Research on capacity calculation and assessment framework for Chinese high speed railway based on UIC406

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Abstract: Railway capacity is not only the basic condition for the allocation of railway resources but also an index set for the evaluation of the usage of them. Sometimes the maximum theoretical results calculated according to the coefficient methodology for the capacity calculation of the Existed Chinese traditional railway (abbreviated as ECTR) would be less than those statistical results from the real railway operation .What's more, it even exists such a paradox that a timetable with many trains gives lower capacity consumption than a timetable with fewer trains. The main reason for these mistakes lies in that in the past it's too much highlighting the number of trains while ignoring other service quality related constraints such as the average speed, the heterogeneity of trains, the timetable stability and the effect of the railway network during the course of the capacity calculation. However, railway capacity is just a kind of comprehensive balance as a result of all of these factors. By overcoming the weaknesses analyzed above, regarding the International Union of Railways (UIC) capacity leaflet as a framework, taking into account the characteristics of Chinese railway operation and the passenger market needs, redefining the criteria for the assessment of Chinese high speed railway in a more scientific way, the purpose of this paper is to build a calculation and assessment framework for Chinese high speed railway capacity, which is indispensable not only for the calculation of the station & line capacity even for the identification of the network bottlenecks but also for the improvement of the railway's service level.

Keywords: Chinese high speed railway, railway capacity calculation and assessment, UIC 406, framework

1. Introduction

The definition of capacity has long been a classical and significant issue in railway industry. It's important to perceive the dynamics, uncertainty characteristics of railway capacity which influenced by the manner of operation management such as the timing of traffic entering each part of the system and outside influence ranging from mechanical failures to labor disruptions even the severe weather. Rob M.P. Goverde (2005)puts forward that factors of capacity of railway lines encompasses the infrastructure (such as single-track, double-track, siding, junction), speed limit of line(such as curve, grade, switch), signaling system (such as the length of block section, signal aspects, train protection)，the characteristics of rolling stock (such as braking capability, accelerating capability, maximum speed, train formation, door width) Rob M.P. Goverde (2005.).

On the other hand, the network effects can't be ignored when measuring the railway capacity, which means sometimes the railway capacity, is reduced due to capacity restrictions outside the analysis area. So one can't define the capacity of a subsystem without considering what happens on the other related one of the whole railway network. So it's widely admitted that railway capacity is not a formulaic science but rather a coordinated effort in the management of all aspects of the railways operation.

Numerous approaches and tools have been developed to address this problem from different angles and based on traffic patterns Forsgren, M. (2003), single-track analytical models Petersen, E., (1974) or algebraic approaches Egmond, RJ van. (1999).

Most of the available literatures regard the maximum number of trains or train routes that would be able to operate on a given railway infrastructure, during a specific time interval and the given operational condition (such as speed, stop station, frequency, train order and train connection at station) as the final measurement of railway capacity Kaas, A. H. (1998), P. A. Farrington, H. B. (1999), R. L. Burdett, E. Kozan (2006), M. Abril, Barber (2008). Instead of considering the traffic volume, other definitions of capacity exist, which are based upon the carrying capacity of trains in terms of passengers and freight, or the ability of the corridor to contain as many trains as possible at any moment of time. However, up till now there is no commonly accepted measurement for capacity. Thought most of the existed researches on the railway capacity have mentioned or taken into account the heterogeneity of trains, they haven't discriminated the characteristics of different trains when expressing the evaluation or calculation result by the train unit. Alex Landex (2006) considers the difficulty and difference for railway capacity definition lie in that it needs to

determine such parameters as number of trains, stability, heterogeneity of train mix and average speed Alex Landex (2006).

The greatest questions about the capacity calculation are its correctness and reliability. To solve these, one must grasp the dynamics and uncertainty property of the railway capacity as sound as possible. So the paper proposes definition of the train service-demand set as a prerequisite.

