Chapter 3

Railway Line Capacity & Throughput

This chapter deals with the theoretical concept of line capacity and throughput. How these important terms are defined and what are the factors on which they depend? In later part of the chapter a clear understanding is developed about the affect of these factors on the line capacity & throughput.

Defining Line Capacity

Line Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources with acceptable punctuality. (e.g. number of tons moved, average train speed, on-time-performance, maximum number of trains per day, etc.). The difference between theoretical line capacity & practical line capacity should be clearly understood.

Theoretical Capacity:

Maximum number of trains physically possible to move across rail line under ideal conditions

Practical Capacity:

Maximum number of trains possible accounting for actual conditions and achieving a reasonable level of reliability

Line Capacity as a Function of Travel Time

A railway network consists of stations and track joining them, punctuated by loops, crossings & yards. Most of the time, two neighboring stations are the boundaries of a block section. The transit time in a block therefore include time for operation of signaling on the block (also called block operation time), time to cross all the signals while approaching a station (also called approach time), actual running time in a block station and a clearing time equivalent to time taken to travel a distance equal to the train-length (to ensure that the full train crosses a block). In other words, the transit time for block is given as

$$t_r = t_{op} + t_v + t_{app} + t_{rb} + t_c$$ [24]

where

Tr = time taken by a train to cross a block section
top = operating time or the time taken for taking decision and operating signals to permit the train to move
tv = visibility time or the time for the driver to perceive the signal and respond
trb = actual running time in a block section
tc = clearing time or train length travel time

The maximum line capacity (C), defined as the maximum number of trains which could run in each direction within 24 hours, would therefore be given as:

[24] Jhunjhunwala, Dr. Ashok & P.R. Goundan, Enhancing Throughput of Existing Railway Network Using Information and Communication Technologies

$$\mathbf{C = [(24\ hrs \times 60\ min/hr)/t_r]}$$ [25] (t_r is in Minutes)

For a block section of 10KM & if trains running with 100KMPH takes 8 minutes to clear the block (6 min running time & 2 min others) the maximum line capacity will be 180. The line capacity of a railway line between two junctions would be determined by the block having highest occupancy time or lowest line capacity.

Line Capacity A Theoretical Concept?

The "Line Capacity" is more of a theoretical concept and above formulations are rather simplistic. Unlike highways, which measure unlinked trips over individual route segments, rail line capacity depends on large number of parameters. Optimum/maximum rail line capacity is not easily determined & need complex simulation techniques to calculate. It is an indication of the efficiency of the operation & a tool to develop future scenarios & to plan infrastructure improvements. Being able to utilize line's capacity to the maximum by removing bottlenecks is the key to success. The "throughput" is a more meaningful & measurable parameter as the desired outcome, defined as the goods or passenger carried from one point to another in a given time, is again depends on line capacity.

Throughput and line capacity are sometime used interchangeably in the same context by assuming other factors as constant.

[25] Jhunjhunwala, Dr. Ashok & P.R. Goundan, Enhancing throughput of existing Railway Network using information and Communication Technologies

Factors Affecting Line Capacity & Throughput

Large parameters affects line capacity; the type of train service, starting and stopping, duration of stoppages, signaling infrastructure, network complexity, length of the line, terrain it operates through (curvature, gradient, etc.), number of tracks, type of train control exercised over the line etc. Train performance characteristics in terms of maximum speeds, acceleration (HP/Ton) and deceleration rates are critical to the line capacity. External factors like routine maintenance or seasonal incidents, accidents & other events also impact line capacity to great extent as they have cascading effect on the train performance.

Crossing of trains & giving way to the faster train also bring down the line capacity. Where trains operate at speeds differentials, the difference in running times between them becomes even sharper & line capacity takes a hit. Terminal operations must also be factored into a line capacity analysis, as trains typically follow a different route/multiple routes at slower overall speeds compared the main line. Finally timetable & charting or efficiency of the operator also plays an important part in line capacity.

The factors affecting line capacity/Throughput can be divided in two broad categories relating to infrastructural & terrain constraints and second the operational problems & issues, as shown in table 3.1.

Table 3.1 Factors affecting line capacity/throughput

Infrastructural (Hardware)	Operational (Software)
– Siding length and spacing – Crossovers – Number of tracks – Signal and traffic control system – Gradient – Curvature, Turnouts – Axle Load – Wagon Dimensions – Bridge's load bearing Capacity – Permanent Speed Restrictions	– Average and variability in speed – Schedule stability – Terminal efficiency – Heterogeneity in train type – Maintenance Requirement – Charting Efficiency – Reliability – External Factors/ incidents

Train Type Heterogeneity

Heterogeneity in train and running characteristics is a key aspect of railway operations that affects capacity. Different trains may have substantially different operating characteristics including: speed, acceleration, braking distances and dispatching priorities, which form basis of heterogeneity in train types (figure 3.1). Different types of trains like passenger with regular stops, fast intercity with limited stops, suburban, bulk freight train, container trains etc form heterogeneous mix of trains sharing same infrastructure. Studies have shown that increased heterogeneity tends to cause greater loss of line capacity and increase delay[26].

