Node capacity and terminal management on Indian Railways

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1. Introduction

Fixed infrastructure forms a large part of the investment base of a railway. Along with demand assessment, service planning and customer oriented operations, good strategies for the efficient use of fixed assets are crucial for the financial performance and viability of any railway.

Terminals and nodes on the Indian Railways network are now recognized as potential bottlenecks in the achievement of effective network capacity. It is necessary to be able to clearly quantify node capacity as part of the overall capacity, to match this capacity with traffic requirements, to be able to plan investments related to node infrastructure and to be able to manage the operations at nodes in an effective manner.

This note outlines the current status and some possibilities in future, in this regard. It also briefly surveys the literature in this area.

2. Assessment of section and node/terminal capacity

Indian Railways has evolved over the years by planning the rail network to cover large geographical parts of the network, to reflect both the flow of freight and also to play its role in regional development.

In the creation of fixed infrastructure and assets, line capacity, with implications of investment of many tens or hundreds of crores over long sections, has been the focus of attention, measurement, monitoring and assessment. Indian Railways maintains records and monitors line capacity statements to identify sections with high utilisation (sometimes over 100%, causing some skepticism about the precise validity of the measure itself).

Some work on line capacities can be found in Kondratchenko (1977), Laszkiewicz, Rangaraj and Srivastava (2000a), Salhotra (1999), Sasaki (1977) and Thoopal (1998).

In order to standardise the measurement of line capacity over sections – especially to do with utilization and related performance measures - it is indicated separately wherever the traffic profile is even slightly different over different parts of a section. (For example, Surat-Vadodara is a natural section on Western Railway. But since some passenger trains terminate at Bharuch and also because of goods sidings near Bharuch, line capacity statements are provided separately for Surat Bharuch and Bharuch Vadodara. This leads to a situation where both these sections individually may have some sectional capacity, but where it is accepted that the larger section cannot handle that number of trains because the intermediate station cannot handle that traffic.)

The situation is compounded as far as network capacity is concerned, where it may be accepted that Bharuch Vadodara and Vadodara Godhra may have some sectional capacity, but it may well be that Vadodara yard cannot handle this number. Partly, these difficulties, added to the problems of measuring non-homogeneous traffic have led to an obscuring of the measurement of some crucial infrastructural bottlenecks. The issue of defining line capacities for non-homogeneous traffic has been briefly discussed in Rangaraj and Srivastava (2000a) and also by the methodology proposed by the Long Range Decision Support System (LRDSS) of the Indian Railways (e.g. see Salhotra (1999)).

As regards node capacities, there are two major difficulties in assessment. One is that a node on a railway network can have traffic of different types and a scheduling model of some kind is required to route the traffic in a safe and effective manner. Only then can the capacity of the node to handle traffic be assessed. The second difficulty is to establish a numerical measure for capacity in the light of the mixed activities at a node. A number such as the maximum number of trains handled in a given direction is not adequate, as a measure, as it cannot be translated into effective service measures or used in judging investment effectiveness.

A possible solution to this is the following. An answer to the question "What time delay does a standard type of unscheduled freight train face, arriving at a random point during the day, while passing through any part of the rail network?" If this answer is considerably more than the normal free running time of the train (given its speed characteristics and the section/yard speed restrictions), it can be concluded that that part of the network (whether node or section or a bit of both) is congested.

Given the line capacities of sections adjacent to a node, the report by Thoopal (1998) presents a concrete method to estimate the bottleneck effect of a node. In this, in addition to the platform occupancy charts of known movements of passenger trains, all possible shunting and other movements due to crew change, loco change and other operations are superimposed. The residual capacity on platform and non-platform lines are used to attempt to handle the freight trains according to some arrival pattern from neighbouring sections. This highlights the loss of capacity due to the node. The study clearly establishes the seriousness of the problem in many congested parts of the Indian Railway network and suggests a number of concrete measures to address the problem.

3. Classification of nodes and terminals

For convenience, we can describe the management of fixed infrastructure facilities in the following three categories: 1) passenger dominant facilities, 2) freight handling facilities and 3) maintenance oriented facilities.

Although there could be an overlap of these activities in some facilities, the above provides a useful classification of activities, investments and strategies that could be followed in each type of facility. The overlap is a result of a mix of concerns that are inevitable in activities such as the railways, where common facilities are used for a variety of purposes. To that extent, the planning and operation of these facilities cannot be segregated into watertight compartments as far as objectives or strategies go.

With this in mind, the characteristics of these different types of facilities are discussed in a little more detail below.