2. Background

2.1. Characteristics of Market Demand of Passenger Flow for Chinese High Speed Railway

Usually the train service can be divided into four levels from the passenger angles, including the core product (e.g. movement of passengers), basic products(e.g. distance, time, direction, safety, speed), the expected products(e.g. environment of the waiting room, service quality, environment en route), extended products(e.g. lodging, convenience of transfer). The chief service object of Chinese high speed railway (abbreviated as CHSR) is the passenger whose value of time and requirement of service quality are relatively higher than those of the existed Chinese traditional railway (abbreviated as ECTR). What's more, the travel behaviour of CHSR passenger is much more regular, which inclines to form a traffic peaking period. Thus different to ECTR, when evaluating the capacity, it's necessary to calculate not only for the whole day but also for the special period (such as the peaking hours).

2.2. Coexistence of Multi-Grade Speed Trains on The Same Time-Space Dimension

Both the passenger market and the railway manager need the connection of the high speed railway with its traditional counterpart, which leads to the coexistence of multigrade speed trains (e.g. MST (medium speed train) and HST (high speed train)) on the same time-space dimension, and the speed gap between the different grade trains is a little great.

2.3. Comparison for Capacity Calculation Conditions between ECTR and CHSR

The capacity of railway system depends on not only the infrastructure but also the way of its utilization. ECTR is operated both for freight and passenger, and the freight item occupies the absolutely higher percent in the past. When

calculating the capacity for ECTR, it took the coefficient method regarding the freight train as the benchmark, and it just calculated for the entire day ignoring the conception of the peaking periods from the angel of railway operation.

Many factors lead to the dynamics and uncertainty of the railway capacity. Indifferent to ECTR, the capacity calculation for CHSR should be set out from the angel of market demand considering the regularity of passenger flow for special periods (such as peak hours, etc).

3. UIC406 Method Framework

The International Union of Railways, more generally known as the UIC (from its French name, Union Internationale des Chemins de fer) proposed the UIC method (UIC, 1983) for calculating capacity in line sections to identify bottlenecks. It takes into account the order of trains, and a buffer time is inserted to achieve an acceptable quality of service.

The method presented in the UIC 406 capacity leaflet (UIC 2004) carry out capacity calculations following common definitions, criteria and methodologies from international standpoint - for lines/nodes or corridors based on different criteria such as traffic quality, timetable quality or effective and economical utilization of infrastructure UIC 406(2004).

As being stated in UIC 406, railway capacity is a combination of the capacity consumption and how the capacity is utilized. It defines the parameters of capacity consumption in the "balance of capacity" (e.g. number of trains, average speed, heterogeneity and stability).Figure 1 depicts the capacity utilization and capacity consumption.

By UIC 406, the capacity consumption can be measured by compressing the timetable graphs while the capacity utilization can be measured by examining the number of trains, average speed, heterogeneity and stability. The paradox the capacity consumption exceeds 100% may occur when using the quality factor in capacity statements. However, capacity consumption above 100% is "just" that it's not possible to operate the traffic with a satisfactory or decided stability/punctuality (something about the buffer time) Alex Landex (2007).

The UIC 406 capacity method can be expounded in different ways and has been applied to some European countries.
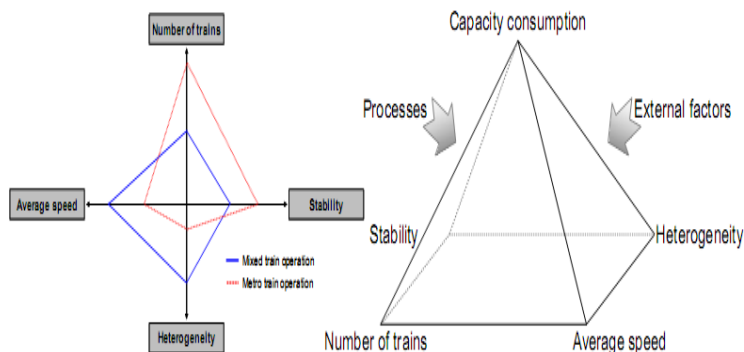
Figure 1: Railway capacity-balance of capacity to the left and the capacity pyramid to the right (Landex, A., 2008)

