable rolling stock. The list of urgent units (units that need maintenance immediately) is received by the maintenance routing planners. The maintenance depends on type of rolling stock. If a unit has travelled its maximum distance since its last maintenance check, it's not allowed to carry passengers before undergoing a maintenance check. Maintenance Planning is done by maintenance routing. The planners modify the regular plan by interchanging units. This may involve adjusted shunted plans at the station. Since shunting is a difficult problem in itself, planner are usually satisfied with the first solution found. If a solution is not found, the routers can send an urgent unit to one station as an empty unit and a non-urgent unit goes back to restore the rolling stock balance. This is not preferred as its quite expensive.

H. Timetabling

[Timetabling refers to a list of railway journeys when they begin and end. The Time tabling Problem can be categorized as follows: Cyclic and non-cyclic. According to Cyclic/periodic timetables, trains of line run every 30, 60 or 120 minutes. The timetable of passenger trains corresponds with the cargo trains if the former has a cyclic timetable. The prime advantage of the cyclic timetable is for consumers who can easily remember the timetable and plan their trips accordingly. However, it also has the drawback of running the train with few passengers. Most countries adopt this model, India being one of them, while some like France and Spain haven't adopted this technique. Currently, several countries like the Netherlands, Austria, Belgium, Denmark, Germany, the UK, Norway and Switzerland use CTT for their railway networks. 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 u constraints,

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

Most cyclic timetabling models are based on the Periodic Event Scheduling Problem (PESP), initially developed by Serafini and Ukovich (1989). Any feasible solution to the PESP system of inequalities provides a timetable satisfying all constraints. PESP can be scheduled at Strategic level as well as tactical level. Nachtigall and Voget (1996) use PESP to generate cyclic timetables with minimal passenger waiting times. Odijk (1996) uses PESP at a strategic level to determine the capacity of the infrastructure around railway stations.][2]

Some constraints for Timetabling are:

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

I. Shunting

Shunting is the process of sorting items of rolling stock into complete trains, or the reverse. Its basic aim is to choose as to which train has to go to which route at the shunt tracks so that the railway can carry its process next morning without any obstruction.

For practical instances, the Train Unit shunting problem(TUSP) is not at all easy to solve and hence it is decomposed in four parts, they are -:

Step 1: Matching arriving to departing train units.

Step 2: Estimating routing costs of train units.

Step 3: Parking of train units at shunt tracks.

Step 4: Routing of train units.

J. Matching Arriving to Departing Train Units.

In the first step, arriving train units are matched to departing ones. A separate network is created for each train where each train is further divided into several parts All networks are connected via an assignment problem of the arriving parts to the departing parts. And hence we get an optimal solution by decomposing train into different parts where arriving parts are assigned with departing parts so as to get the least no. of parts.

[2]Http://Www.kportal.indianrailways.gov.in/Index.php/Subjects/Operations-Research, Indian Railways, www.kportal.indianrailways.gov.in/index.php/subjects/operations-research.

K. Estimating routing costs of train units &Routing of train units.

In the second step, we try to find the cost in between the routing blocks to shunt tracks, its main objective is to track every train on such tracks that they don't face any conflict. The problem of one train can be solved by tailor made extension of A* -search (it accounts the cost of current path to goal as well as actual cost for the path). The final step determines the routes for train that need parking.

L. Parking of Train Units at Shunt Tracks.

The third step is the portioning problem. In this track assignments are selected which is assigned to a specified track for parking. To calculate pricing track assignments for individual tracks are generated, based on information of master problem. To compute this in real life it takes around 20-60 minutes.

M. Constraints

1. The main objective here is to create a minimum number of blocks, since this implies a minimum amount of required resources, e.g. crew and railway infrastructure.

2. The total shunting costs are minimal.

3. Create a minimum number of blocks.

N. Crew scheduling

Crew scheduling refers to the assignment of railways personnel to maintain a schedule so they can meet organizational goals. Railway require people with different skills and experience to run it.one who schedules the crew is crew scheduler. His job is to assign people specific information about the route they need to access so as to save time and money.

