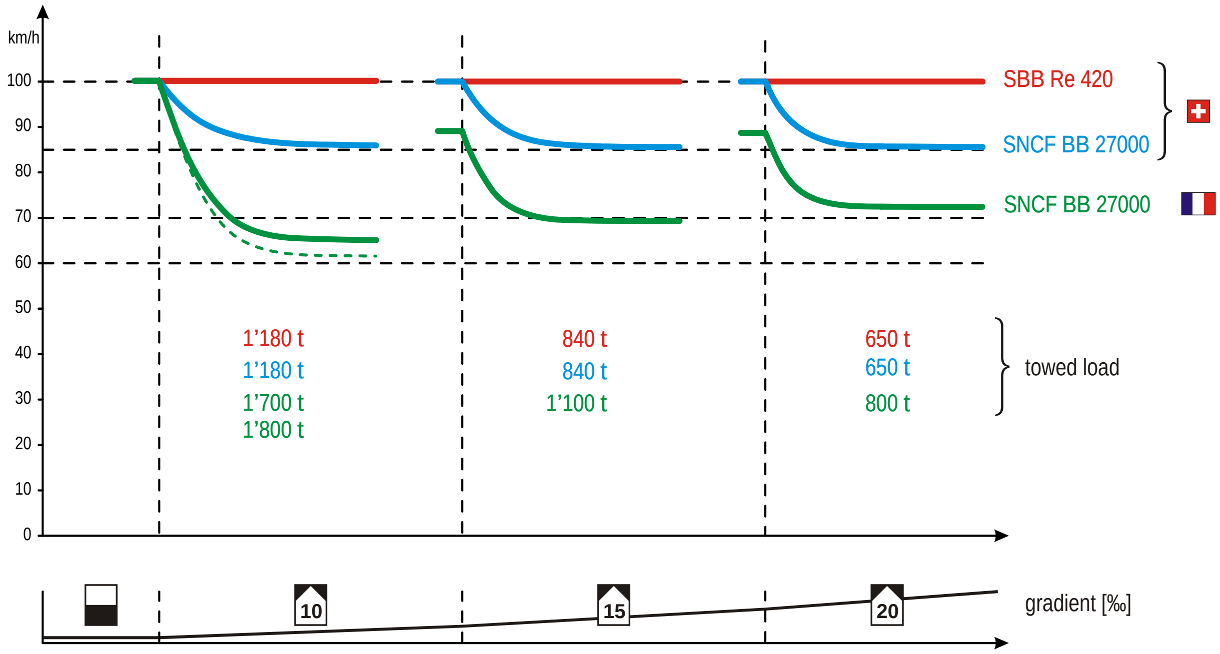


Increasing line capacity with constant infrastructure

Jean-Daniel Buri, EPFL-LITEP
Panos Tzieropoulos, EPFL-LITEP

Conference paper STRC 2009

STRC | **9th Swiss Transport Research Conference**
Monte Verità / Ascona, September 9. - 11. 2009

Increasing line capacity with constant infrastructure

Jean-Daniel Buri
EPFL-LITEP
Station 18
1015 Lausanne

Phone: +41 21 693 24 79
email:
secretariat.litep@epfl.ch

Dr Panos Tzieropoulos
EPFL-LITEP
Station 18
1015 Lausanne

Phone: +41 21 693 24 79
email:
secretariat.litep@epfl.ch

August 2009

Abstract

Faced with growing transport demand, many rail networks experience significant capacity bottlenecks. Often, increasing the number of tracks on the whole or on part of a congested line seems to be the obvious answer. However, investing in infrastructure may prove extremely expensive and extending rail infrastructure in densely urbanized areas next to impossible. Thus, any solution able to limit construction of new infrastructure must be considered.

Speed difference between trains is one of the most critical parameters influencing the capacity of a railway line. Increasing speed difference between the fastest and the slowest train decreases the available capacity of the line. Reducing the speed differences between train paths helps increasing the line capacity under a constant infrastructure assumption.

The paper presents a research project aimed to identify the variables that determine commercial speed of trains and to assess their relative importance. Commercial speed of trains depends on characteristics such as the traction and breaking performances of the rolling stock, dwell times, as well as on some regulatory provisions. Unless slowing down fast trains, reducing the speed difference requires speeding up the slowest ones; on mixed traffic lines, the slowest train paths are either the passenger trains with the most frequent stops or the freight trains. The influence of the different variables is assessed by means of a sensitivity analysis whereof the potential capacity benefits can be inferred. As some regulatory provisions can differ from country to country, the analysis is based on the Swiss and French examples. Nevertheless, the methodological approach is generic and not country-specific. Obtained results are presented as proposals for actions to increase line capacity without adding extra infrastructure.

The described methodology recognizes explicitly that railways are complex systems, involving three major components: infrastructure, rolling stock, and organisational/regulatory provisions. Optimisation of the system requires a holistic view that takes into account not only individual components but also the interactions between them.

Keywords

railway infrastructure – line capacity – rolling stock – regulatory provisions

1. Introduction

With increasing demand, many European rail networks experience capacity issues. Several factors contributed lately to sharp increases in public transport demand, especially rail demand: fuel prices, road congestion, environmental awareness, and public transport supply enhancements. Lack of capacity appears often around conurbations, where transport supply needs to be strengthened, though main lines between urban areas also start suffering from insufficient capacity.

Often, the most obvious response to capacity shortages is to add extra tracks to saturated line sections. This is costly, and may prove impossible to carry out in heavily urbanized areas. In this case, intensifying use of existing infrastructure to increase train traffic with limited investment becomes paramount.

Among the various variables that determine line capacity, train speed differential is decisive. If we manage to homogenize commercial speed of trains on a line, we may expect dramatic improvements in capacity. On short sections, incoming or outgoing from major stations, this may be achieved by slowing down faster trains. On longer sections, however, slowing down fast trains is both inefficient and uneconomical - they are often the most lucrative trains. Therefore, the sound option to reduce the speed differential is to speed up slower trains. On mixed traffic lines, those are either freight trains, or local passenger trains providing frequent stops. Their commercial speed depends on their power and braking characteristics, but also on regulatory provisions and constraints induced by infrastructure.