Table1 different view of capacity (UIC406)

Market(customer needed)	Infrastructure Planning	Timetable Planning	Operations
expected number of train paths (peak); expected mix of traffic and speed (peak); infrastructure equality need; journey times as short as possible; Translation of all short and long-term market introduced demands to reach optimized load.	expected number of train pats (average); expected mix of traffic and speed (average); expected conditions of infrastructure; Time supplements for expected disruptions maintenance strategies.	requested number of train paths; requested mix of traffic and speed; existing conditions of infrastructure; time supplements for maintenance; connecting services in station; Requests out of regular interval timetables (system times, train stops…).	actual number of trains; actual mix of traffic and speed; actual conditions of infrastructure; delays caused by operational disruptions; delays caused by missed connections; Additional capacity by time supplements not needed.

4. Basic Mind Map for CHSR Capacity Calculation and Assessment

4.1. A Predefinition for Train Service-Demand Set and the Criteria for Capacity Assessment

According to UIC 406 capacity leaflet, capacity can be viewed from the position of the market, infrastructure planning, timetable planning and operations which is summarized as Table1.

There are two main scenarios under which railway capacity should be evaluated, namely the case in which no trains has been scheduled yet (blank

diagram) and the case in which there is an existing timetable and one wants to add new paths (reserved diagram). As the large scale of CHSR network is being under construction, this paper adopts the former scenario. Under this scenario, a predefinition related to the train diagram should be proposed before the capacity calculation because the core for capacity management is timetable scheduling. Moreover, this paper calculates the capacity from the angel of timetable planning combined with market demand. At first a definition of train service-demand set is proposed as following:

The train service-demand set is composed of the trains set, of which the "service" means the designation of the trains' entering points of the railway system, dwelling (or through) platforms and leaving points of the railway system according to the connected direction of the studied railway system in its physical topology; while the "demand" means the designation of trains' type, frequencies, commercial stops as well as the mutual trains' connection from the angel of passenger market.

As analyzed above there are always a lot of factors can affect railway capacity, most of which leads to the additional consumption in the time dimension. Considering this effect and in order to embody the dynamics and uncertainty property of railway capacity, instead of focusing on the number of trains or train routes when calculating the capacity, this paper regards the minimum time occupation for completing the predefined train service – demand set in the given period and infrastructure area as the optimized criteria for capacity evaluation. At the same time, it's advised to take into account the timetable through the whole iterative process of the capacity evaluation so that the result can be proved reliable and validated.

4.2. Classification of Capacity

According to Alex Landex (2007), the CHSR capacity can be classified into three levels such as the fundamental capacity (abbreviated as FC), the practical capacity (abbreviated as PC) and the developed capacity (abbreviated as DC) illustrated as the formula:

FC= PC+ DC

Usually FC is the maximum one and achieved from theoretical analysis by analytical method under a certain punctuality level. PC is (normally) smaller than the FC and allows for restrictions in the reliability of the infrastructure, rolling stock and crew, which can either occur randomly or as planned and recurrent. Therefore, PC can adopt different values depending on the probability

of failures and it needs to be optimized. However, the practical capacity may be taken into account more management aspects of the real operation.

And there exists a trade-off between capacity and operational reliability. Moreover, the most realistic capacity is the practical capacity which should be aimed at stating. DC lies in between FC and PC.

4.3.   Methodology and Theory

4.3.1   Method

The traditional way for ECTR capacity calculation is the coefficient method, which specifies certain type of train as the benchmark, and then a conversion would be made according to the coefficient factors while considering other types of trains altogether. Of course, the coefficient method has been outdated for the CHSR.