1) Passenger dominant facilities: These are sections and stations (including junction stations) on the railway network. In such facilities, there is a fair amount of homogeneous traffic (often with a significant fraction of traffic being of the scheduled or timetabled variety, applicable to passenger trains). In terms of objectives, there are customer driven schedule constraints and there is a concern for maintaining punctuality and to follow timed activities as best as possible. A good measure of the operating effectiveness of such facilities would be the extent of slack provided in the timings of passenger trains that use such facilities.

Some papers that deal with modeling passenger-dominated facilities are Zanelweld et al (1995,1996, 2001).

2) Freight handling facilities: These are exemplified by goods yards and sidings, loading and unloading points for bulk traffic, and facilities such as container terminals. In such facilities, the major objectives are to do with throughput or turnaround (rather than any specific time of completion) and utilisation of facilities. Conventionally, the major bulk freight customers of the railways would be handled at such facilities. Daganzo (1986, 1987a, 1987b), and Daganzo et al (1983) give some insights into the operations that take place and their modeling.

3) Maintenance oriented facilities: These are facilities, such as EMU car sheds and loco sheds. These facilities are somewhat fewer in number, but are still important in the overall effectiveness of operations.

4. Operations management practices on Indian Railways

We briefly outline some operating practices on Indian Railways and discuss options and strategies in the coming years.

4.1 Control regime: The control regime on Indian Railways is section oriented, for historical reasons. This was appropriate and continues to be so, when sectional capacity is in fact a likely bottleneck in resources and where sectional resources need to be optimally allocated. This has lead to a situation where congested nodes are managed through a largely informal structure of communication between section controllers of adjacent sections, together with cabins which control the movement through some key points. A limitation of these procedures as far as node management is concerned is that on a typical control chart, all the station resources are bunched together at one location (on the vertical axis) and detailed decisions such as loop/platform allocation are done only by the experience of the section controller.

4.2 Organisational and management structure: It is often the case that nodes are at the boundaries of divisions or sometimes zones on the Indian Railways. This naturally means that under the normal quantitative performance measures used at the sectional, divisional and zonal levels, the performance of the node itself may be suboptimal. In those situations where the node is in fact a bottleneck in the network context, this could be crucial in determining overall performance. At the very least, control of traffic at such interface nodes requires additional efforts in communication and sharing of priorities.

4.3 Area control: Although Indian Railways has largely moved away from the marshalling yard set up, where trains would be classified and formed, in some yards, area control for the purposes of train examination, loco attachment and sometimes loading and unloading, is practiced. Area control charts, which represent the various lines available for handling traffic, are used for this purpose. It is worth examining whether these principles can be used for handling traffic at junction stations.

4.4 Operating practices: A cascading impact of delays and detentions due to nodes are often evident in reviews of operations. To provide more flexibility in handling traffic at nodes, it is common to see signaling measures such as automatic signaling or multiple lines or twin single line operation for a few block section on every section leading to a congested node. Other practices such as loco change or crew change rationalization are done to improve the flow of traffic at nodes.

4.5 Freight terminal management: The management of freight terminals is an important one in the Indian Railways context, and it is an important part of the ongoing phase of the LRDSS project. There are a variety of technological and operational options to increase the turnaround of rolling stock, to reduce customer delays and increase node level performance. Some of these measures are Engine-on-load, integrated train maintenance procedures, closed circuit movement of rakes etc. In the Indian Railways context, some of these principles are outlined in Thoopal (1998) and other studies.

4.6 Supply chain management: Some principles of supply chain management can be applied to the issue of management of freight and passenger terminals. Some of these, from an IT perspective, are listed in Rangaraj and Srivastava (2000b).

4.7 Examples and case studies: Several internal studies at Railway Staff College, Vadodara and other institutions provide rich insight to the issues at particular nodes. Such studies have proposed diagnostic measures, such as the average throughput time taken by freight trains through a node, and have listed a number of engineering and managerial options to improve node performance.

5. Models for estimating node capacity and models for managing node operations

There is a very large literature in the area of railway operations and management, which deal with theoretical models for estimating node capacity and for managing node operations. We provide a representative sample of the literature, with a few comments.

5.1 An initial classification of models: The models for assessing node capacity and for management of node operations can be broadly classified into: 1) Planning models and 2) Operations Management models

Planning models: These models take a long-term view of the situation like the expected number of trains ten to fifteen years down the line, etc. They mostly deal with the infrastructure of the node, like, how many more platforms will be needed, or how many more lines would be needed. This is because these capacity enhancement operations are very costly and takes some time to complete. An example of a planning model is Jovanovic and Harker (1991).