The analysis described in this paper is based on the Swiss and French cases. Nevertheless, the methodological approach that is developed is generic and not country-specific. Whenever comparisons are made, they are not meant to point the cleverer or less clever operators; they merely try to demonstrate, through real-life examples, the consequences on capacity of specific technical choices and regulations.

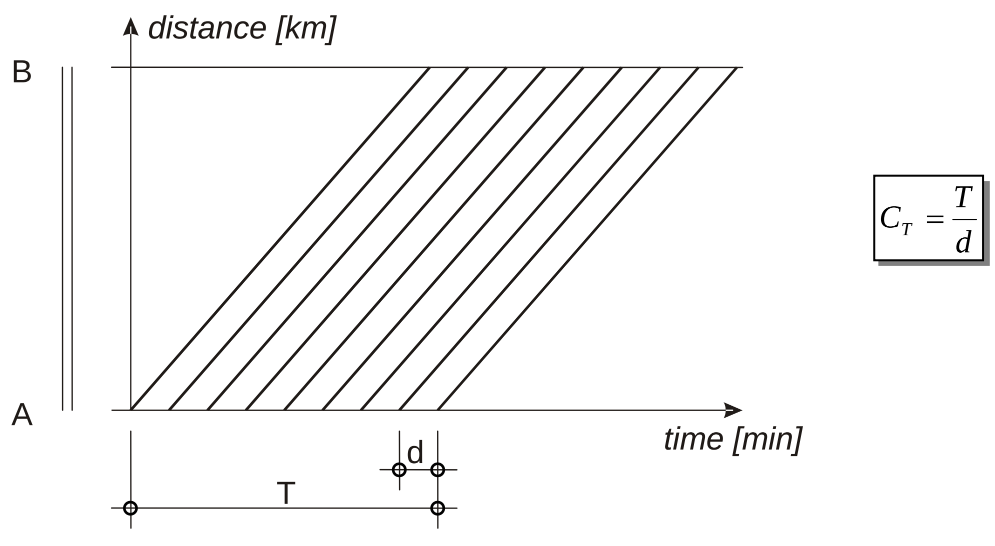
2. Defining capacity

In quite general terms, capacity can be defined as the "*maximum number of trains that can run through a section in a given time interval*". Unfortunately, for a network, capacity cannot be expressed as a single value we can compute by using a formula. Network throughput is strongly related to a specific timetable and the underlying traffic structure. Actually, different timetables can produce different throughputs, depending on the spatial and over time distribution of train paths, and require different investments in infrastructure. Just as residual capacity of an infrastructure varies widely with differences in traffic distribution (e.g. mix of passenger / freight trains).

2.1 Capacity of a line with homogeneous traffic

Computing the capacity for a line where all trains run at the same speed and have identical stop patterns is straightforward. In a space-time diagram, train paths are homothetic. In this case, capacity is the inverse of the minimum headway, i.e. the smallest time interval that should exist between 2 consecutive train paths (Figure 1)

Figure 1 Capacity of a line with homogeneous traffic



Actually, this simple formula may be misleading. When intermediate stations have a single platform for train stops, overall capacity of the line may be set by the station capacity: following trains cannot enter the station until the previous one leaves. Stop duration, and therefore passengers' exchange, may be a critical factor in determining minimum headway.

Metro lines are a classical example of lines with homogeneous traffic. Rapid regional services (S-Bahn, RER, etc.) around major conurbation are also mostly operated with identical train paths. The same goes for heavily loaded sections of national networks (e.g. North-South Junction through Brussels). This is the configuration of operations that maximizes capacity, as long as network effects do not induce extra constraints at the ends of the most loaded section.

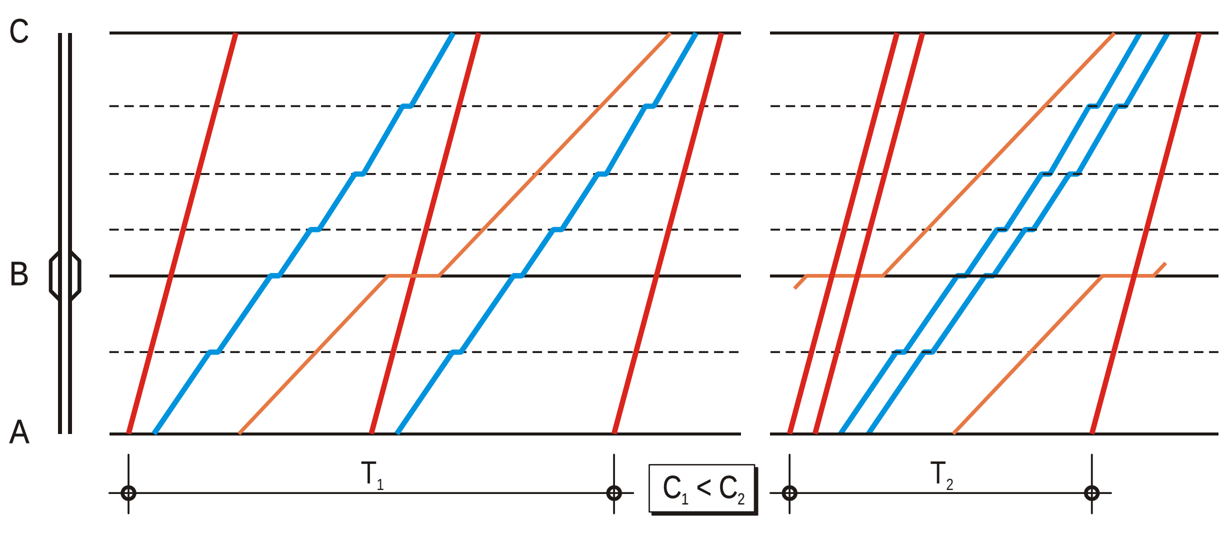
2.2 Capacity of a line with mixed traffic

Nevertheless, most of rail lines support mixed traffic, with several type of trains running, providing different services with different stopping patterns. Commercial speed is not uniform and train paths on the space-time diagram are not homothetic. In those cases, two more factors at least enter the game of determining capacity:

- Distance between consecutive stations where a faster train may overtake a slower one
- Sequence of the train paths (i.e. the order in which the train paths are scheduled)

Capacity cannot be calculated anymore by means of a single formula. To determine capacity, design of the timetable becomes unavoidable, as shown in Figure 2, where 2 different train sequences lead to 2 different values of capacity for the same section.