As well as known, analytical methods, optimization and simulation are the three general methodologies for capacity management, which can also be applied to CHSR capacity calculation.

Analytical methods may be a good start for optimization methods and represent a preliminary solution. The optimization and simulation method need to be adapted to each application environment for obtaining a desired train schedule and validation. One can refer to M. Abril, (2008) for more details about these methods. On the other hand, a series of computer-based systems for capacity management have been developed and more information about these systems can be found in Barber, F. (2007).

Mathematical calculation (UIC 406) is a good method to give an overall description about the changes in the railway system. The method has good acceptance by railway generalists and experts in Sweden RailDelft (2005).

At present, though much energy has been put into the CHSR capacity study, it hasn't form a mature or perfect system at least concerning the methodology. An integrated method which embeds analytical, optimization and simulation approaches is necessary for capacity calculation and evaluation. Of course, each approach should be considered in detail according to the particular case of CHSR.

4.3.2   Theory

The theory for railway capacity refers to the blocking time, headway time as well as the buffer time. The blocking time means the time interval that one

section (usually the blocking section) of line can only be allocated to one train and block other trains to use at the same time in the fixed blocking railway system. It includes not only the physical occupation time of the line section, but also the approaching time, clearing time, route formation and release time.

The headway time means the time interval between the consecutive trains in the stations or junctions, such as the arrival-departure interval time, the departure-departure interval time, arrival-arrival interval time, and the departure-arrival interval time.

There is a close relation between the capacity calculation and the buffer time as the core for railway operation is the timetabling management, while the robustness and stability depends on the margin and distribution of the buffer time, which would in turn affect the capacity. Alex Landex suggests that fixed (time) intervals are used as quality factors for double track railway lines Alex Landex (2007).

4.4.   Decomposition and Composition of CHSR Network By Systems Engineering Method

It's difficult or even impossible sometimes not very necessary to calculate the capacity for an entire complex railway network. So it's advisable to regard the whole railway network as a complex system composed of some subsystems (such as nodes and lines) and calculate each subsystem respectively, then combine it into together by the system coordination technique considering the network effect.

4.5.   Basic Mind Map for CHSR Capacity Calculation and Assessment

Considering the above discussions, there can be several steps for the CHSR capacity calculation and evaluation.

Step 0: Predefine the train service-demand set for CHSR;

Step 1: Divide the infrastructure topology of CHSR into nodes and lines;

Step 2: Calculate the maximum node CHSR capacity and line CHSR capacity for the timetable planning by means of analytical methods;

Step3: Calculate the fundamental capacity and practical capacity for CHSR operation by means of optimization methods taking into account the number of trains, average speed, heterogeneity and stability;

