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Methods for saturation modelling of railway lines: the case of High-Speed Line Paris-Lyon

Florent Laroche*

This paper discusses the saturation for a high-speed line. It shows that the saturation is a relative concept and that different solutions exist to increase capacity of one infrastructure. **Key words:** infrastructure, capacity, railway, utilization rate, innovation

The congestion phenomenon remains a poorly-researched issue in railway studies (Brunel et al., 2013). Well-known in road transport, socio-economic interest in studying congestion has been reinforced in the railway sector in the process of market opening from the 1980's, supported by the European Commission. The EC/91/440 directive introduces as the fundamental principle the access right to infrastructure and addresses the issue of capacity allocation. Capacity is a complex concept to apprehend in the railway sector because of the diversity of stakeholders and networks (Abril and al., 2008)

This issue is currently researched in France on the case of the Paris-Lyon High-Speed Line (HSL). Being the first historical line of the French high-speed network, it is also the most used one in 2014. According to the infrastructure manager, the anticipated traffic evolution could lead to its saturation as soon as 2020-2025 (RFF, 2011). The solution considered by the National Transport Infrastructure Scheme (SNIT, 2011) is to build a new line to relieve the existing one. The project, for which costs are estimated at 14 billion€, raises the questions of its economic relevance in a context of scarce public funds and of possible alternatives of adaptation of capacity to demand increases.

This paper suggests an analytic framework of the saturation of transport infrastructure, applied to the Paris-Lyon case study. The objective is two-fold: how to conceptualise the saturation of a high-speed line? Which levers to increase its capacity?

A definition of saturation is proposed in the first part. The second part introduces the saturation assessment method, and the last section explores the alternatives for a possible adaptation of the capacity.

Which type of saturation?

Saturation can be defined by an utilisation rate measuring the relationship between demand and supply for an

infrastructure.

Two rationales can be distinguished:

- The infrastructure managers' for whom the demand is expressed in trains and the supply in the "number of trains that can circulate on a given section, in a given time" (Burdett and Kozan, 2006);

- The operator's rationale for which the demand is expressed in users and supply in number of seats in a train.

As a result, saturation might be considered as between users or between trains (Brunel and al., 2013).

Considering infrastructure, the literature identifies two types of capacity:

- The absolute or theoretical capacity (C_t), being the maximum number of trains that can circulate on the infrastructure (Burdett and Kozan, 2006);

- The practical or commercial capacity (C_p), that considers the effective capacity of the infrastructure (Liotta and al., 2009).

The difference between them is the resilience of the system, meaning its capacity of recovering a normal functioning after a traffic disruption (Setra, 2009). It puts the infrastructure manager in a judge position between the capacity offer and the targeted level of quality of service. The econometric analysis demonstrates a non-linear relation between traffic density and delay risks (Brunel and al., 2013). In contrast to road, delay is not factual and is expressed as a risk (planned activity). From a certain threshold, it increases exponentially for a supplementary circulation. The threshold usually stands for a risk of below 10 minutes delay.

As a consequence two levels of saturation can be considered for the infrastructure:

- A "structural" saturation (S_2) based on the theoretical capacity, including heavy investments on both mid- and long-terms;

- A "daily" saturation (S_1) linked to the commer-

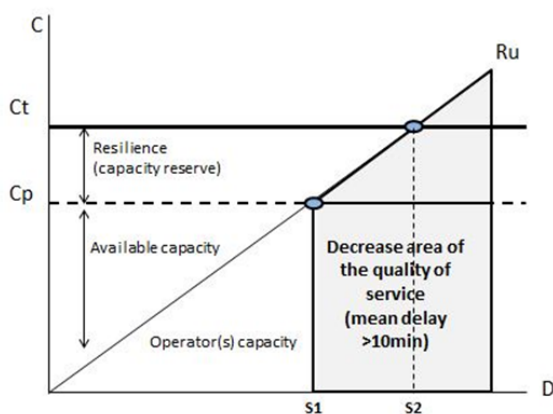
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cial capacity resulting in the system performance and the trade-off made by the infrastructure manager.

The disaggregation of the different capacity levels leads to the identification of the train capacity and the commercial strategy of the operator(s). This capacity has a bias for the infrastructure manager who only has an indirect link with the demand, as expressed in travellers. The operator manages its capacity in terms of available seats per train, under typical technical and comfort constraints, but also in terms of frequency, under the constraint of the capacity made available by the infrastructure manager.

This deeper study of the saturation concept highlights several capacity thresholds and a strong interaction between the different stakeholders. However, they all correspond to very distinct rationales that are even clearer in an unbundled system.

Figure 1: Conceptualisation of capacity for an infrastructure railway.



Which assessment method for saturation?