Figure 2 Capacity of a line with mixed traffic



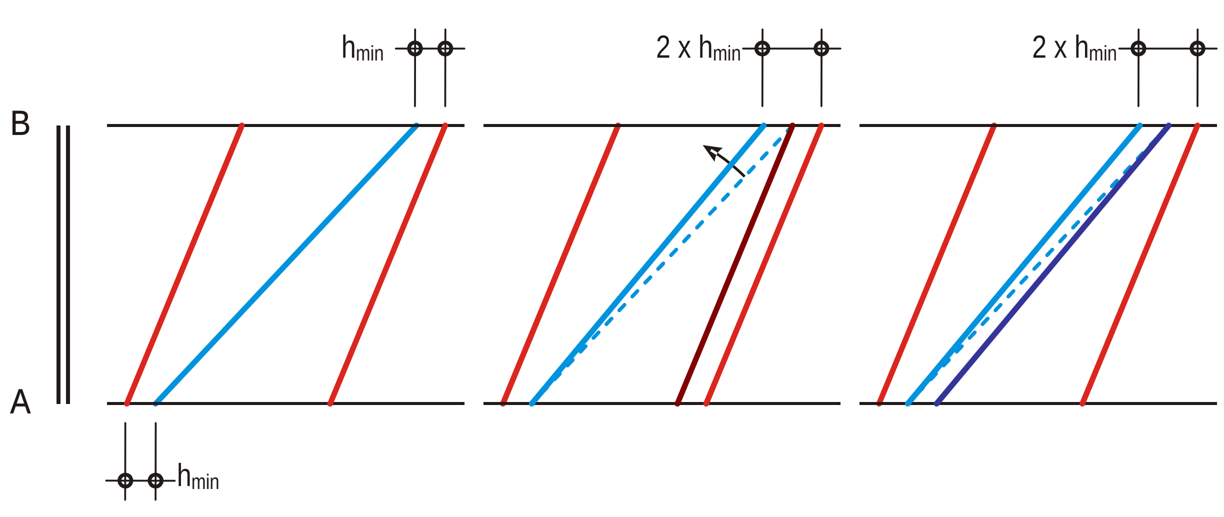
Now, extending the stopping time of a slow train, to let a faster train overtake it, increases the line capacity, but at the expense of service quality for the slow one. This is a commonly used solution for freight trains, but that should be applied to local passenger trains with reluctance. Even on top-equipped lines, the slow train stop lasts for at least 5 to 6 minutes, which clearly degrades its service and its commercial appeal.

2.3 Gaining capacity by speeding up slowest trains

On mixed traffic lines, train paths come the closest to each other on entering or leaving major stations where fast trains overtake slower ones. Maximum capacity is reached when those converging or diverging train paths are separated by time intervals equal to the minimum headway set by the safety installations.

Speeding up the slowest train, makes it possible to let it enter earlier or leave later the major stations. All other things being equal, that increases headways in the tightest part of the space-time diagram. If time savings reach or exceed the minimum headway set by the signalling, it becomes possible to offer an extra train path, usable by a fast or a slow train (Figure 3).

Figure 3 Effect on capacity of speeding up a slow train



In those cases, it is wiser to value the speeding up of slow trains in terms of minutes and not on commercial speed. One can therefore compare directly time gains to minimum headways' values and to verify whether the speeding up is sufficient to reach the threshold where capacity gains become possible.

This is obviously not the only possible measure to improve capacity, but it is an important lever to use in overall optimisation of the railway system.

Next sections deal with technical and regulation issues related with the commercial speed of trains that offer significant potential time savings. Freight and passenger trains are dealt with separately, as they raise quite different issues.

3. Passenger trains

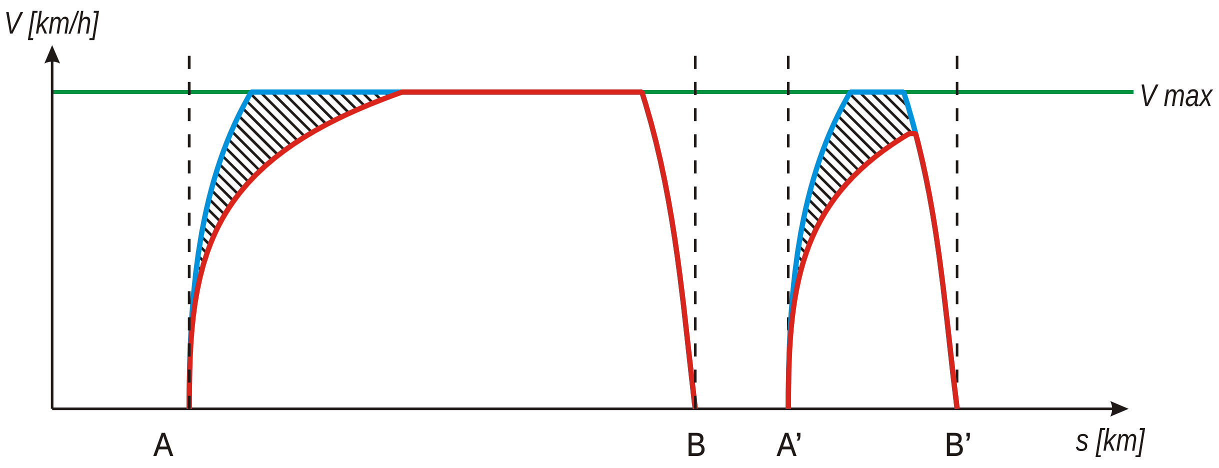
Local passenger trains, stopping in almost every station are the slowest ones. Besides the speed restriction on the line and the distance between stops, we may site also the following factors that influence the commercial speed:

- Tractive effort characteristics and, to a lesser extend, train braking performance
- Speed limits, for technical of regulatory reasons, mainly in entering or leaving stations
- Stop duration

3.1 Power characteristics

Admitting that the train is able to reach the maximum allowed speed on the track section, further time savings may result from improved acceleration and, to a lesser extend, braking (see the hatched area in Figure 4 for the time savings due to better train performance).