Step 4: Evaluate the CRHS network capacity by means of systems engineering methods;
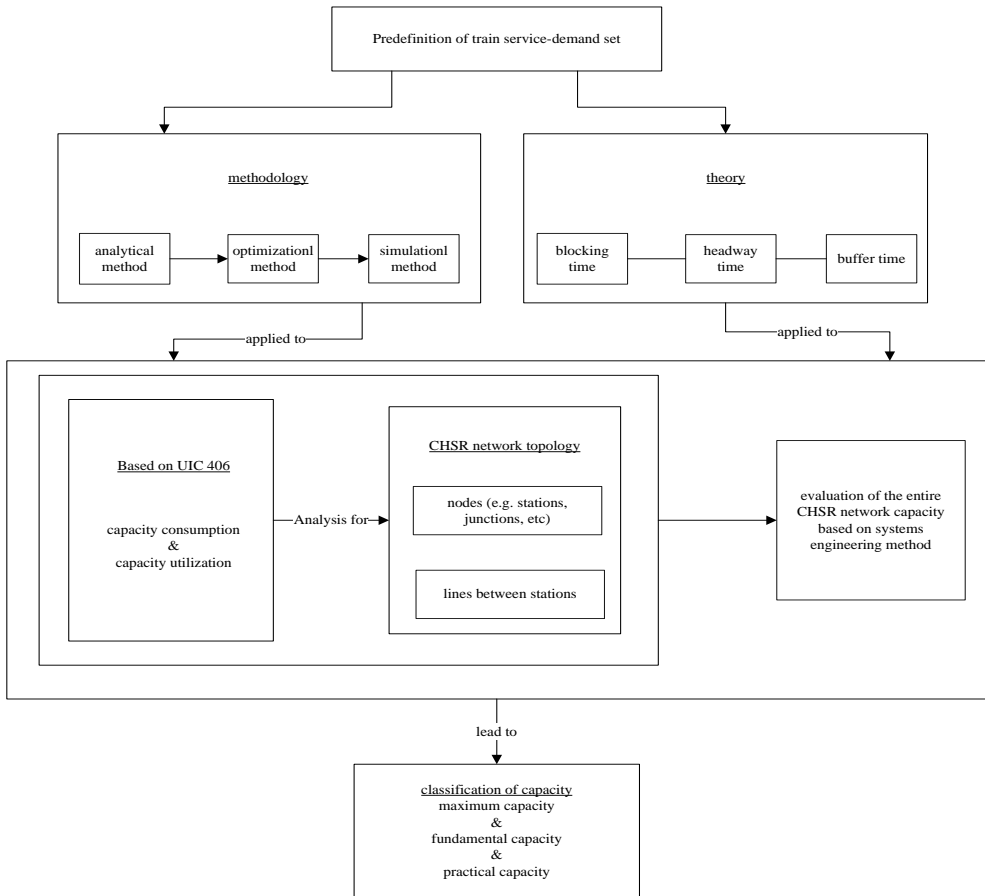

Figure 4 basic mind maps for capacity calculation and assessment of railway network

Step 5: Calibrate the relative parameters by means of simulation tools.

As a section summary, the basic mind map for CHSR capacity calculation and evaluation can be obtained and illustrated as Figure 4.

5. Calculation of Node Capacity

In the sense of physical topology, the node of the CHSR infrastructure refers to the stations (overtaking stations, terminal stations, turn stations, etc), junctions, etc.

The train operations in the node areas are always more complicated than those in the line sections, and more incline to be delayed by the constraints of bottlenecks.

Some analytical methods (such as queuing model and its extended form) have been applied on the station capacity De Kort, A.F., Heidergott, B. (1999) under the assumption of the random permutation of the train's order. However, this kind of presupposition makes it unpractical to the estimation for the propagation delay of periodical timetable. Nie lei & Hanson (1995) compares the estimated blocking time, buffer time and occupation time of tracks with the statistical analysis from the practical operation, which concludes that the train service quality would be improved greatly as long as the blocking time and buffer time in the station areas can be estimated as accurately as possible according to the real operational data. Meanwhile, some optimization methods have also been applied on the station capacity. Peter J. Zwaneveld (2001) Richard Lusby (2006) aim at maximizing the number of feasible routes through the station areas, regarding the feasible routes arrangement as weighted node packing problem solved by branch-and-bound algorithm; but once the route has been set up, the occupation time of the track sections en route can't be modified. For this problem, Xavier Delorme (2004) suggests the hybrid model solved by heuristic algorithm.

The effective route capacity depends on the mix and order of train service-traffic heterogeneity – conflicting trains routes at nodes; effective nodes capacity depends on the conflicting routes and node dwelling time which relies on the planned route connection (transfer and connection of rolling stock). All of these factors can be reflected in the predefined train service-demand set.

