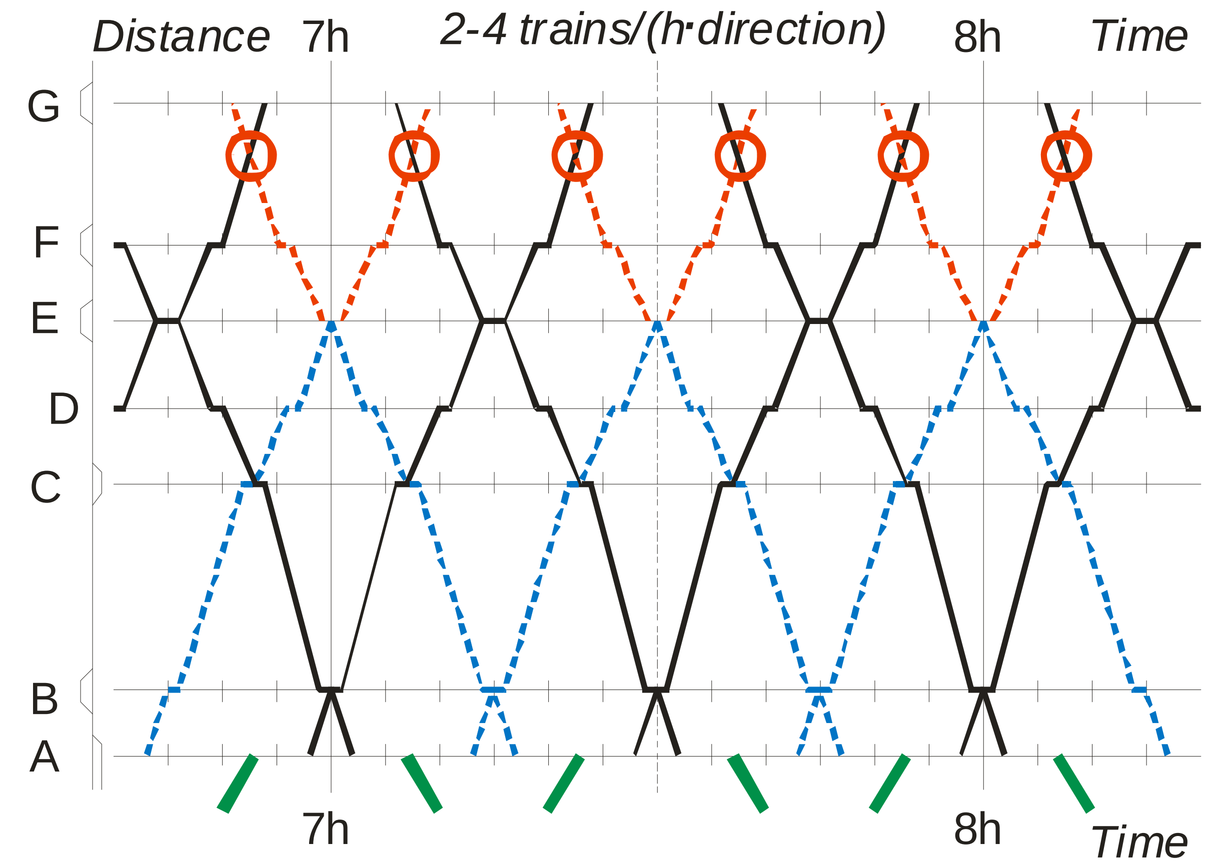

Increasing the capacity of a single-track line

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Conference paper STRC 2010

STRC | **10th Swiss Transport Research Conference**
Monte Verità / Ascona, September 1 - 3, 2010

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August 2010

Abstract

Capacity of single-track lines is quite low by nature. In fact, the need of frequent crossings of trains running the opposite direction consumes a lot of capacity; as a result, alternation of trains running in opposite directions within a given timeframe becomes a critical factor. The number of alternations increases in the case of regular interval timetables, as the density of trains is the same for both directions and the grouping of many trains in one direction is prevented by the regular spacing of the timetable. Furthermore, capacity is sensitive to the length of sections between adjacent crossing stations.

The aim of this contribution is to estimate what measures are the most convenient before considering more fundamental (and quite costly) measures such as designing extra crossing stations or double-track sections.

Assessing capacity utilisation according to the UIC 406 Capacity leaflet is inappropriate for single-track lines. Based on eighty-eight Swiss single-track lines with heavy traffic, this study highlights parameters to consider in order to increase the number of trains without having to build new infrastructure. Some of these parameters are journey time between crossing stations, duration of intermediate stops, mix of train categories, number of block sections dividing the critical section between crossing stations, and direction alternations.

There are however limits in this approach. When traffic density goes up to 15-minutes regular interval timetable, the need to have to build new crossing stations or even double some track sections becomes significantly higher.

Keywords

Capacity, single-track, crossing station, regular interval timetable

1. Introduction

Railway passenger traffic is increasing in many lines and, as a result, congestion has to be dealt with. For that, an attempt to harmonise the concept of capacity was made during this last decade. In 2004, The UIC, International Union of Railways, re-edited a leaflet about capacity: the UIC 406 Code [1]. Although recognizing that "a unique, true definition of capacity is impossible", this leaflet tries to define a critical level for the utilisation of the capacity. This article shows that, in some cases, single track railway lines can be saturated even when exposed to very low capacity utilisation. The leaflet qualifies the "market-oriented quality" of a timetable only by two parameters: timetable stability and average speed (cf. "capacity balance §.2.1). Nevertheless, regular interval timetables and connections are important components in Switzerland. They cannot be ignored and the compression method the UIC leaflet proposes is inappropriate for such an evaluation. No universal method of capacity calculation is applicable unless quality of service is ignored [2].

Several works [3-6] conclude that the UIC leaflet give an appropriate method only for double-track railway line with no intermediate stops and pretty small and well-equipped stations. UIC leaflet deals neither with main stations containing junctions, diamond crossing and slips nor with sub-networks combining commercial lines.

This paper pinpoints the main parameters having to be observed in order to determine if capacity has to be raised or only to be better used. For that, it analyses eighty-eight Swiss single-track lines with heavy traffic. Most promising parameters for better use of capacity in order to avoid high infrastructure investments are identified.