O. Operational Planning for crew scheduling:

Crew scheduling is one of the most successful OR applications in the transportation industry.A set of tasks, which can either be passenger train movements, empty train movements, or shunting activities, must be assigned to train drivers such that each task is covered and each train driver has a feasible duty. Each and every employee must get equal work and equal time over the depots.

P. Short Term Planning for Crew Scheduling:

As the time table changes day to day and there is a change in rolling stock circulation. The schedule of crew need to be rescheduled. In short term there need to be slight changes so crew scheduler need to make a schedule such that all tasks are covered

COMPARISON BETWEEN ISSUES AND OR TECHNIQUES OF DIFFERENT COUNTRIES

A. Netherland Railways

a). Rolling Stock Management:

To solve problems arising in railway stock management, there is a method known as the 8 o'clock rolling stock assignment where rolling stocks are allocated to trains operated around 8 o'clock in the morning. A standard day of the week is determined with the main idea being that if the rolling stock is allocated for the morning peak times, then the allocations for the evening time will be appropriated accordingly. There needs to be an optimal match between the required and the provided capacity of these trains. Constraints such as the availability of the rolling stocks, length of the train not exceeding the platform must also be considered.

In the rolling stock circulation problem an appropriate allocation of rolling stock units to the trips to be operated needs to be determined. Relevant objectives to be pursued are service to the passengers, efficiency, and robustness. Service to the passenger's means that on each trip the provided capacity should be sufficient to transport the expected numbers of first and second-class passengers according to given norms. This problem is usually solved on a line-by-line basis and per day of the week. The rolling stock circulation is determined on a line-by-line basis in order to reduce the well-known snowball effect of delays. Rolling stock circulation for each day of the week is determined and they are modified so that they fit after each other. They need to be balanced over the week. The main input needed for formulating a solution to this problem consists of the timetable, the expected numbers of passengers on the involved trips, and the numbers of train units (per subtype) that can be used. Other relevant data consists of the maximum train lengths per trip and the lengths and the capacities of the different subtypes.

[If train units of different subtypes can be combined in one train on a single trip, then a relevant issue to be taken into account is the order of the train units in the trains. This issue cannot be handled by an ordinary multi-commodity flow model. In order to deal with this issue, the concept of a so-called transition graph was introduced. A transition graph of a train represents the feasible transitions from one composition to another at the successive locations along the journey of the train. The rolling stock circulation problem can thus be described as an integer multi-commodity min-cost flow problem, where, at the same time, for each train a feasible path through its associated transition graph has to be found.

In case of extra trains due to sport events or speed limitations on some parts of the infrastructure due to track maintenance, the number of train units of each type and the order of these units in the train should be determined for each individual trip and the rolling stock should be balanced at the stations at the end of each day such that at the next day the correct amount of rolling stock of each type is available at each station. This can be done by adding extra rolling stock to few trips, or a more expensive option would be to add empty train movements.

In dense systems rolling stocks are routed to maintenance on a day to day basis i.e. each day it is determined which rolling stock units need to be taken away from the operations in order to undergo a maintenance check, and how these units are routed towards the maintenance facility. Each rolling stock has a chain of duties for the next day and in case of efficiently routing urgent train units to a maintenance facility, there is a min cost flow model. Arcs are created with zero cost and capacity one and they and they represent the potential swap of duties.][3]

b). Crew Scheduling:

Railway companies in Europe have begun using crew scheduling software in the recent few years to make their operational schedules. Some well-known packages are CARMEN (Kohl, 2003) used at among others the German Railways, TRACS II (Foreset al., 2001) used at several operators in the UK, and TURNI used at NSR (Kroon &Fischetti, 2001; Abbinket al., 2004a).