Operations management models: On the other hand, these models look at activities over a short time span, for example, how to handle a freight train that is to come in about five minutes. These models have two characteristics, (a) the computational procedure has to be quickly validated and implemented (in a matter of seconds) and (b) an accurate modeling of the node, as far as interlocked and parallel movements needs to be present. These models may have some simple scheduling rules, but would not permit modeling of the infrastructure of the node (including the network description) at a high level. The network infrastructure would be taken as fixed during the implementation of these models.

5.2 Planning models: A rough classification of the methodologies that are used for node modeling is: 1) Exact Mathematical Programming, 2) Simulation, and 3) Constraint-based models

In the mathematical programming models, a (network) model of the node is made and some kind of an integer program is formulated, which is then solved to get the necessary decisions at the node. Some examples of the models of this type are Cai et al (1994), Carey et al (1994), Carey (1994a, 1994b), Greenberg et al (1988), Higgins et al (1996, 1997), Petersen et al (1981).

In simulation models, suitable approximations are made to model the operating rules, but the models usually permit a higher level description of the operating environment, in terms of facilities and infrastructure. Some amount of randomness (e.g. random arrivals of traffic or equipment failures) is incorporated into the analysis and the behaviour of the system is studied under various environments. Some simulation models can be found in Bourachot (1986), Breur (1973), Ghose et al (1998), Goswami (2001), Guieysse (1970), Krishna Kant (1984), Petersen (1982) and Sahin (1999).

In constraint-based models, usually, some kind of AI tool is used and then all the constraints are represented in the tool. Then a search of a feasible region of options is done to get the desired results. Chiu et al and Jose et al have applied constraint-based models.

5.3 Traffic control or operations management models: Some models for railway traffic control are described below:

Bastin et al (1991) developed an automatic control based approach for the railway traffic control problem. In this, a traffic model is developed, taking into consideration the time deviations (the vector of deviations is taken to be the state of the system) and an objective function is written that captures these delays along with the passenger delays and the feedback control law is to minimise this objective function.

Vernazza et al (1990) developed an intelligent control model for traffic control. The main purpose in this model is to define a control system that can be applied to any system irrespective of the size. The problem is modeled in terms of resources (train lines), users (trains) that compete for resources and managers (decision controllers) that allocate resources to users. The decision process is governed mainly by two things: urgency and priority.

Jose et al use a constraint-based model to manage situations where normal operations are disrupted. This model attacks some situations where line management, involving traffic along a small number of lines is needed. The problem is modeled as a constraint satisfying optimisation problem. The model requires location data like location type (line or station) and capacity, train data like train type and priority and some other data like time spent by a train on the location.

6. Some work at IIT Bombay on modeling of railway traffic through sections and nodes/terminals

In this section, we briefly look at some past and ongoing academic research at IIT Bombay, in this area.

6.1 Section capacity: In the area of section capacity assessment, a simulation tool is being developed for Indian Railways Institute of Signal Engineering and Telecommunications (IRISET). This tool will permit numerical simulation and experimentation that will examine a variety of traffic and investment scenarios. The special feature of the model is that it permits modeling of automatic signaling investments and evaluates the performance of a section in two unique dimensions (i) speeds that depend on signal aspect and (ii) impact of signal failures. Apart from this, parametric experimentation is possible with block section lengths, freight train speeds, number and accessibility of loops, loop turnout velocity and other parameters of typical interest. The tool has a graphical user interface as well as a charting procedure for validating train positions, signal aspects and velocities. The major output statistics are the average section traversal times for unscheduled freight trains and loop occupancy measures.

The work done on section capacity at IIT Bombay can be found in Malik (1999) , Ashok Kumar (2000), Goswami (2001), Naik (2002).

6.2 Node capacity: We describe two models below, which attempt to look at the handling of rail traffic through nodes, junctions or terminal stations on a railway network.

1) Malde (2001) describes a detailed model along with a software implementation of the routing of traffic through a node and creating a schedule of movements. The model is a general one, which is designed to find a feasible timetable for trains with certain characteristics over a railway section that includes track sections and stations. It has sufficient detail in route selection to make it useful for modeling traffic through terminals or junction stations. The general form of the model is shown to be theoretically difficult one to solve exactly, and what is proposed is a heuristic which takes trains one at a time according to a priority and finds feasible paths (if available), through the network in question.

The model allows the specification of alternate routes for traffic streams through various track segments, and selects the shortest possible such route for each unit of traffic and then calculates a feasible schedule for a known set of trains through a node. Passenger trains with scheduled times at departure nodes can be specified as part of the input. Trains over track segments move with a specified speed. The trains are taken up in the order of a pre-specified priority. Crossovers are modeled along with their intersection with various block sections.