2. Main parameters impacting the capacity of a single-track line

2.1 Discussion on the four parameters of the UIC 406 Capacity leaflet

The compression method in UIC 406 tries to deal with four main parameters, defining the so called "**capacity balance**": **number of trains** per time unit, **timetable stability**, **heterogeneity** of train services and **average speed**. The parameter *number of trains* is clear and can be easily quantified; On the contrary, the parameter *timetable stability* is hard to define. Importance of one freight train delayed for one hour is not the same than 4 delays of 15 minutes each for four passenger trains. By the way, a delay at a dead-end of a line has not the same impact on passengers than the same delay at arrival in a connecting station. Sometimes, recovering the planned timetable very fast for all trains is less efficient than accepting increasing delay for one train in order to avoid impacting all other trains. The parameter *heterogeneity* is also difficult to grasp. In some cases slow freight trains consume less capacity than frequently stopping passenger trains. Finally, the parameter *average speed* is ambiguous. In fact, the maximum of the capacity is obtained at a defined speed, not too low but also not too high, as the braking distances to be kept between trains is proportional to the square of speed. For example, for a unique type of service carried out with identical train compositions and with an optimised block system on a very simple double-track line, the maximum of the capacity is normally obtained at a speed about 80-120 km/h (cf. fig.1).

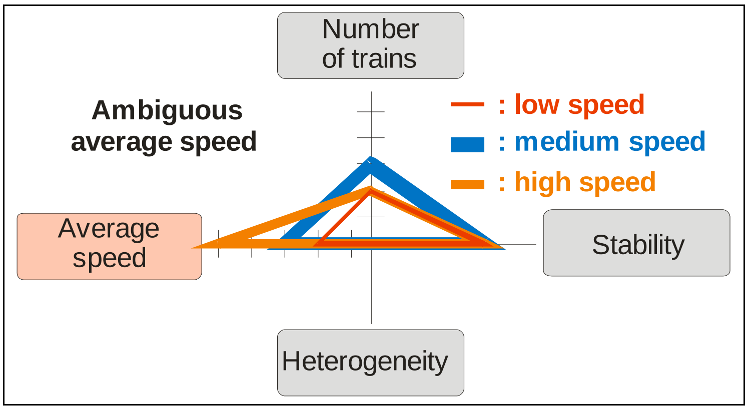

Figure 1: Capacity balances for homogeneous service on a double-track section
(identical train compositions and optimized block sections)

With the introduction of two service types, the same capacity consumption can be achieved with quite different average speeds, the three other parameters being kept the same. How could we quantify the heterogeneity difference between the two timetable structures shown in figure 2, as they are perfectly symmetrical?

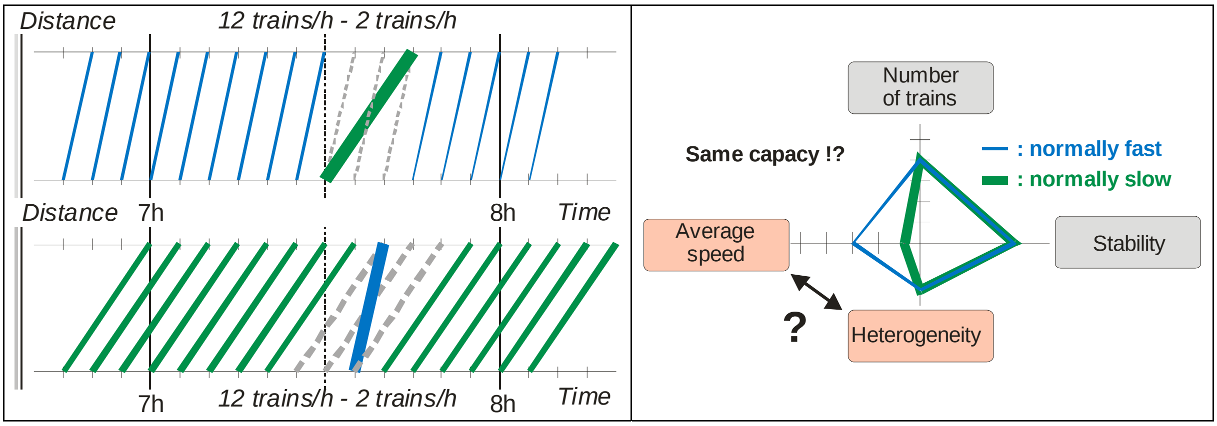

Figure 2: Same capacity in spite of a quite different average speeds
(all others balance parameters staying the same)

Figure 2 clearly shows that the **quality of service** can not to be reduced to the timetable stability parameter alone, too. In fact, short journey times are important for most passenger services.

Besides those general limitations of the "capacity balance" criterion, some other limitations appear as soon as we try to define capacity for a single-track line operated with a coordinated regular interval timetable.

2.2 UIC 406 Capacity leaflet and regular interval timetables on single-track lines

Some parameters are specific for single-track lines in general. For heterogeneous traffic, both the *length* between two crossing/passing stations and the *differences* between train speeds are more important regarding capacity than *average speed*. For homogeneous traffic, the *time* between crossing stations is much more significant than the *average speed* (fig. 3).