Effects of Heterogeneity & Speed Differentials on Line Capacity

Speed differential in trains sharing same track increases delay & reduces line capacity. For example in a block section of 20 KM, all trains running with 120 KMPH will give a line capacity of 144 per day. It will be 84 in case of slower trains running at 70 KMPH. If for example, in a section a equal mix of fast train at 120 KMPH & slow trains at 70 KMPH are run one after another the line capacity obtained will be just 106, way below 114, average of both the trains (calculations at appendix IA). The result will be much more chaotic in case more speed differential and unpredictable train movement.

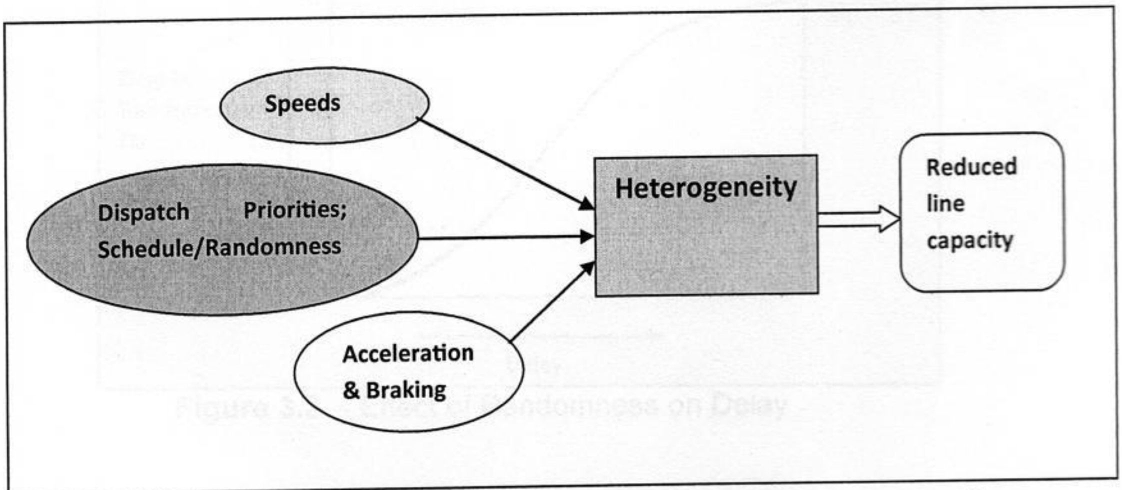

Figure 3.1 Impacts of various parameters on heterogeneity

[26] Dingler, Mark (2008). Using the RTC Simulation Model to Evaluate Effects of Operating Heterogeneity on Railway Capacity. *The William W. Hay Railroad Engineering Seminar Series*

Various studies have shown that delay due to heterogeneity follows normal distribution (figure 3.1). Similarly the randomness of dispatches also tends to increase the delay and reduces the line capacity (figure3.3).