Figure 4 Speed-space diagrams for various acceleration rates



Gaining some seconds over long sections covered without intermediate stops is not important. On the contrary, for trains with frequent stops, the cumulative gain of seconds in every stop may result in significant gains. This is especially true for short sections, where better performance makes it possible to reach and maintain as long as possible the maximum line speed.

Accurate estimation of time savings requires computing the running of the train. Meanwhile, some general purpose characteristics of train sets make it possible to roughly assess the capabilities:

- Acceleration rate; unfortunately, seldom provided by the manufacturer
- Massic (or specific) power; this can be computed by dividing the engines' power by the total weight of the train set, and makes it easy to compare rolling stock performances

A concrete example, based on 2 recent electrical train sets, may show the stakes. The first train set is the so-called "Flirt" SBB's EMU, designed for Regional rapid services (S-Bahn). The second one has been ordered by the BLS company for semi-direct train services on the Lötschberg ridge line. Meanwhile, BLS considers using those train sets also on Bern's S-Bahn network. Table 1 summarizes the characteristics of those 2 train sets.

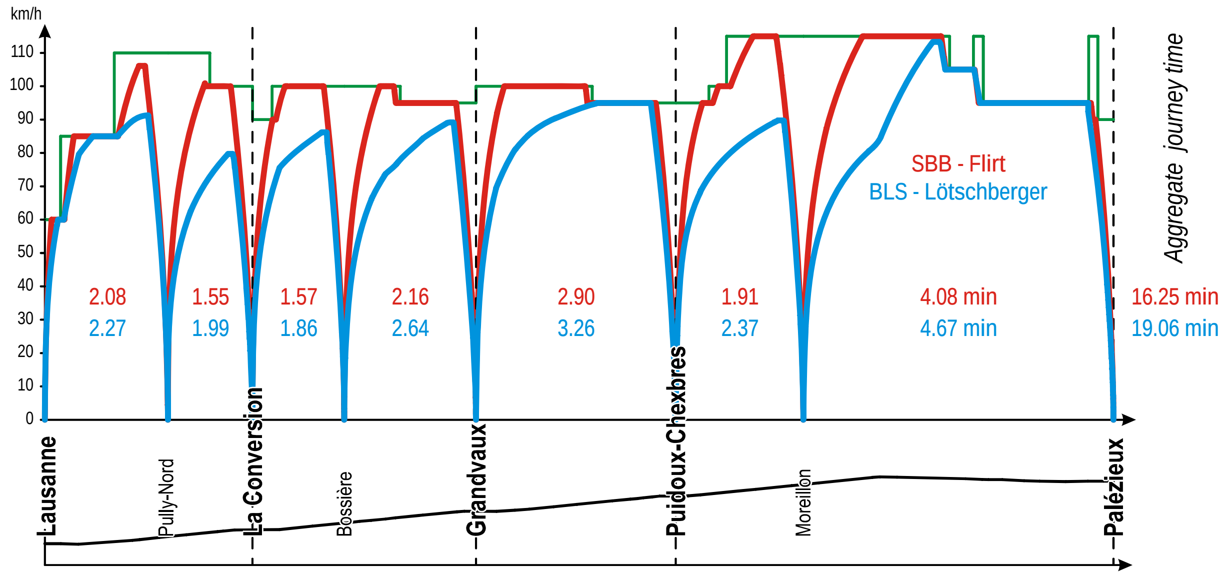
Table 1 Main characteristics of Flirt et Lötschberg EMUs

Electric multiple unit	FLIRT (SBB)	Lötschberg (BLS)
Designation	RABe 523	RABe 535
Service start-up	2004	2008
Overall length	74'078 mm	62'710 mm
Axle arrangement	Bo' 2' 2' 2' Bo'	Bo' 2' 2' 2' Bo'
Seating capacity 1^{st} + 2^{nd} class	10 + 138	28 + 143
Tare weight	120 t	105 t
Maximum output at wheel	2'600 kW	1'000 kW
Starting tractive power	200 kN	123 kN
Maximum acceleration at gross weight	1.2 m/s^2	?
Specific power (empty train sets)	21.6 kW/t	9.5 kW/t

Source: Stadler and Bombardier (train set manufacturers)

Comparing the specific power values shows clearly that the Lötschberg EMU is not designed for a frequent stop service on a saturated line, though this first impression is not sufficient to estimate the travel time differences. Those are obtained by computing the running on the Lausanne - Palézieux S2 line of the Regional rapid transit of Canton de Vaud (Figure 5).