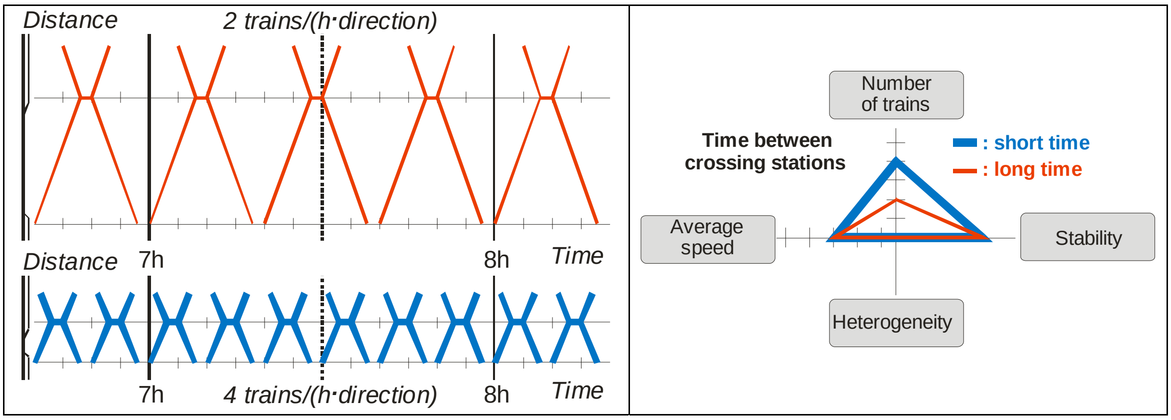

Figure 3: Increase of number of trains according to journey time on the critical section (one type of service)

Coordinated regular interval timetables require **adequate connecting times**. Aim of planners is not only to efficiently use the line capacity (cf. [7]) but also to provide a desirable level of service within given constraints. Depending on the infrastructure and the connection requirements, a timetable may provide medium-quality, low-cost solutions (cf. fig.4), whilst better solutions may sometimes prove extremely costly (cf. fig.5).

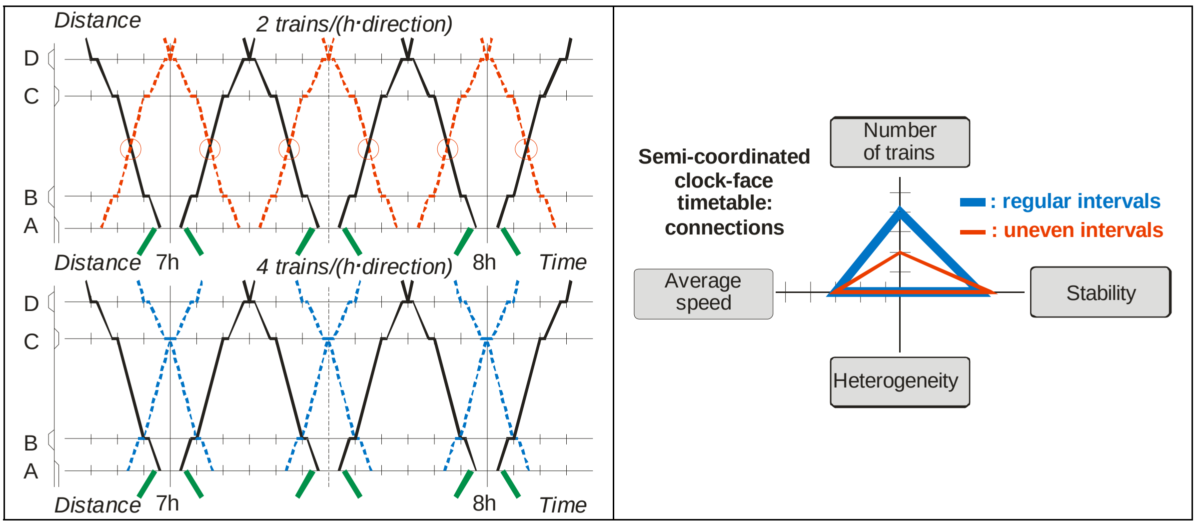

Figure 4: Capacity reserve of a single-track line depending on the connections and the regularity of the intervals (a single category of trains)

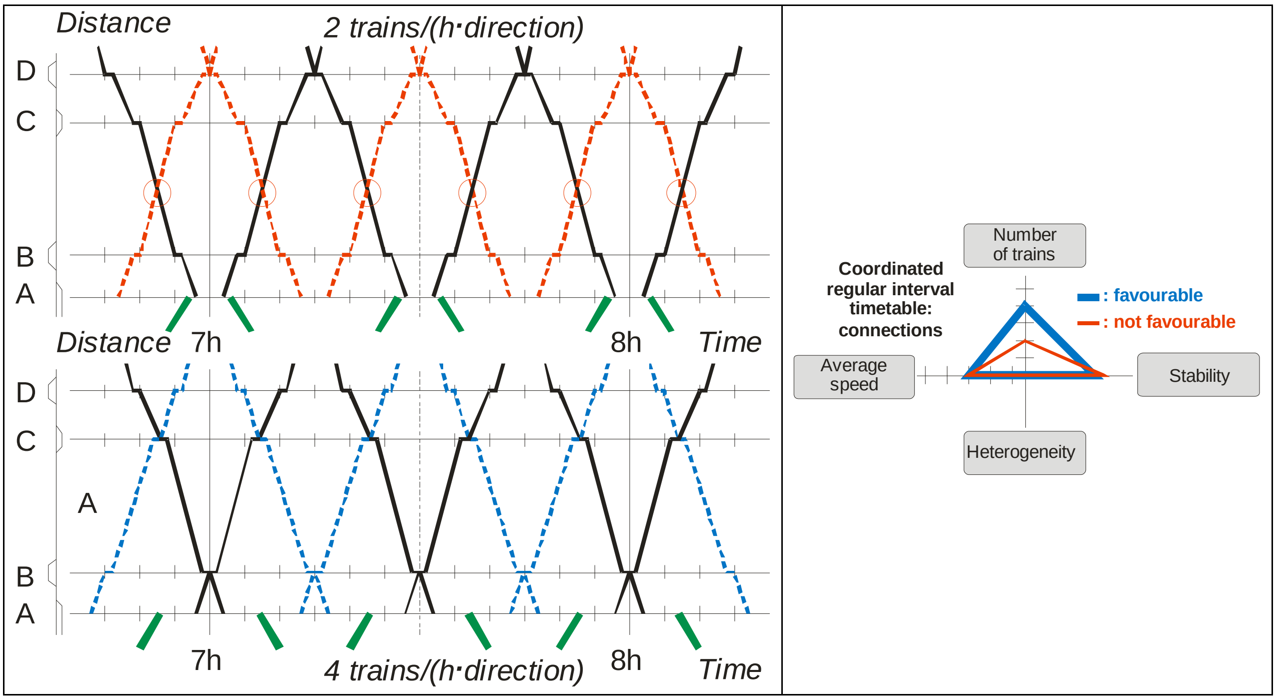

Figure 5: Impacts of connections on the capacity reserve of a single-track line (regular interval timetable - a single category of trains)