Train drivers are assigned a set of tasks be it passenger train movements, empty train movements, or shunting activities. This is done so that each driver has a feasible duty which is a sequence of tasks after each other that can be carried out by a single employee on a single day. Constraints such as the length of the duty does not exceed the maximum spread time, there is a meal break in a duty with a certain minimum length, and so on need to be fulfilled and maximum average working time for all drivers and a fair division of the work over the depots also needs to be considered. These constraints are typical for the Dutch and are referred to as “Sharing Sweet & Sour” rules. They aim at allocating the popular and the unpopular work as fairly as possible among the different crew depots. For instance, some routes are more popular than others and intercity trains are preferred over regional trains.

B. Indian Railways

Indian Railways is the largest railroad under a single management with revenues upwards of 12 billion USD. A few of the areas Indian railways which have a potential for optimization are capacity in railway sections, robust capacity, strategic decisions, timetabling, freight supply limits etc. The most important issues for

[3]Abbink, E.J.W, Fischetti, M., Kroon, L.G., Timmer, G., Vromans, M.J.C.M. (2005). *Reinventing Crew Scheduling at Netherlands Railways*. Interfaces, 35(5):393–401.

Indian Railways though are locomotive assignment problems, optimal design of time tables and dynamic pricing of services.

a). Locomotive Assignment Problems:

Planning stage in railroad is divided into strategic, tactical and operational planning. Locomotive scheduling is the final stage of the railroad scheduling and depends on incoming requests, but with this assumption, engines and crews are rostered and appropriate cars are available. A mixed integer programming formulation contains 197 thousand integer variables and 67 thousand constraints. Such large numbers cannot be solved optimally using commercial software hence approximation algorithms need to be employed to find solutions in reasonable amount of computation time. Neighborhood search algorithms (alternatively called local search algorithms) are a wide class of improvement algorithms (which are solutions that start with feasibility and move towards improved solution) where, after every iteration an improved solution is found by searching the "neighbourhood" of the current solution. Thus an integrated model with sub divisions of planning, scheduling and routing when implemented by a OR specialist can be hugely beneficial.

b). Dynamic Pricing of Services:

In the interim budget speech of 2014, the railway minister 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. Freight as well as passenger trains, peak and non-peak seasons, premium and non-premium services and busy and non-busy routes were targeted for these fair rates. As per this method, prices for non-peak, non-premium and non-busy were relatively lesser than the general rates and for peak season, premium and busy routes the rates would be higher than usual. These tariffs are decided keeping in mind air tariffs and the demand curve for such tickets. Thus prices of premium trains are generally kept lower than airfares. The dynamic pricing strategy contains social learning and pricing with strategic customers. Dynamic pricing (also known as yield management or revenue management) is a set of pricing strategies aimed at increasing profits.

c). Optimal Design of Time Tables:

Train schedules are classified into static and dynamic. In static scheduling, there is information of all the trains beforehand. But in dynamic it is available sometimes only when it enters the network. Researchers have used Integer Programming solved by Langrangian relaxation and its constraints as mentioned above.

C. Railways in Emerging Countries:

Emerging countries have gradually developed a system of rail transport and undertake projects which are brought about by their development. [Nigeria's largest city, Lagos, for instance is constructing a light rail system under a Public Private Partnership (PPP). Kenya Railways Corporation is in the process of developing a new standard railway line for passengers and Congo transportation between Mombasa, which is the largest port in East Africa and Nairobi, the capital city. Application of operation research techniques in such railway transport projects can help these countries maximize the value for money and meet policy objectives. For such countries linear programming model can be used to solve a broad range of problems in different sectors of an economy including health and transportation sectors.][4] Linear programming model is a planning technique that uses mathematical model in maximizing or minimizing appropriate measure to optimize the value of some objective after identifying some constraints. In most emerging countries, the urban rail transit transportation system consists of the carrying tool, infrastructure and operation management. While carrying tool refers to the equipment required by railway officials, consisting of safety monitoring, maintenance & protection, infrastructure basically refers to the public works engineering system, tractive power supply system, and communication signal system. Operation management refers to the operation organization and the service management system organizing various transportation resources scientifically and reasonably, and provides high quality transportation services for passengers and owners of cargo based on the requirements on the transport of travelers and goods. Constraints for the above can be the limitation of the railway network, poor condition of the railway infrastructure and limited volume of traffic.