Figure 5 Comparison of speed-space diagrams for Flirt and Lötschberg EMUs



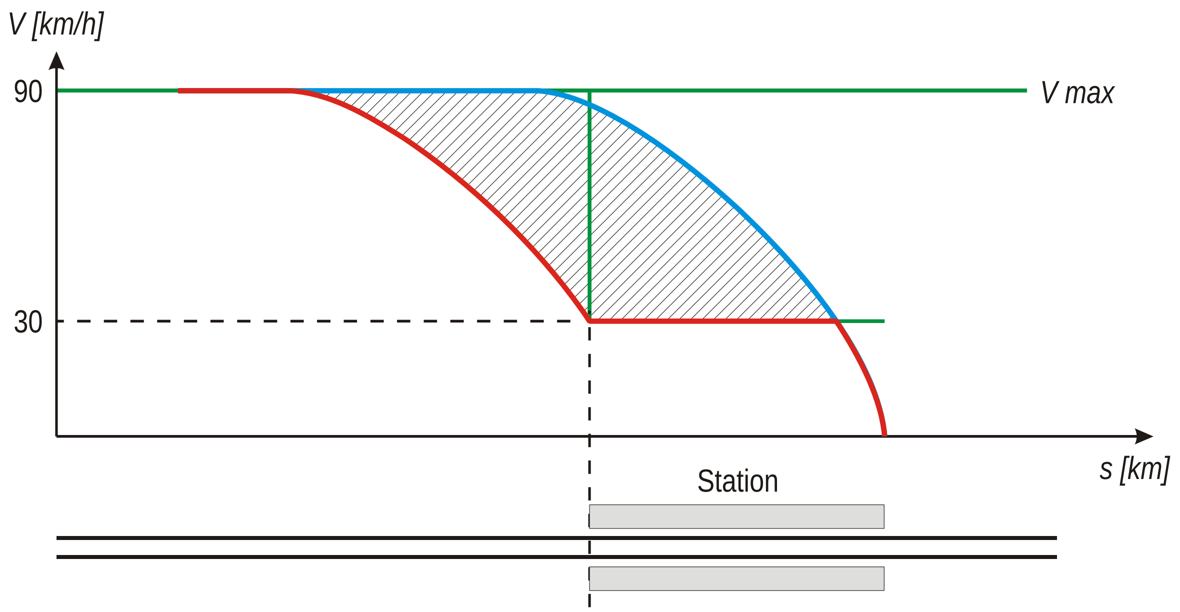
On this 20.6 km section with 6 intermediate stops (with an average of 2.9 km between stops), travel time difference is of 2 minutes and 48 seconds, i.e. about 30 extra seconds per stop station. The difference would be even larger in a line with shorter distances between stops. What is important here is not so the time savings for the passengers, but rather the possibility to provide frequent stops in a densely inhabited area while keeping the pace of faster trains.

3.2 Speed restrictions in station entrance

Ideally, braking to stop in a station should occur as late as possible, as any early braking leads to purposeless time losses. The earlier speed restrictions apply when entering a station, the larger are the time losses. Speed restrictions are due to:

- Technical reasons — taking the diverting direction in a switch induces speed restrictions which require previous braking
- Safety reasons — when slip distance is not sufficient, or in dead-end stations, speed restrictions ensure that a train stopping beyond the nominal point bears no consequence
- Regulation — in France, for instance, trains that will stop in a station should not run along the platform at speeds exceeding 30 km/h

Figure 6 Speed-space diagram with speed restriction in station entrance



The hatched area in Figure 6 shows the loss of time in this case, which reflects also the potential gains if the restriction is lifted. In what follows, several computations of train runs with multiple hypotheses show the magnitude of potential savings.

3.2.1 Switches used in the diverting direction

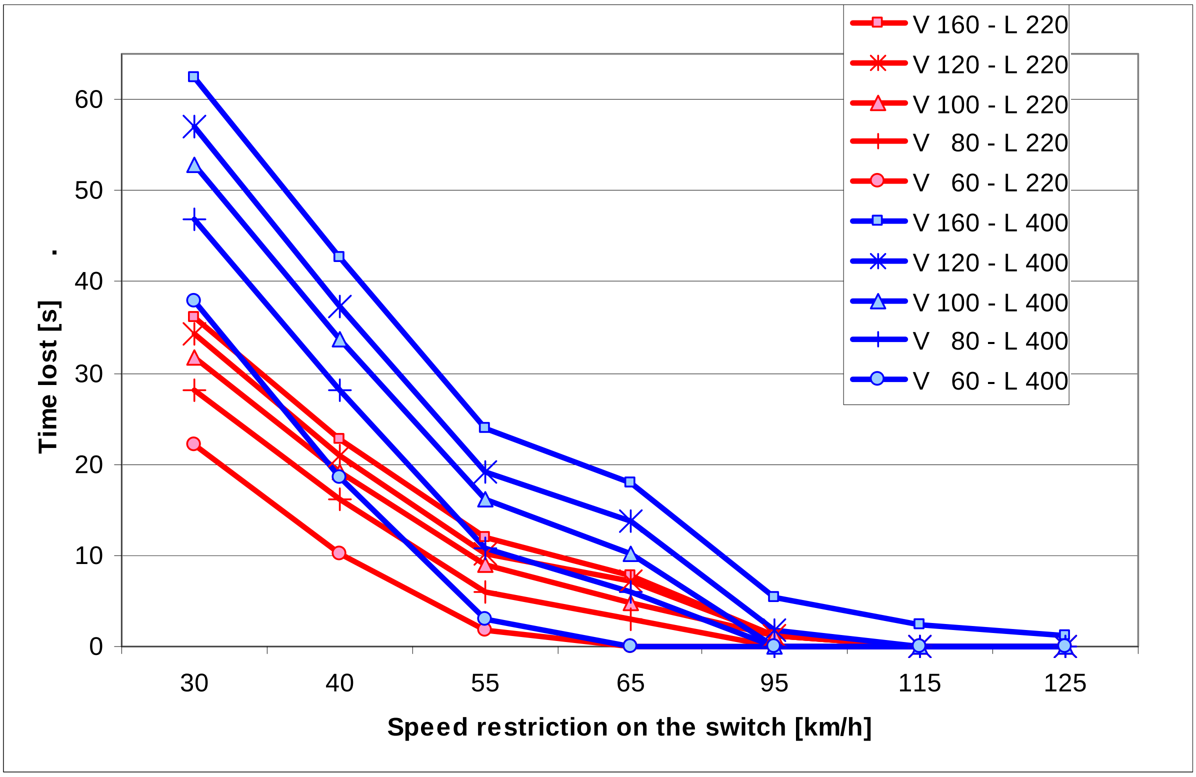
In major stations, the entrance speed limit is defined depending on the speed restrictions applied when switches are used in the diverting direction. The train must decelerate while crossing the switch zone, which induces loss of time. Switches being unavoidable, it is interesting to assess time lost as a function of the switch types.