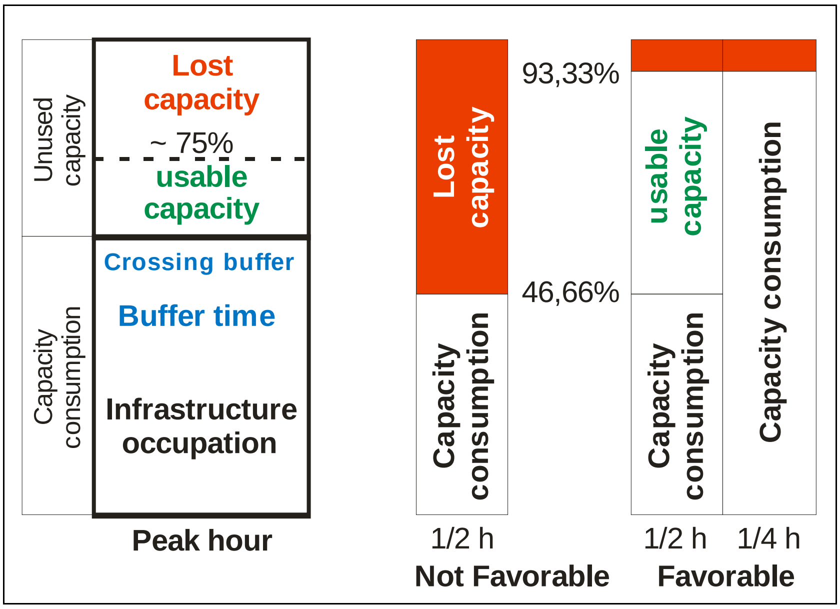

Figure 6: Quantification of the figure 5 according to the UIC 406 leaflet

The examples shown in figures 5 and 6 demonstrate that, in one hand, single-track section operations can be planned with a capacity consumption of only 47% according the UIC 406 leaflet. In the other hand, the same single-track section can be operated with a capacity consumption of 93%.

Furthermore, even when the critical single-track section has a usable capacity reserve, there is no guaranty that non-critical single-track sections along the same line could allow a reinforcement of the timetable (cf. fig.7).

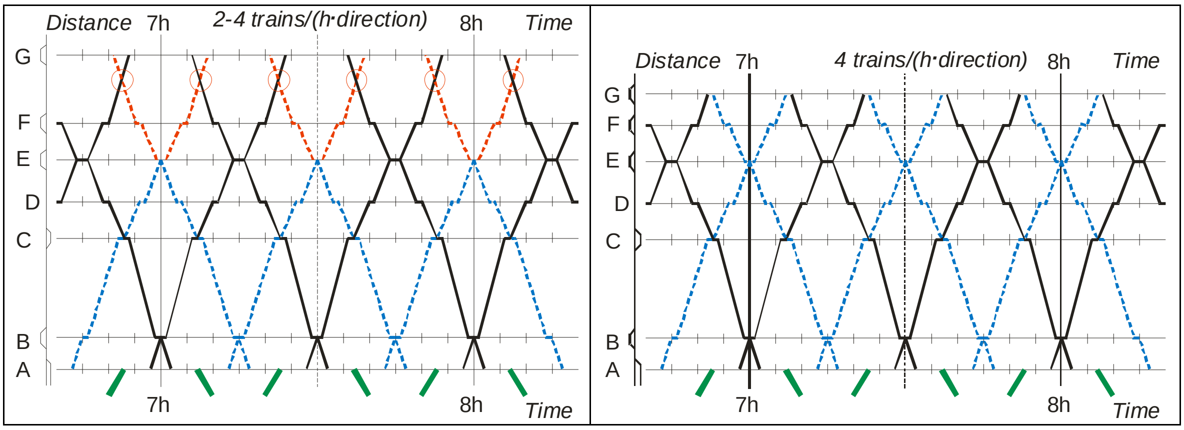

Figure 7: Impacts of section successions on the capacity reserve of a single-track line
(regular interval timetable - a single category of trains)

2.3 Analyse of eighty-eight Swiss single track lines with heavy traffic

General considerations

In 2009, eighty-eight Swiss single-track lines were operated with four or more trains per hour on their critical single-track sections. Some statistics are shown in Table 8. Times are always given for the slowest train category. For each line, the analysis of the timetable was made on one of their critical section between 6am and 9am.

General values	
number of lines investigated	88
number of Infrastructure Managers	> 20
total length of single-track lines investigated	382 km
number of trains between 6am and 9am taken into account	1594
number of trains in the peak-hour direction	842 (53%)
number of freight trains	62 (4%)
number of stop trains (regional trains)	1272 (80%)
number of alternations	1293

Critical section values	
average length	4.3 km
average time	5.2 min
number of critical sections without freight trains	60 (68%)
average number of intermediate stops	0.95
number of critical sections with more than 20% freight trains	5 (6%)
number of critical sections with a commercial speed lower than 40km/h	22 (25%)

Table 8: Main characteristics of the set of eighty-eight Swiss single-track lines
Timetable 2009 - 6am - 9am

Lengths, journey times and intermediate stops of the critical sections

number of intermediate stops	number of sections	Average length [km]	Average time [min]	Average speed
0 intermediate stop	41	4.3	4.3	60.1
1 intermediate stop	24	4.2	5.1	50.0
2 intermediate stops	17	4.9	4.4	42.8
3-4 intermediate stops	8	2.6	5.3	29.3
Total	88	4.3	5.2	---

Table 9a: Critical sections: Impacts of the number of intermediate stops on critical sections
(average values are obtained by summing the 88 values and dividing the result by 88)