Using a mathematical model-

D. Decision Variables:

Let

x_1 represent the carrying tool

x_2 represent the infrastructure

x_3 represent the Operation management

a). Carrying Tool (x_1):

Let

[4]M. C. Agarana, T. A. Anake, H. I. Okagbue. Optimization of Urban Rail Transportation in Emerging Countries Using Operational Research Techniques. PP. 1116-112

x_{11} = safety monitoring

x_{12} = facilities of maintenance and protection

b). Infrastructure (x_2):

Let

x_{21} = Public works engineering system

x_{22} = tractive power supply system

x_{23} = communication signal system

c). Operation Management (x_3):

Let x_{31} = Passenger flow demand forecasting

x_{32} = demand rules analysis

x_{33} = Passenger transport path

x_{34} = transportation organization model

x_{35} = train operation plan

x_{36} = train graph

x_{37} = motor train unit application

x_{38} = train and station organization

d). Contributions:

From the data gathered, the percentage of success (contribution) of each of the decision variables is given. Therefore, the contributions c_{1j} as regards the carrying tool are as follows:

$c_{11} = 10$, $c_{12} = 15$

The contributions c_{2j} as regards the infrastructure are as follows:

$c_{21} = 5$, $c_{22} = 10$, $c_{23} = 5$

The contributions c_{3i} as regards the operation management are as follows:

$c_{31} = 6$, $c_{32} = 5$, $c_{33} = 5$, $c_{34} = 10$, $c_{35} = 10$, $c_{36} = 4$, $c_{37} = 7$, $c_{38} = 8$

The performances of the decision variables towards optimization of urban rail transportation in emerging countries, therefore, are respectively:

$$\sum_{j=1}^{2}\sum_{i=1}^{2} c_{1j}x_{1i} = c_{11}x_{11} + c_{12}x_{12} \quad .... \ (1)$$

$$\sum_{j=1}^{3}\sum_{i=1}^{3} c_{2j}x_{2i} = c_{21}x_{21} + c_{22}x_{22} + c_{23}x_{23} \quad \text{........ (2)}$$

$$\sum_{j=1}^{8}\sum_{i=1}^{8} c_{3j}x_{3i} = c_{31}x_{31} + c_{32}x_{32} + c_{33}x_{33} + c_{34}x_{34} + c_{35}x_{35} + c_{36}x_{36} + c_{37}x_{37} + c_{38}x_{38} \quad \text{.... (3)}$$

E. Objective

The objective is to maximize total performances of the decision variables. That is:

Maximize

$$Z = \sum_{j=1}^{2}\sum_{i=1}^{2} c_{1j}x_{1i} + \sum_{j=1}^{3}\sum_{i=1}^{3} c_{2j}x_{2i} + \sum_{j=1}^{8}\sum_{i=1}^{8} c_{3j}x_{3i} \quad \text{........ (4)}$$

$$= c_{11}x_{11} + c_{12}x_{12} + c_{21}x_{21} + c_{22}x_{22} + c_{23}x_{23} + c_{31}x_{31} + c_{32}x_{32} + c_{33}x_{33} + c_{34}x_{34} + c_{35}x_{35} + c_{36}x_{36} + c_{37}x_{37} + c_{38}x_{38} \quad (5)$$

F. Resource Utilization

Let a_{ij} be the amount of resource j used to achieve one unit of decision variable x_i. From the data gathered and with some simulations, we have the following:

Table 1. Decision Variables and Their Corresponding Contribution.