Two series of computations have been made:

- For a station of a regional line
    - 220 m long platforms
    - point of switch tongue located 200 m before the platform begins
    - FLIRT train sets in multiple units (3 units for a total length of 220 m)

- For a station on a main line
    - 400 m long platforms
    - point of switch tongue located 300 m before the platform begins
    - Swiss ICN train sets in double unit (for a total length of about 400 m)

Figure 7 Time loss as a function of speed limit on the open line, speed restriction on the switch, and train length



Red lines are for the regional station, and blue ones for the main line station

Figure 7 shows the time lost with the commonly applied speed restrictions in Switzerland (depending on the switch type) and also for a speed restriction at 30 km/h, which is the rule applied in France for the tightest switches used there. The same analysis can be done for station exits, and for metric or other than normal track gauges as well.

Figure 7 also shows that for speed restrictions set at 30 km/h, time losses may become significant. Actual loss of time may be even larger, exceeding 1 minute, when the first switch or the signal preceding it is located further away.

It is thus important to consider, during infrastructure renewals, the opportunity to redesign station ends to be able to use switches with larger radius. Potential gains may benefit to both line and station capacity.

3.2.2 Safety induced speed restrictions

Speed restrictions due to insufficient slip distance or the presence of level pedestrian crossings are not explicitly dealt with here. The actions to lift those restrictions are obvious, although costly ones.

3.2.3 30 km/h at the beginning of the platform (French regulation)

The distance over which the restriction applies is the platform length, except for short train sets where this distance is equal to the distance between the end of the platform and the point where the front of the train stops. Computations are based on FLIRT EMU (SBB, RABe 523 series (Figure 8, Figure 9).

Figure 8 shows that time losses for very short platforms are small, but increase rapidly with the platform length and become important, especially with large differences between the speed limit on the open line and the speed restriction (some 3 to 5 seconds for each additional 50 m of platform length).

Figure 8 Time loss as a function of speed and platform length

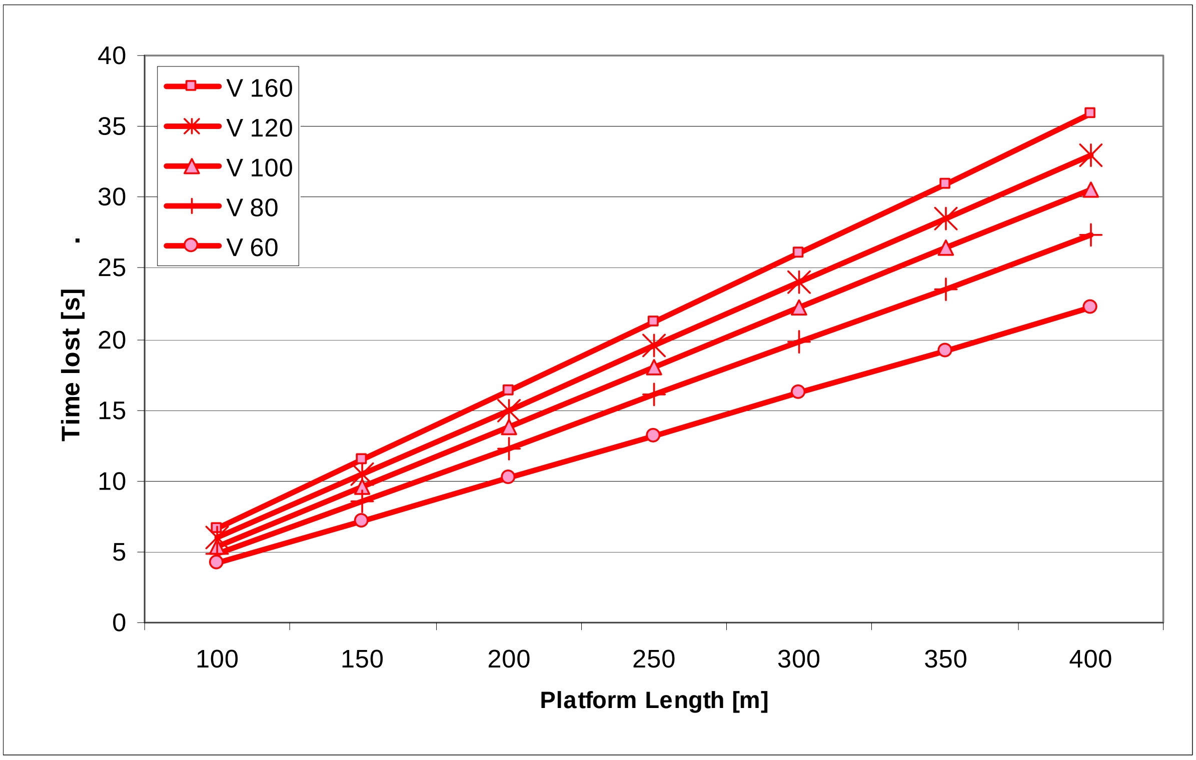
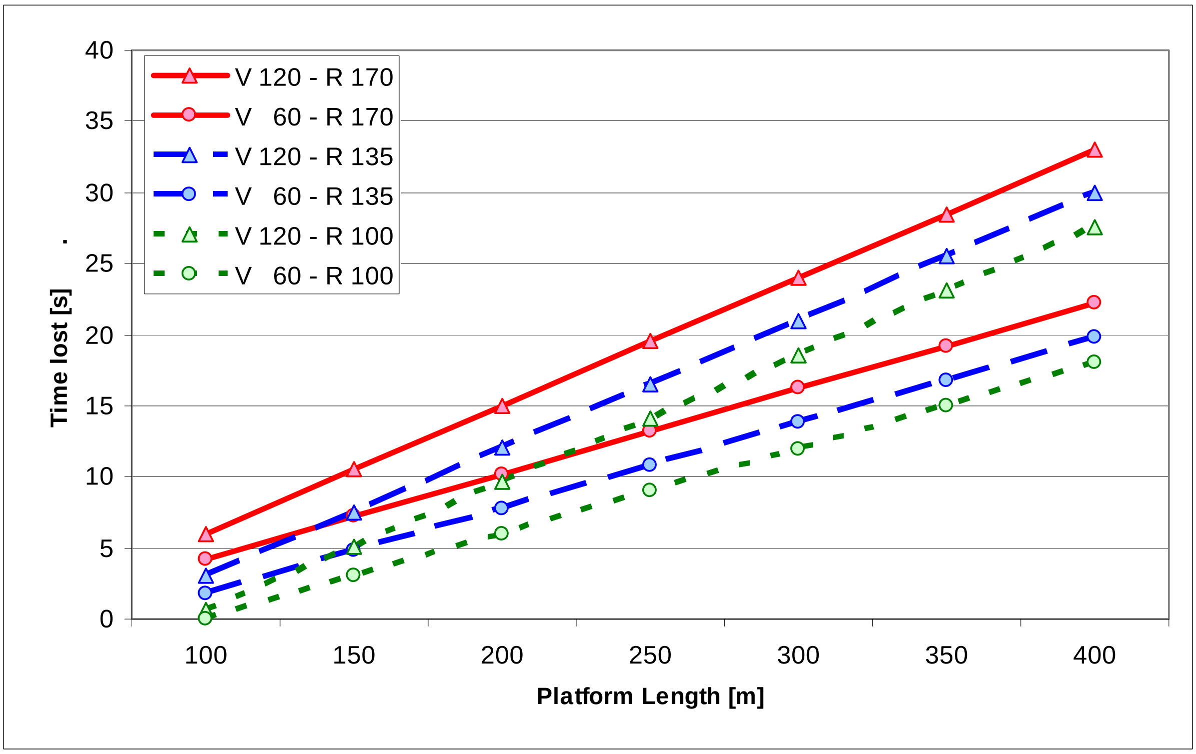