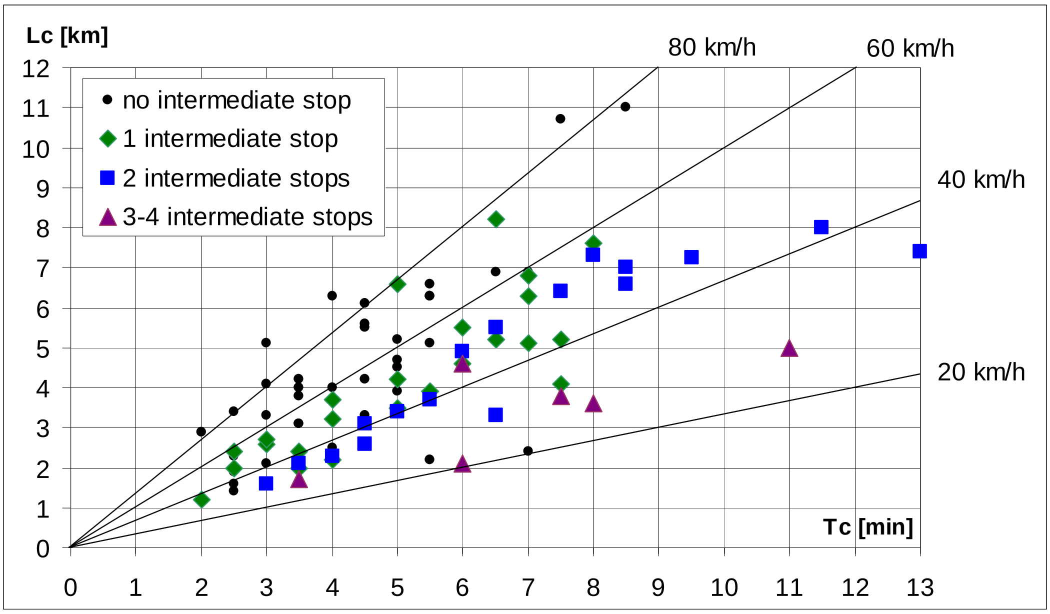

Figure 9b: Critical sections: Impact of the number of intermediate stops on the average speed
(Lc: Length of the critical section, Tc: Journey time on the critical section)

A first observation is that the length of the critical section of these 88 single-track lines is seldom higher than 8 km. A second is that the journey time is seldom more than 9 minutes. A third one is quite obvious: average speed on the critical section is generally related to the number of intermediate stops (cf. tab.9a and fig.9b). However, some caution is necessary in analysing average speed, as journey times are based on graphical and numerical timetables which can show shorter times than those effectively needed to run the critical section.

Alternations, block sections and train categories

Without specific constraints on timetabling and balanced flow in both directions, the probability of having one train followed by another one running in the same direction (B) is equal to the probability of a train followed by another one running in the opposite direction (A). Both those probabilities are equal to 50% (figure 10).

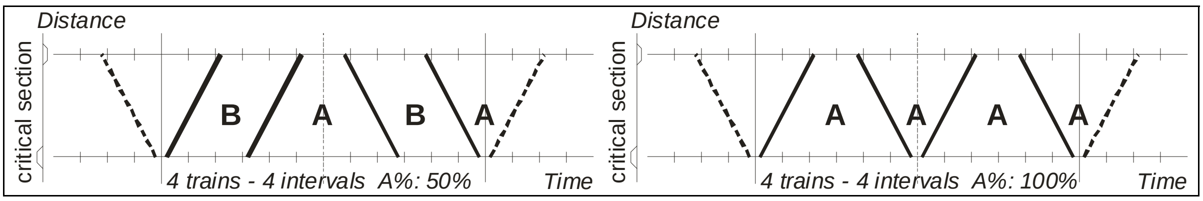

Figure 10: Alternation and definition of the A-ratio

Table 11 shows that there is no correlation between the number of block sections dividing the critical section and the probability to have grouping of trains in the same direction. Such a correlation could perhaps have existed in the past, but it is not shown within the 2009 timetable. Table 12 and Figure 13 lead to a second conclusion: that the A-ratio is relatively low as soon as heterogeneity occurs.

number of block sections	number of sections	Average time [min]	A-ratio [%]
1 block section	55	5.3	81.2
2 block sections	28	5.0	83.5
3 block sections	5	5.5	90.6
Total	88	5.2	82.5

Table 11: Critical sections: Impact of the number of block sections

Mix of train categories: Definition	Abbreviation	number of sections	Average time[min]	A-ratio [%]
Passenger - 1 category - No freight	P-1cat	40	5.5	93.2
Passenger - 1 category + Freight trains	P-1cat + F	20	5.4	75.5
Passenger - 2&3 categories - No freight	P-2-3cat	9	4.0	79.8
Passenger - 2&3 categories + Freight	P-2-3cat + F	19	4.8	68.4
Total	---	88	5.2	82.5

Table 12: Critical sections: Impact of the mix of train categories

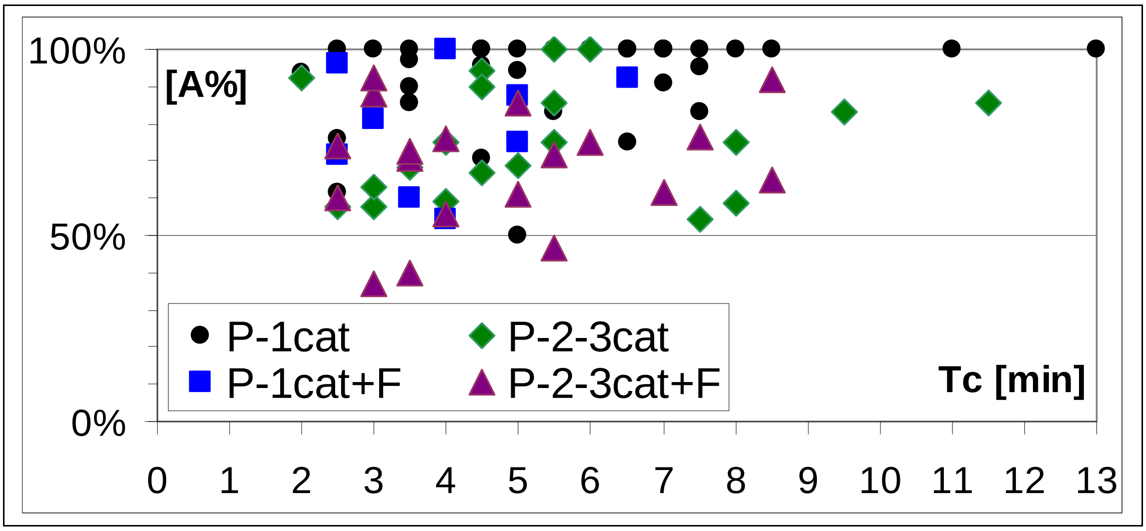

Figure 13: Critical sections: A-ratio and mix of train categories

Number of trains and limit of capacity

The number of trains on the critical section during the peak hour is very variable (4 for a half an hour regular interval timetable and only one train category to 24 for a 5-minute regular interval timetable).