The assessment method of saturation is adapted to a French-model based high-speed line. Traffic is recognized as being homogeneous both in terms of speed and service. Only passenger high-speed trains have the possibility to circulate on the network.

The utilisation rate (Ru) is calculated according to the theoretical capacity of the infrastructure section (an entry/exit). It is the ratio between demand in terms of passengers and offer in terms of available seats.

The demand (D) is calculated on peak-hours regarding the concentration coefficient (k). This coefficient enables to assess the demand concentration during peak-hours in comparison to off-peak hours.

Supply (C) is calculated regarding the maximal capacity of train, expressed as the number of seats (Cr) and the theoretical capacity of the infrastructure (Ct) expressed as the number of trains per hour. The train capacity is

weighted by the load factor (k) and the double train rate (μ). The theoretical capacity is weighted by the resilience coefficient (k) to result in the commercial capacity (Cp). Supply is divided by the number of commercial exploitation hours (h) during a year.

$$(1) Tu = (D \cdot \phi) / [((Cr \cdot \theta) \cdot \mu) \cdot ((Ct \cdot \kappa) \cdot h)]$$

Infrastructure is a priori saturated when the utilisation rate is higher than 100% to the theoretical capacity. However, saturation is considered, in this analysis, according to the commercial capacity. It shows an increasing tension in the system between demand to satisfy and the purposes for regularity.

Application to the Paris-Lyon HSL

Regarding the Paris-Lyon HSL, the method assesses the horizon of saturation of the commercial capacity as being up to 2020-2025 (between 75 and 80% of the theoretical capacity). The reference year is 2008, and the hypotheses of demand and offer are based on studies undertaken by RFF (2011) in the context of public debate about the project of doubling the line by creating a new line Paris-Orleans-Clermont-Ferrand-Lyon (POCL).

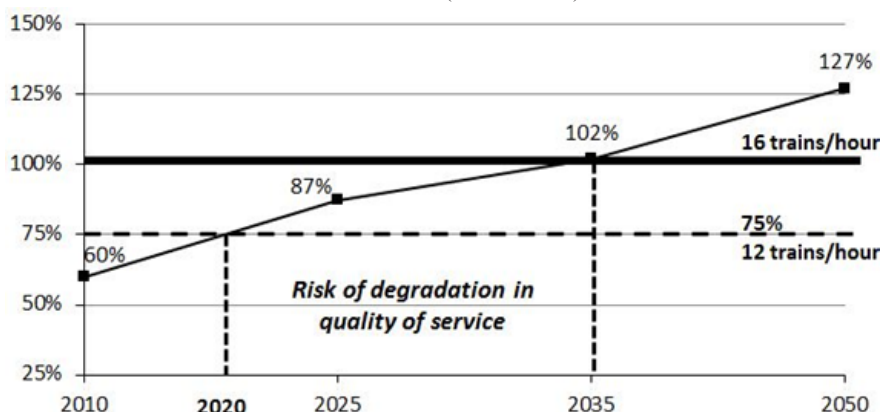
In 2008, the effective demand was up to 38 million passengers. The central scenario foresees a rise of 39% in 2020 (53 million passengers) and of 115% in 2050 (83 million passengers). This dynamic is due to the expected 30% of economic growth and 70% of the development of the HSL network, according to the SNIT (2011).

The supply situation in 2008 is as follows: the average theoretical capacity of the circulating trains is up to 450 passengers. This result considers the Duplex trains offering 512 seats and the first generation of HST (377 seats), still circulating to Switzerland. The observed double train rate is of 1.3 during peak-hours and the average load factor is up to 80%. The network operability is of 18h/day (5:30 – 23:30). The theoretical capacity is up to 16 trains/hour, in accordance with the signalling system (TVM 300) for a commercial capacity of up to 12 trains/hour (75% of the theoretical capacity). Eventually, the concentration coefficient is estimated at 1.5.

Which ways to adapt capacity?

Regarding the saturation risk, since 2007 the public actors have been calling for the doubling of the line (POCL project). This solution would lead to the doubling of the theoretical capacity (+100%) and to the improvement of the exploitation of the Paris-Lyon corridor, thanks to the redundancy of the route (Leboeuf, 2014). The deadline

Figure 2: utilisation rate of the HSL up to 2050 according to the observed situation on the network in 2008 (source: author)



of saturation is postponed beyond 2050 for a commissioning start date in 2025. Nevertheless, this lever raises two main controversial issues. On one hand, the cost is estimated at 14 billion€ and would stand for a record among all HSL projects (SNIT, 2011). On the other hand, the saturation risk might be postponed from the line towards Lyon railway hub, which opens to question the issue of the re-planning of the main interconnectivity stations and its financing scheme.