Figure 9 shows that the braking rate has also an influence on those time losses. Quite naturally, the better the braking performances, the more significant are the losses.

For those stations where no other speed restrictions apply, French regulations result thus in 15 to 30 seconds loss per stopping station[1]. This is a typical example, where regulation of dubious purpose, may reduce capacity.

[1] Between Cannes and Nice, for instance, where local trains do 9 intermediate stops, total time loss is between 2 to 4 minutes.

Figure 9 Time loss as a function of the braking rate



3.2.4 Driving sensitivity

The human factor is also a key element in the operation's stability. Manual driving never reproduces accurately the speed-space diagrams that planners compute, due to inherent variations in drivers' behaviour. Usually, time differences resulting from drivers' behaviour variability do not exceed a couple of seconds, and train scheduling takes them into account by including recovery times in timetable design (travel times in the timetable are slightly increased compared to computed running times, by means of an added percentage increase).

Despite recovery times, some drivers (the most cautious ones) may experience difficulties running on time, especially during peak periods. On heavily loaded or near-saturated lines, this may impact stability. Without driving assistance systems onboard, some companies[2] design drivers' roster so that the most alert drivers are assigned to peak-period services.

[2] There are documented cases that will be not referred to for concerns of confidentiality.

3.3 Stop duration

Minimum stop duration in a station depends on volume of passengers' movement per vehicle door, width of the doors, step distance (both height difference between the platform and the first step and gap between the platform and the vehicle), etc.

Rail operators set stop duration depending on the type of station and the rolling stock. Minimal values vary across countries and operators. In Switzerland, for instance, minimum stop duration for a regional train is between 30 and 326 seconds (0.5 to 0.6 min); in France, minimum stop duration in such cases is 1 minute.

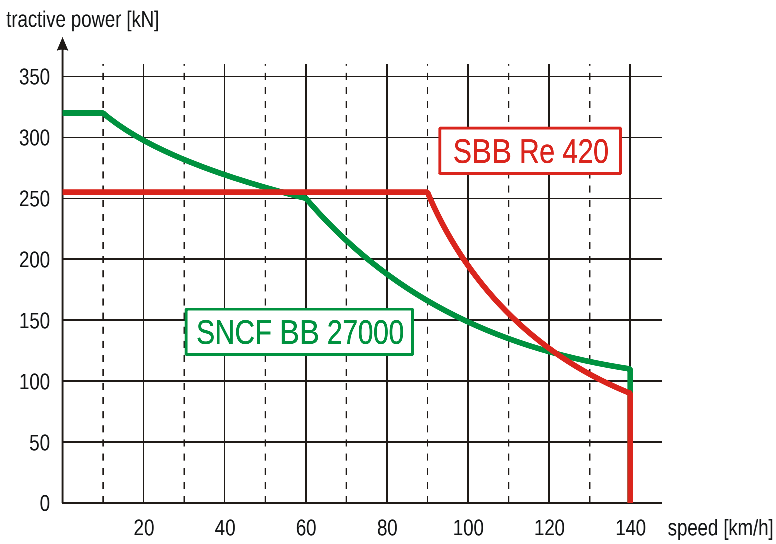
In minor stations, stops frequently require significantly less time; the extra time spend in waiting to exhaust the minimal time of 1 minute is lost. Losses cumulated over several minor stations may become significant. Saving this time, in conjunction with other optimisation measures can be helpful in increasing capacity of saturated lines.

4. Freight trains

Several considerations for passenger trains are also valid for freight. Consequences of slowing down in station entrances may even prove more dramatic for freight trains, whose length can reach 700 m.

Thanks to the opening the European freight rail services to competition, a purely technical property of locomotives became a factor in determining capacity: this is the allowed hauled load for locomotives. We will refer to the French BB 27000 case. This locomotive, built with the technical requirement to haul 1'800 tons on a 10‰ grades, has received the authorisation to run on the Swiss network with 1'180 tons of maximum hauled load. During its homologation, the Swiss infrastructure manager qualified it as equivalent to the SBB Re 420 series[3].

Figure 10 Re 420 (SBB) and BB 27000 (SNCF); Tractive effort vs. speed



Comparing both characteristic curves (Figure 10), one can notice that the BB 27000 offers more power at starting and, also, on high speed (> 120 km/h). It is however less powerful in the 60 to 120 km/h range. This is precisely the operational speed range for freight trains.