Limits for the theoretical capacity on the critical section can be computed based on the journey time of a single train category with a Non Coordinated Timetable (3 black curves L-1cat in figure 14). Additional assumptions are: headway of 3 minutes and no buffer time for train crossings. A-ratio equal to 0% means that all trains run in the same direction and 100% means a perfect alternation.

The limit for a Coordinated Regular Interval Timetable with a single train category is also given (1 black curve L1-100%-Coordinated Regular Interval Timetable in figure 14)

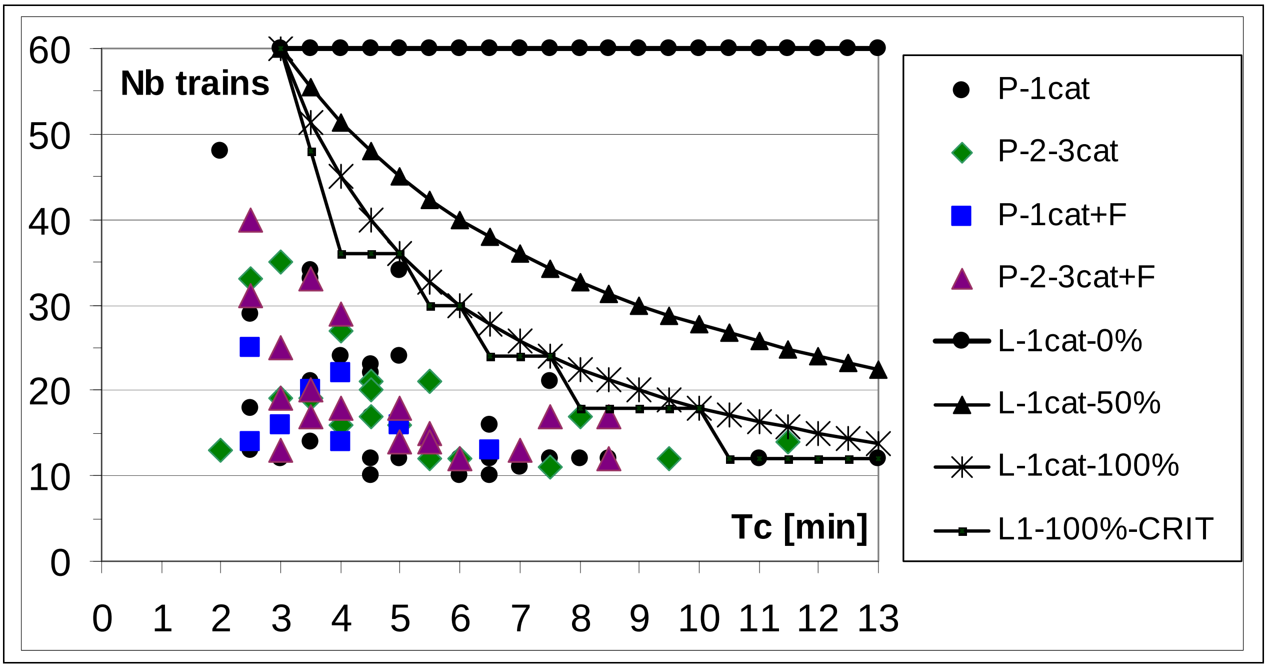

Figure 14: Critical section capacity: A-ratio and mix of train categories

Figure 15 shows that a third of the single-track lines analysed has a 30-minutes regular interval timetable with high alternations on the critical section. Many companies with such a timetable consider the possibility to develop 15-minutes regular interval services.