The model can be extended to consider signal aspects and acceleration or deceleration of trains through various station block sections. If priorities can be set dynamically, then scheduling rules that attempt to optimize the flow of traffic can also be implemented.

2) Garg (1997) describes a preliminary study of traffic through a real life node (Kurla station of Central Railway). Kurla station handles more than 1200 trains a day. There are a number of types of suburban services through the station, including some which terminate at the station. There is a car shed near the station which houses rakes for maintenance and there are some stabling lines near the station. The station also handles a number of long distance trains, and some amount of freight traffic through the station.

The study identifies a "sufficient" collection of station section resources, and works with a number of streams of traffic (22 in the study) through the node. The performance of the node is modeled with respect to the delays encountered by different streams of traffic. Since much of the suburban traffic is streamlined and timetabled, a key performance parameter is the time taken for freight trains to cross the yard, since paths have to be identified as and when possible for these unscheduled trains. In a manner similar to recent line capacity studies, the consequences of insufficient capacity show up as delays to activities, and these can be quantified more meaningfully.

The physical control framework that is assumed is that of route relay interlocking, where different routes through the node can be used simultaneously, subject to safe operating conditions.

The technique used is discrete event simulation, where freight train arrival timings are generated randomly and their progress through the station is decided by some operating rules. The simulator permits some randomization in the timings of scheduled trains as well.

Some of the input parameters used in the study are:

- priorities accorded to each stream (which are then translated into some simple scheduling rules for handling conflicting streams of traffic). This reflects the fact that some streams have priority over others (perhaps even varying with time of the day)
- a certain amount of look ahead (in terms of time) to decide on the impact of scheduling one stream of traffic. This reflects the behaviour of a typical section controller who will attempt to assess the impact of traffic over some time slice in the future.
- headway of traffic in a stream (minimum time interval between two trains on the same path). This is one of the parameters to do with technology and hard investments, which could increase capacity. Other such parameters are speeds on different sections (especially crossovers) and accessibility to different routes through the node.

The results of the study indicate that there are quantifiable benefits through certain actions (like increasing the amount of look ahead and reducing the headway). These are to be expected, in general, but there are some cases in which there are thresholds of improvement, beyond which the savings are marginal. In any case, the extent of savings in the presence of different traffic conditions can be estimated through such studies and investments can therefore be prioritized more effectively.

6.3 Proposed work at IIT Bombay: Continuing work at IIT Bombay is briefly discussed. A new project will focus on operating effectiveness of handling traffic at congested nodes on the Indian Railways. The project will try to achieve three major goals:

1) An assessment of theoretical approaches to this problem from the available literature. A crucial part of this is to develop appropriate measurement norms for assessing node performance. The project will consider operating norms based on volumes of throughput (where relevant) and also time-based measures.

2) Development of a computer based implementation of an appropriate model for the purpose. This will use appropriate models drawn from the literature and practice, which are relevant for the effective modeling of railway operations.

3) A comparison of two or three nodes on the Indian Railways network to examine the infrastructure (e.g. lines and crossovers while entering the yard from different directions), control administration (e.g. designation of jurisdiction for section controllers and area controllers), signaling and other control strategies (e.g. twin single line working) and overall scheduling strategies to improve performance.

It is anticipated that there will be the following three concrete outcomes of the project.

1) A concrete, quantitative framework for estimating terminal/node capacity for different traffic/operating scenarios. This will be along the lines of the line capacity measures in use in the Indian Railways as well as the modified, time-based measures proposed under the LRDSS framework.

2) A prototype software model for simulating terminal operations for a selected class of operating conditions. This model will be capable of representing node/terminal configurations and movement patterns, various train and traffic profiles and some control strategies as inputs and will provide reports on the desired performance measures.

3) A quantitative and qualitative comparison of some of the different control strategies being used on Indian Railways, and which can be used for terminal management.

7. Conclusion

The management of freight terminals and nodes (junctions) on the Indian Railways is of great significance from the operations management goal of effective utilization of resources as well as the commercial goal of adding value to services and customer benefit. It is a practically challenging problem with a number of dimensions to it, as well as a theoretically challenging problem in terms of modeling and computation. Although we have not specifically discussed semi-automated support for node traffic management, it is an area where new developments are taking place, and where Indian Railways should take the lead in technology and software development. Managerially, more awareness regarding terminal performance, definition of some performance measures and integrated analysis of options to do with node capacity will go some way in addressing the issue.

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