To assess the consequences, running of trains have been computed based on rules valid for the Dôle to Vallorbe section and for both sets of allowed hauled load as shown in Table 2 (Figure 11). Trains accelerate on the flat until they reach 100 km/h and then they are sent climbing the

[3] Formerly known as Re 4/4 II, built between 1967 and 1985

3 grades. The Re 420 locomotive is able to keep running at 100 km/h; the speed of the 1'180 t train hauled by the BB 27000 drops down to 85 km/h. This is enough for operating with freight train paths scheduled for a maximum speed of 80 km/h, although it leaves little spare power to recover from possible delays.

Table 2 Allowed hauled load

	BB 27000 in France	BB 27000 and Re 420 in Switzerland
10‰ grade	1'700[4] t	1'180 t
15‰ grade	1'100 t	840 t
20‰ grade	800 t	650 t

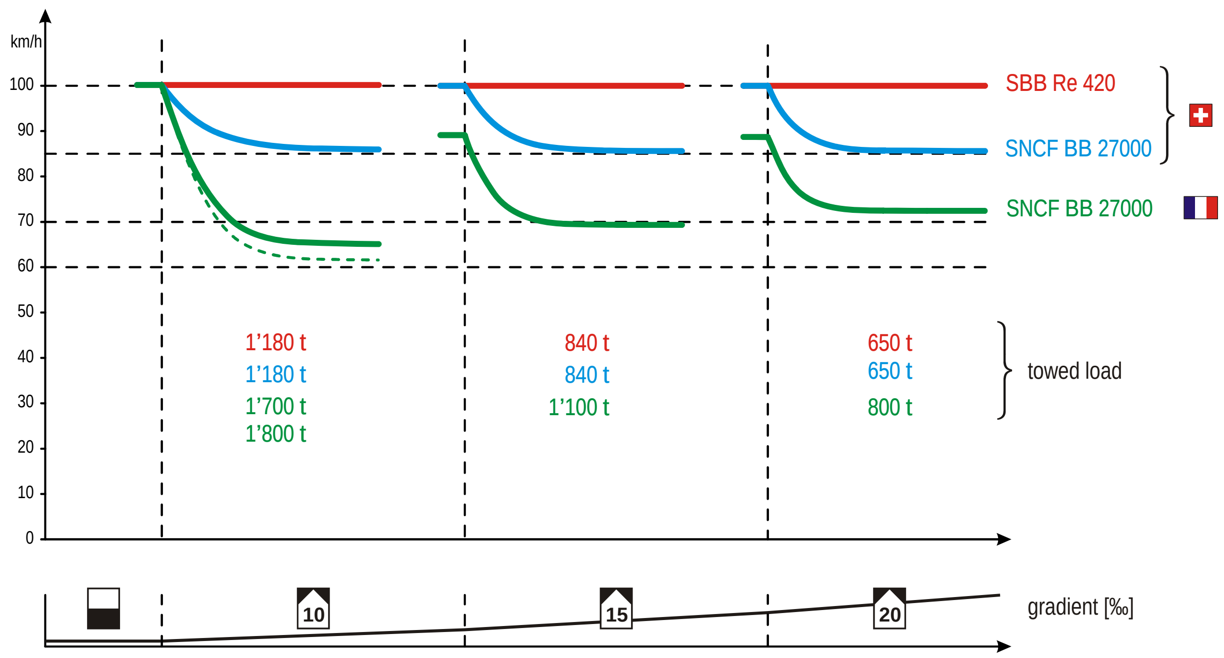
Source: RFF (RT de la ligne Dôle-Vallorbe); CFF (DE-PCT transport)

Increasing the hauled load for the BB 27000 to 1'800 t drops the speed ceiling at 60 km/h on a 10‰ grade. The increased speed differential with the passenger train paths clearly reduces overall capacity. What is more, on a 10‰ grade, the BB 27000 needs more than 20 km to reach 60 km/h with a 1'800 hauled train and still more than 15 km to reach 85 km/h with a 1'180 t train. On the other hand, the Re 420 reaches 100 km/h in less than 10 km, making it easier to insert freight train paths in a dense schedule.

This is a typical example where, by using regulatory provisions (lowering in this case the allowed hauled load) planners can reduce the time differential between train paths and increase the capacity. A collateral conclusion is that it is possible to increase overall capacity (in terms of volume of train paths) of the French network of mixed traffic lines without investing in infrastructure. Switzerland may face a similar issue, while more and more freight wagons are built for 120 km/ and - at the same time - increasing congestion will require that more freight trains operate at this speed. Prospectively, further analyses would become necessary to adapt the table of the allowed hauled load.

[4] Although technical specification of the locomotive allow for a 1'800 t hauled load on 10‰ grade, regulations on the Dôle - Vallorbe line limit this value at 1'700 t.

Figure 11 Speed-space diagrams for the different cases shown in Table 2



5. Conclusions

The paper shows that there are factors that can influence commercial speed and, therefore, capacity. It gives also a trail on ways to improve rail line capacity without necessarily building new tracks. Possible actions focus on rolling stock, regulations, and - to a lesser extend - infrastructure (switches in station ends).

As far as rolling stock is concerned, increasing specific power is thought to be extremely interesting in helping speeding up of slower trains to reduce variability of train paths and make them easier to insert in dense timetables.

Separation of infrastructure management and train operations may, for those issues, produce an adverse effect, as it does not facilitate comprehensive optimisation of the railway system. Infrastructure managers are in charge of the capacity issues, while train operators make choices regarding rolling stock. It is therefore necessary, in this new environment, to invent ways, rules and procedures to push both stakeholders to work hand in hand.

6. References

Hachemane, P. (1997) Évaluation de la capacité de réseaux ferroviaires, *Ph D Thesis*, **1632**, EPFL Lausanne.

Noordeen, M. (1996) Stability analysis of cyclic timetables for a highly interconnected rail network, *PhD Thesis*, **1435**, EPFL Lausanne.

Buri, J.-D. (2008) Increasing railway capacity by jointly improving infrastructure and rolling stock, STRC Ascona