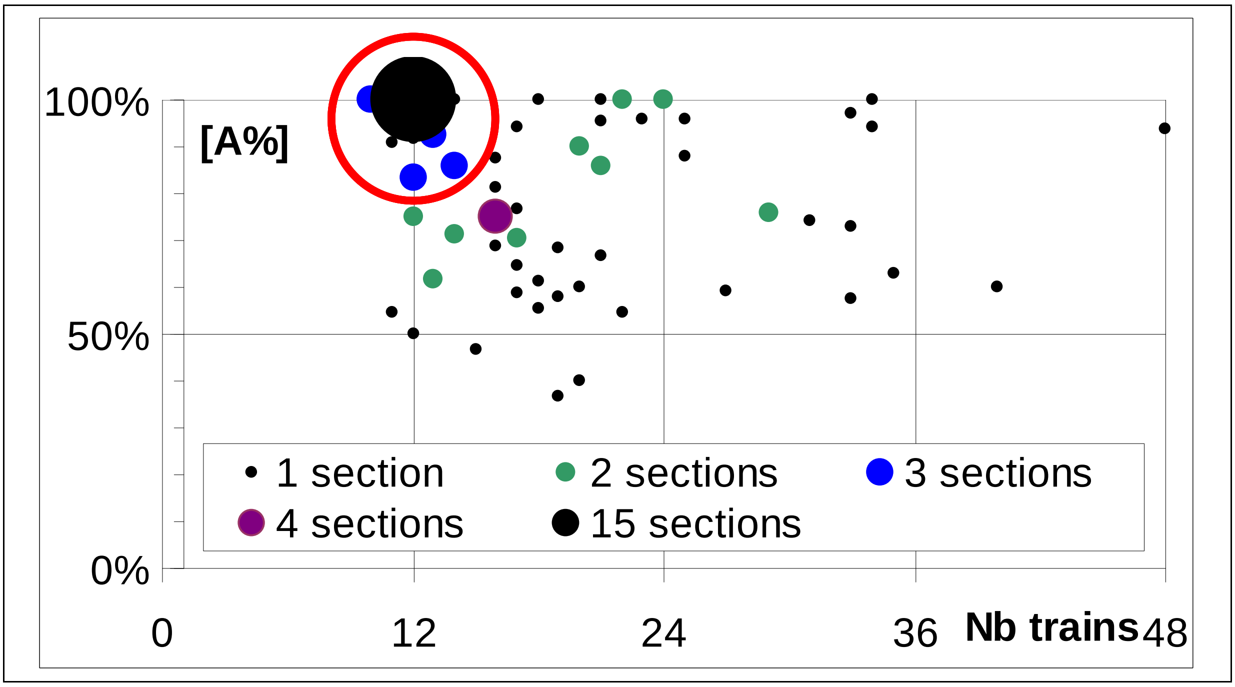

Figure 15: Critical section capacities: A-ratio and number of trains

The next section focuses precisely on these lines.

2.4 From a 30-min regular interval to a 15-min regular intervals timetable

Among the eighty-eight lines, twenty-nine of them are operated with mainly a half an hour timetable during peak hours.

Six of the 29 sections have too long journey times to make it possible to operate 15-minutes regular interval services with an alternation ratio of 100%. 26 critical sections of these 29 sections have a capacity consumption under 60% with 30-min regular interval timetables, when computed according to the UIC leaflet. Actually, 17 of 29 (65%) should be qualified as saturated in the sense they can not accept additional trains at regular intervals without modifying either the infrastructure or the existent timetable. Among the 9 critical sections for which 30-min regular interval operation is possible without infrastructure modifications or train path shifts, 3 would have a final capacity consumption of more than 90% (cf. tab.16a and fig.16b). This high value is considered as excessive by the UIC leaflet but daily exceeded in practice.

					Total
number of critical sections	6	14	7	2	29
probability 30->15 min [%]	0	14-29	43-57	71-100	Expected: 7.4 sections OK
					In fact: 9 sections OK

Table 16a: Critical sections: Impact of the number of block sections

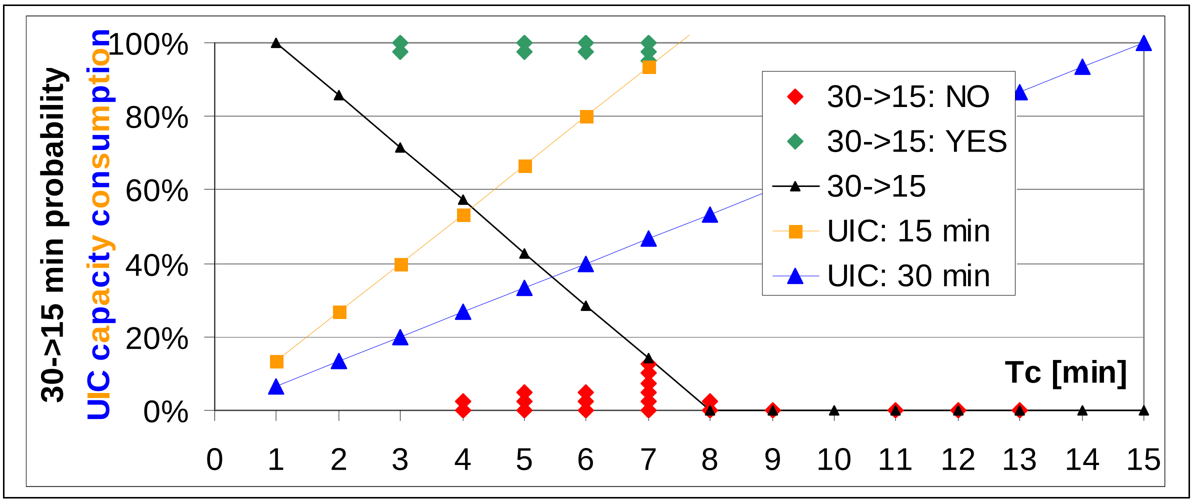

Figure 16b: Critical sections: A-ratio and mix of train categories

Even if the 9 critical sections accept the doubling of the frequency, there is no guarantee that other single-track sections of the same line will accept such a change (cf. fig.7).

It is also quite interesting to notice that a single-track section operated with a half an hour strict regular interval timetable has a probability of 14% to be qualified as congested even if its capacity consumption is of only 13% according to the UIC leaflet!

2.5 Need for increasing the capacity of single-track line operated with a single type of service and a coordinated regular interval timetable

The table 17 resumes what has to be examined before admitting that the only solution is to build new crossing stations or new double-track sections on those Swiss single-track lines.

Parameter	To examine **in priority** for a Swiss single-track line with heavy traffic operated with a regular interval timetable
Journey time reduction: - dwell time reduction at intermediate stops - rolling stock (door, floor height) - infrastructure (platform height) - speed in crossing stations - infrastructure (switch in deviation) - infrastructure (overlap, dead-end) - speed in open line - regulation/infrastructure (ATP, curves) - rolling stock (construction, braking power) - rolling stock (tilt) - acceleration/deceleration - rolling stock (power, braking power) - infrastructure (line voltage)	 Yes: To reduce dwell time, and thus travel time on critical sections. Yes: To allow simultaneous entrances at relatively high speed. Yes: To contain speed reduction on downward slopes To allow maximal speed above 90km/h. No: Critical sections length is too short Yes: To contain speed reduction on downward slopes High acceleration up to maximal speed
Regularity margin - driver's aids - line voltage	 No: Critical sections length is too short Yes: If necessary
Crossing buffer reduction - automatic block system - extension of the double-track in crossing station	 Yes No: Too expensive
Headway reduction: - optimised automatic block system	 No: High alternation ratio

Table 17: Parameters to examine in priority for the analysed Swiss single-track lines before resorting to consider building new crossing stations or double-track sections

However, in many of the analysed cases, applying all those "soft" measures is still not sufficient to double the service frequency. One or two new crossing stations are necessary (LEB or NtSCM, by example).