Out of the infrastructure, four means of adaptation can be identified: three technical levers (exploitation, traffic management and rolling stock) and one economical lever (pricing). Each lever is characterised by the parameters of the previous equation.

The tested hypotheses are the results of current experiences. Their generalisation could be effective at the horizon 2025.

The rolling stock lever: solution “Ouigo”

This scenario proposes to test the “high density TGV” principle, according to the experience currently undertaken by SNCF (Ouigo offer). It increases the existing train density through the generalisation of the second class standard. This type of solution applied to the whole commercial offer on the Paris-Lyon line could lead to a capacity gain at least as important as the doubling of the infrastructure (+131%). The lever of this hypothesis relies on an average capacity per train of 600 seats. This estimation takes into consideration the increasing of capacity of Duplex trains (634 seats) and the replacement of the first generation of HST by AGV 10 trains (462 seats). The double train rate is up to 2 (optimisation of the rolling stock management) and the load factor up to 90% (optimisation of sales and tickets booking).

However, while this scenario seems to be credible on

a technical standpoint, it raises the issue of the operator’s ability to evolve the business model which is until now focused on the first-class and comfortable seats spacing. Similar to the airway model, this evolution involves a new conception of high-speed and services.

The traffic management lever: the solution of an optimised schedule

This scenario suggests to testing the adaptation of the daily capacity on the basis of a better traffic management. The resilience can be improved on the model of the new schedule, defined by RFF in 2013 after the opening of the Rhin Rhone HSL (Deborde, 2012). The commercial capacity is, so far, up to 13 trains/hour (80% of its capacity) during a peak-hour in a week (Friday evening). The generalization of a schedule optimization could increase the capacity by 13% and postpone the saturation horizon by 5 to 15 years. To achieve such a scenario, the effort must be made on the solidity of the circulation schedule, the management real-time tools and the ability to deal with disruptive situations. Without any significant change, the increase of the commercial capacity might damage regularity and raise the delay risk.

The exploitation lever: the ERTMS 2 solution

The exploitation scenario tests the effect of an increase of the theoretical capacity by introducing the new European signalling standard ERTMS level 2, in replacement of the existing (TVM 300). This standard is known to allow a better traffic management in real time by because of a shorter interval between trains and a better resilience of the system (Delaborde, 2012). The theoretical capacity is up to 20 trains/hour for a corresponding commercial capacity of 16 trains/hour (80% of the theoretical capacity).

The capacity gain is of 33% and the saturation deadline postponed by 15 to 25 years. This scenario enables a greater capacity on the line without any particular optimisa-

tion of the offer to be made by the operator. Nevertheless, the estimated cost is 500 million€ equally shared by the infrastructure manager and the dominant operator (Leboeuf, 2014). The necessary communication between the on-track installation and the cabin to make the system operational requires coordination in investments. Guihery and Laroche (2013) have demonstrated that there might be several barriers to migration if the historical operator does not align its choice to the infrastructure manager.

The pricing lever: the congestion economics solution

The last lever possible relies on the principle of railway congestion developed by RFF to weigh the value of the network use (Brunel and al, 2013): valorisation of surplus by discriminatory pricing between peak and off-peak hours. The price signal leads to a staggering of circulations and a reduction of the concentration coefficient (1.3). The given rate is directly inspired by the Japanese model, whose observed difference in 2013 was up to 1.3 on the Tokyo-Osaka line. On the operator standpoint, the hypothesis has to be made that the price signal of the infrastructure manager is passed on the pricing policy (scarcity effect) resulting in an optimised load factor (90%) without particular change in supply.

The global gain is around 30%, and the saturation deadline postponed by 10 to 25 years. The associated cost of such a scenario can also be a gain for the sector, but it feeds some social reluctance, if not supported by a deep evolution of mobility behaviours. The maximisation of surplus could indeed lead to a rise in the users' transport cost, and thus a running out-of-course effect.

Thus, this scenario would be, nowadays, limited by the pricing regulation of the state-controlled ticket prices (Perennes, 2012) and by the development of intermodal competition.

Conclusion

In conclusion two options can be considered regarding the saturation issue: the creation of a new infrastructure, despite high investment costs; or the evolution of tools

and production methods, following an increasing-return rationale. The latter scenario could lead to better results than the doubling of the line, both in terms of capacity and costs. Nevertheless, it supposes a redefinition of the operator's commercial high-speed train supply and the introduction of new conditions of exploitation (ERTMS). For the infrastructure manager, it means finding the right price signal to encourage investments and support the evolution of mobility behaviours.

The Paris-Lyon HSL case study certainly provides the experiment basis for the future of high-speed lines. Nevertheless, the capacity increase of the lines might worsen the railway hubs situation, necessitating great investments, mainly because of their location, in urban areas.

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