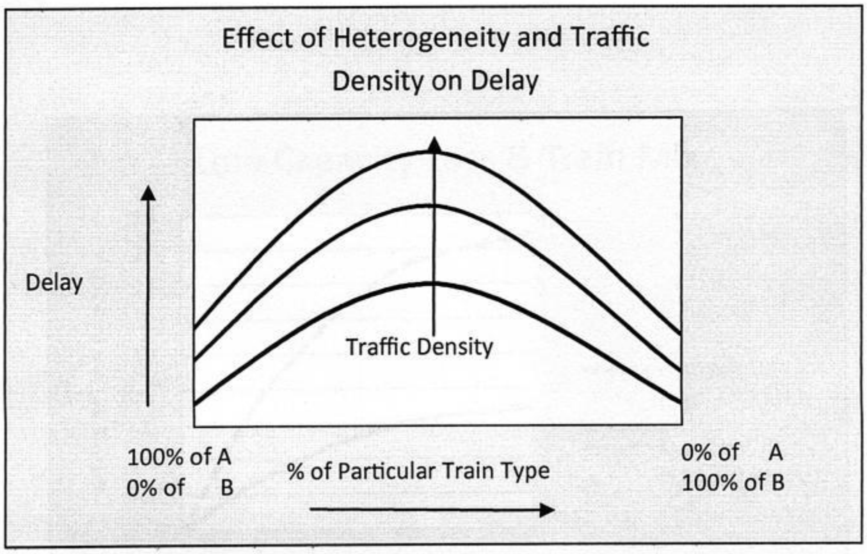

Figure 3.2 Effect of Heterogeneity and Traffic Density on Delay

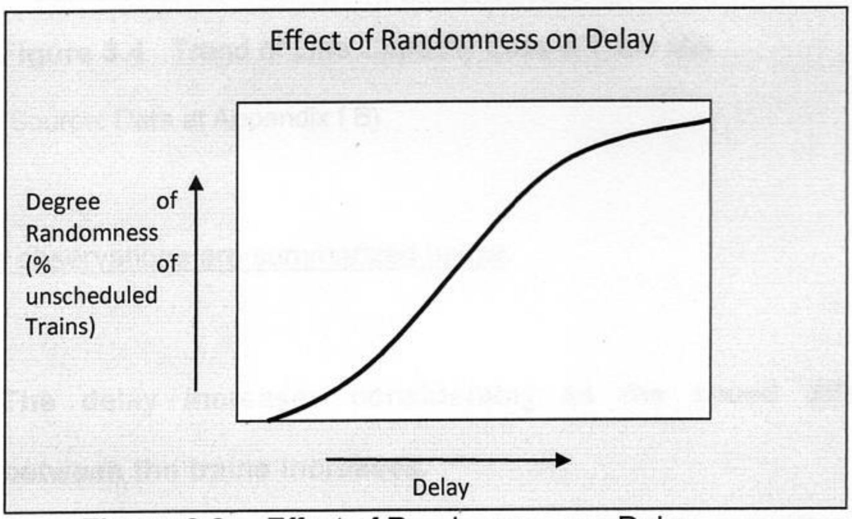

Figure 3.3 Effect of Randomness on Delay

Source (Figure 3.2 & 3.3): Derived from the study by Mark Dingler (September 12, 2008), "RTC Simulation Model to Evaluate Effects of Operating Heterogeneity on Railway Capacity", The William W. Hay Railroad Engineering Seminar Series

The trend is also verified mathematically by calculating delays in a hypothetical 2 train mix model by varying train speed differentials & block length (calculation placed at appendix I B). The trend observed is as per the figure 3.4.

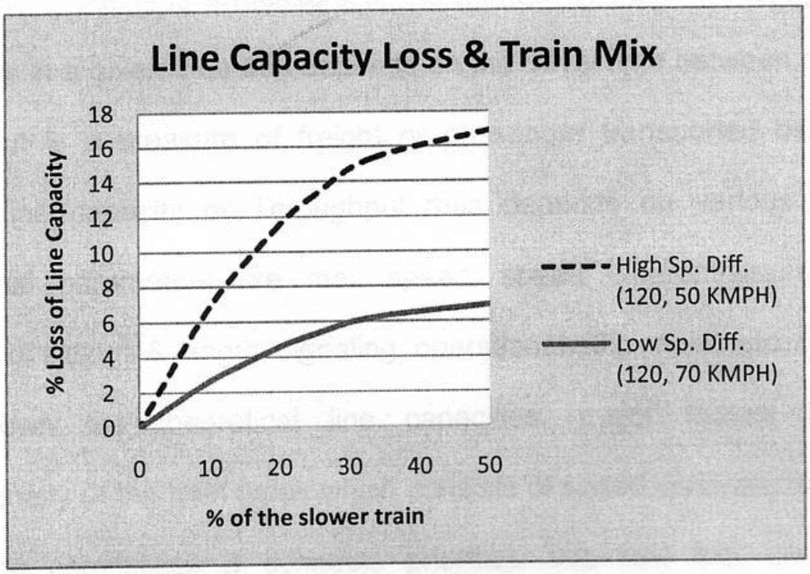

Figure 3.4 Trend of Line Capacity Loss & Train Mix

(Source: Data at Appendix I B)

<u>The observations are summarized below:</u>

1. **The delay increases considerably as the speed differentials between the trains increases.**
2. **The delay is maximum when train mix is maximum (50-50)**
3. **Block length has no effect on the relative delay**

The last observation appears to be contrary to the general belief. This indicates that reducing the block length by additional signaling will not nullify the negative effect of the speed differentials.

Summary

Line capacity is a measure of the number of trains travelling between two points in a given time and depends on the travel time between them while throughput is a measure of freight or passenger transported between the points. Line capacity or Throughput thus depends on various track and operational parameters like max speed, speed differentials, scheduling, distance of sidings & length, signaling, operational efficiencies etc. Bottlenecks bring down the theoretical line capacities, major factors being the heterogeneity of the train types which consists of speed variance, acceleration & braking capabilities & schedule priorities. We saw that higher speed differentials & randomness of the trains tends to increases the delay to a great extent and thus reduces the line capacity.