a_{11} = unit cost of achieving safety monitoring

a_{12} = unit cost for acquiring facility of maintenance and production

a_{22} = unit cost for tractive power supply system

a_{23} = unit cost of installing communication signal system

a_{31} = unit cost to achieve passenger flow demand forecast

a_{32} = unit cost to carry out demand rules analysis

a_{33} = unit cost to achieve the transport path

a_{34} = unit cost of formulating transport organization model

a_{35} = unit cost of building train operations plan

a_{36} = unit cost of making train graph available

a_{37} = unit cost of motor train unit application

a_{38} = unit cost of proper train and station organization

The amount of available resources used to achieve a unit of the decision variables are represented in Table 2 as follows [12] [13].

G. Constraints

$$a_{11}x_{11} + a_{12}x_{12} \leq 25\% \text{ of T}$$

$$a_{21}x_{21} + a_{22}x_{22} + a_{23}x_{23} \leq 20\% \text{ of T}$$

$$a_{31}x_{31} + a_{32}x_{32} + a_{33}x_{33} + a_{34}x_{34} + a_{35}x_{35} + a_{36}x_{36} + a_{37}x_{37} + a_{38}x_{38} \leq 55\% \text{ of T}$$

$$a_{11}x_{11} + a_{12}x_{12} + a_{21}x_{21} + a_{22}x_{22} + a_{23}x_{23} + a_{31}x_{31} + a_{32}x_{32} + a_{33}x_{33}$$
$$+ a_{34}x_{34} + a_{35}x_{35} + a_{36}x_{36} + a_{37}x_{37} + a_{38}x_{38} \leq T$$

$$a_{ij} \geq 0; i = 1,2,3,; j = 1,2,\cdots,8$$

where T is the total amount available for rail transport in sub-Sahara African countries, which is put at $20 million. in a year, on the average, for the purpose of this paper.

H. The Model

Maximize

$$Z = 10x_{11} + 15x_{12} + 5x_{21} + 10x_{22} + 5x_{23} + 6x_{31} + 5x_{32} + 5x_{33}$$
$$+ 10x_{34} + 10x_{35} + 4x_{36} + 7x_{37} + 8x_{38}$$

Table 2. Values of Resources Used to Produce A Unit of Different Decision Variables.

Subject to

$$25x_{11} + 50x_{12} \leq \$5 \text{ million}$$

$$25x_{21} + 25x_{22} + 25x_{23} \leq \$4 \text{ million}$$

$$5x_{31} + 5x_{32} + 5x_{33} + 5x_{34} + 10x_{35} + 5x_{36} + 7.5x_{37} + 12.5x_{38} \leq \$11 \text{ million}$$

$$25x_{11} + 50x_{12} + 25x_{21} + 25x_{22} + 25x_{23} + 5x_{31} + 5x_{32} + 5x_{33}$$
$$+5x_{34} + 10x_{35} + 5x_{36} + 7.5x_{37} + 12.5x_{38} \leq \$20 \text{ million}$$

$$x_{ij} \geq 0; i = 1,2,3; \; j = 1,2,\cdots,8$$

I. Model Solution

The model is first of all written in its standard form before applying simplex method to solve it.

a). Standardized Model

Maximize

$$Z = 10x_{11} + 15x_{12} + 5x_{21} + 10x_{22} + 5x_{23} + 6x_{31} + 5x_{32} + 5x_{33}$$
$$+10x_{34} + 10x_{35} + 4x_{36} + 7x_{37} + 8x_{38}$$