3. Conclusions

On single-track lines with heavy traffic operated with a regular interval timetable, capacity can hardly increase without building new crossing stations or double-track sections. However, in cases where only one or two minutes are missing to ensure crossings, many measures to reduce journey times and buffers have to be considered first. Modern Electro-Motive Units with a power rate above 15 kW/t and numerous and wide doors may provide an alternative. Simultaneous entrances in crossing stations and adapting platform and vehicle floor height may also help. Finally, going towards an automatic block system and increasing the number of sub-stations to provide permanently adequate overhead voltage should also be considered, before planning infrastructure extensions.

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5. Annex

Infrastructure Manager (IM)	Single-track length [km]	Critical section	Critical section length [km]
LEB	22.8	LS-Chaud.-J.--Mézery	3.6
TL	7.8	Mouline-EPFL (M1)	1.2
MVR	5.7	St.Légier-Blonay	2.1
MOB	75.3	Montreux-Colondales	1.7
AOMC	11.2	Aigle-Ollon	3.7
NStC	27.0	Arzier-St.Cergue	5.2
OC	3.9	Chavornay- Granges	2.5
TN	8.8	NE-Serrières-Auvernier	2.4
CFF	38.9	Chx-de-Fds-Le-Locle	7.6
CFF	44.0	Reuchenette-Sonceboz	6.3
CFF	25.1	Sonceboz-Tavannes	6.9
CFF	22.4	Zwingen-Grelingen	5.5
CJ	23.0	Tramelan-Orange	4.6
CJ	10.9	Porrentruy-Alle	4.2
CFF	40.3	Glovelier-Courfaivre	6.3
CFF	49.9	Fribourg-Givisiez	4.0
ASM	21.1	Nidau-Lattrigen	3.8
RBS	7.4	Worb-Langenloh	1.6
BLS	24.2	Moutier-Grenchen N.	10.7
BLS	6.8	Laupen-Neuenegg	5.1
BLS	29.8	Konolf.-Tägertschi	3.3
BLS	21.8	Uetendorf-Thun	5.2
BLS	20.7	Burgdorf-Kirchberg	4.1
BLS	21.5	Hasle-Lützelflüh	2.4
BLS	63.9	Gümmenen-Rossh.	5.6
BLS	17.3	Schwarzenb.-Mittelh.	8.0
RBS	8.9	W.Dorf-Boll-Utzigen	3.1
RBS	20.0	Jegendorf-Grafenried	3.8
BLS	16.0	Interlaken-W.-Därligen	4.0
BOB	42.7	Interlak.-O.-Wilderswil	3.3
BLM	4.3	Mürren-Winteregg	2.4
BLS	34.9	Spiez-Wimmis	4.6
BLS	33.8	Konolfi.-Oberdiessb.	3.7
BLS	22.1	Solot.-W.-Langendorf	1.9
OeBB	4.0	Oensingen-Klus	2.6
ASM	25.6	Weihern-Flumenthal	2.6
ASM	11.9	Langen.-Roggwil-D.	4.9
BLS	39.3	Madiswil-Lotzwil	2.7
BLS	55.3	Littau-Malters	6.1
ZB	1.6	Horw-Hergiswil	1.4
ZB	65.3	Brienz-Oberried	7.3
MIB	5.0	Meiringen-Innertk.	5.0
ZB	3.7	Stansstadt-Stans	3.7
CFF	28.8	Schopfheim-Zell	7.3

Infrastructure Manager (IM)	Single-track length [km]	Critical section	Critical section length [km]
WB	13.1	Bubend.-Lampenb.	2.4
BLT	4.5	Ettingen-Witterswil	2.0
CFF	24.4	Zofingen-Safenwil	6.6
CFF	16.9	Küsnacht-Meggen	5.5
CFF	15.8	Walchwil-Arth-G.	6.3
CFF	11.0	Tenero-Riazzino	3.9
FLP	11.0	Lug.-FLP-Cappela	2.6
WSB	10.2	Muhen-Hirschtal	2.2
WSB	22.0	Blein-Gränichen	2.0
CFF	40.7	Birwil-Seon	7.4
BDWM	17.1	Dietikon-Stoffelbach	1.6
CFF	5.5	Fluhmühle-Rotsee	3.4
SOB	47.8	Schindel.-Biberbr.	3.2
CFF	17.0	Siggen.-Dottingen	6.6
CFF	9.6	Buchs-D.-Otelfingen	3.5
CFF	25.3	Bonst.-Birmensdorf	4.7
SZU	16.2	Adliswil-Langnau	3.4
SZU	9.1	Triemli-Borweg	2.1
CFF	7.2	Horgen-Sihlbrugg	3.1
CFF	14.9	Stadelh.-Tiefenbrun.	2.3
FB	7.5	Egg-Esslingen	2.3
CFF	25.0	Schmerik.-Bolligen	5.1
CFF	14.9	Aathal-Uster	4.1
CFF	33.9	Wetzikon-Hinwil	4.5
CFF	50.3	W.-Seen-Kollbrunn	4.2
CFF	17.9	Lottstetten-Jestetten	4.2
CFF	12.1	Steinm.-Nweningen	6.4
CFF	52.2	Zurzach-Koblenz	7.0
CFF	27.7	Hettlin.-Winterthur	6.6
DB	12.2	Beringen-Neunkirch	6.3
CFF	44.3	Etzwilen-Stein	3.1
CFF	28.2	Wallrüti-Seuzach	2.9
THUR.	19.5	Kehlhof-Weinfelden	5.2
THUR.	19.2	Wil-Bettwiesen	5.5
CFF	15.1	Romanshorn-Arbon	8.2
CFF	23.0	Bischof.-N-Sulgen	6.8
CFF	20.0	Wil-Bazenheid	6.9
AB	32.1	Gonten-Appenzell	5.1
AB	20.1	Bühler-Gais	3.3
AB	8.1	Schw.Bären-Vögel..	2.0
CFF	34.7	Wattwil-Kaltbrunn	11.0
RhB	63.7	Landquart-Igis	2.2
RhB	79.4	Reichnau-Bonaduz	3.9
RhB	56.8	Samedan-Bever	2.1

Table A1: Eighty-eight critical sections on eighty-eight Swiss single-track lines with heavy traffic

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