Subject to:

$$25x_{11} + 50x_{12} + s_1 \leq 5{,}000{,}000$$

$$25x_{21} + 25x_{22} + 25x_{23} + s_2 \leq 4{,}000{,}000$$

$$5x_{31} + 5x_{32} + 5x_{33} + 5x_{34} + 10x_{35} + 5x_{36} + 7.5x_{37} + 12.5x_{38} + s_3 \leq 11{,}000{,}000$$

$$25x_{11} + 50x_{12} + 25x_{21} + 25x_{22} + 25x_{23} + 5x_{31} + 5x_{32} + 5x_{33} + 5x_{34} + 10x_{35}$$
$$+5x_{36} + 7.5x_{37} + 12.5x_{38} + s_4 \leq 20{,}000{,}000$$

$$x_{ij} \geq 0; i = 1,2,3; \; j = 1,2,\cdots,8$$

From the results, we see that safety monitoring, tractive power supply and Transportation organization model are significant for the efficient working of railways in emerging countries such as the Sub-Saharan African region. In any of the emerging countries, these three factors, classified under carrying tools, Infrastructure and operational management respectfully, are very critical in optimizing the urban rail transport in emerging countries.

J. Vertical Separation:

The present Indian railway system suffers from one huge drawback: adoption of modern technology and Operation Research. India’s fastest train (Gatiman Express) can clock a speed of 160km/hr whereas

Railways in other countries such as China and Japan have reached the maximum speed of 315 km/hr and 320km/hr respectively and are looking to develop their network even further to 500km h.

A prime reason for the immense development of European railways and Australia has been vertical separation. A railway can be divided into one or more than one entities that own and manage the railway infrastructure (IMC) and one or more entities that operate train operating companies operating transport services (TOC). Or it can choose to allow vertically separated 'tenant' train operating companies to use infrastructure of vertically integrated dominant railway. While the concept of vertical separation has been lauded as a great success for railway development, it's primarily useful in countries where Governments are looking to expand the part of Private sector in railways.

Why separate railways vertically?
• to promote competition in or for the rail transport market, and encourage private sector participation in rail transport operations while maintaining state ownership and control of the railway network • to increase transparency in use of government subsidies (more apparent than real as track access charges may still transfer subsidies between IMCs and TOCs)
What are the most favorable circumstances?
• larger railways with multiple and separable types of TOCs that can operate as viable entities, within markets that are large enough to be viably competitive • countries aspiring to join the European Union (although institutional vertical separation is not an EU requirement) • countries with strong implementation, administrative and regulatory capacity
What are the least favorable circumstances?
• Vertical fragmentation of small national rail markets that are unable to support competition or have no intention of seeking private participation in TOCs

The above table describes the advantages of vertical separation with details about where it would be most useful. Vertical Separation can be considered a subsidiary to liberalization of railway industry. Most of the modern railway reforms have revolved around liberalization with opening-up of rail services to competition through the granting of open access to monopoly infrastructures.

There is a pattern to be noticed here. Most countries looking to develop and modernize their railways have implemented Vertical Separation in one way or another. Vertical separation can be used for different reasons pertaining to the same objective. While in Europe, it's used for increasing competition, in Japan it's used for financial reasons.

But this model has its limitations. One, it takes away the benefits of economies of scope by separating the infrastructure from the operation of trains. Another, a vertically tougher system is a lot tougher to regulate. India can't adopt this system even if it adopts partial vertical separation like Europe. It would imply that Indian Railways owning the infrastructure and being the most dominant player in the operation of trains. Independent and fair regulation is the only guarantee for potential private entrants against unfair distribution of high cost infrastructure.

Thus, it can be concluded that though Vertical Separation is a proven way to development for railways, it's not for every country or at least not at this point of time. The debate on this concept is still ongoing and the outcome of it along with the future development of the countries will determine the extent usefulness of this model

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CONCLUSION

From this research paper we see how different components and systems of a rail transport can be made efficient through operations research. We also see variations in OR techniques used in different countries depending on their requirements, demands and availability of resources. All in all, there still persist issues in the railway industry in both developed and developing countries. While some manage to effectively implement solutions to further modernize their systems, many are unable to do so due to multiple constraints. In the future, we hope to see large scale usage of Operations Research for smoother functioning of the railway department and better tools and techniques to solve the difficulties faced today and settle the debates on the existing optimization methods.

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