Considering the factors and the existed researches such as Dan Max Burkolter (2005)，this paper comes up with the idea of FTHNs & RTCG double-layer model for calculation of the CHSR node capacity based on the train service-demand set observing the following steps: at first, to simplify the physical topology of the node areas ignoring its detailed witches arrangement; secondly, assuming the capacity of each simplified sub region unlimited, to construct the tentative timetable for the train service-demand set as the aggregated level; thirdly, to check the feasibility of the tentative timetable considering the specific points arrangement of each sub region, if unfeasible, to feedback to modify the tentative timetable with additional new constraints and then check the feasibility in the sub regional level, to repeat the above processes until get the optimized time consumption for completion of the train service-demand set. In order to

improve the credibility of the calculation, the timetable is encompassed through the iterative process.

6. Calculation of Line Capacity

All of the CHSR lines are designed to be double-track. According to the UIC 406, here lines are the sections between two neighboring nodes (without overtaking or crossing possibilities), which are composed of subsections and nodes (e.g. junctions, overtaking stations, crossing stations, terminal stations, etc).

According the conclusion of M. Abril (2008), in double-track lines the capacity is affected by heterogeneity more than by train speed; while in single-track lines capacity is more affected by train speed than by heterogeneity. Usually one line can be divided into some line sections by the nodes distributed on it. Besides the factors mentioned above, other factors such as the interdependency of one line section with other line sections in the connecting node, the length of the line section, the possibility to organize overtaking within the whole line, headway time between consecutive trains, blocking time in the block section as well as the dynamics of the train operation can also affect the line capacity.

Malaspina & Reitani (1995) uses analytical method for line capacity considering the possible delay and introducing the probability priority coefficient for the combination of all types of trains Malaspina, R. (1995).

According to Joern Pachl (2002), the framework for line capacity calculation can be illustrated as figure 6.

By this, the maximum line capacity can be obtained. As for the fundamental or practical capacity, the buffer time and more real operational scenarios must be taken into account.

The UIC406 suggests different values for maximum capacity consumptions depending on the type of railway lines (such as homogeneous or heterogeneous) and time period (such as peak hour or daily period) examined on the basis of current practices among European IMs which illustrated as Table 2.
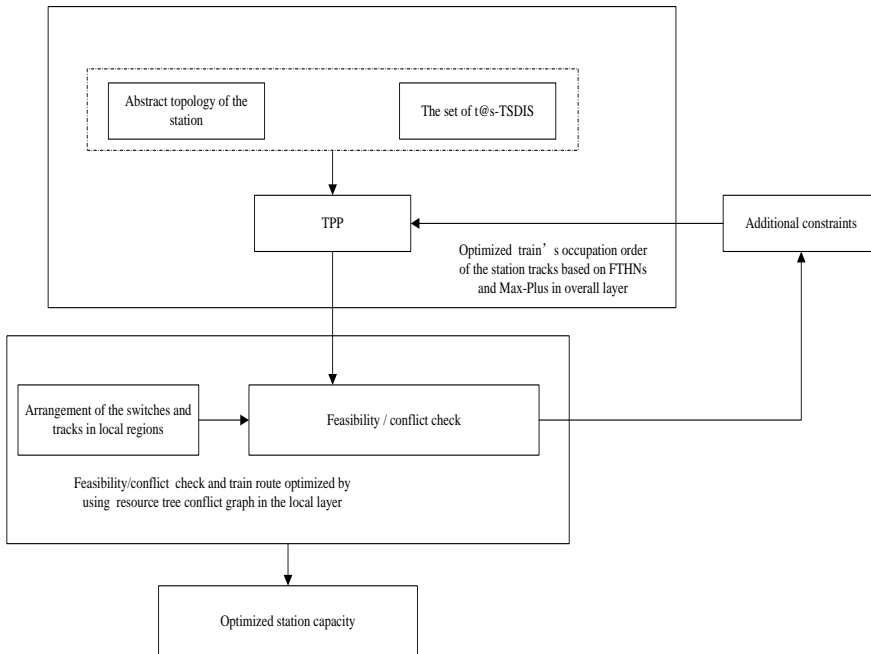
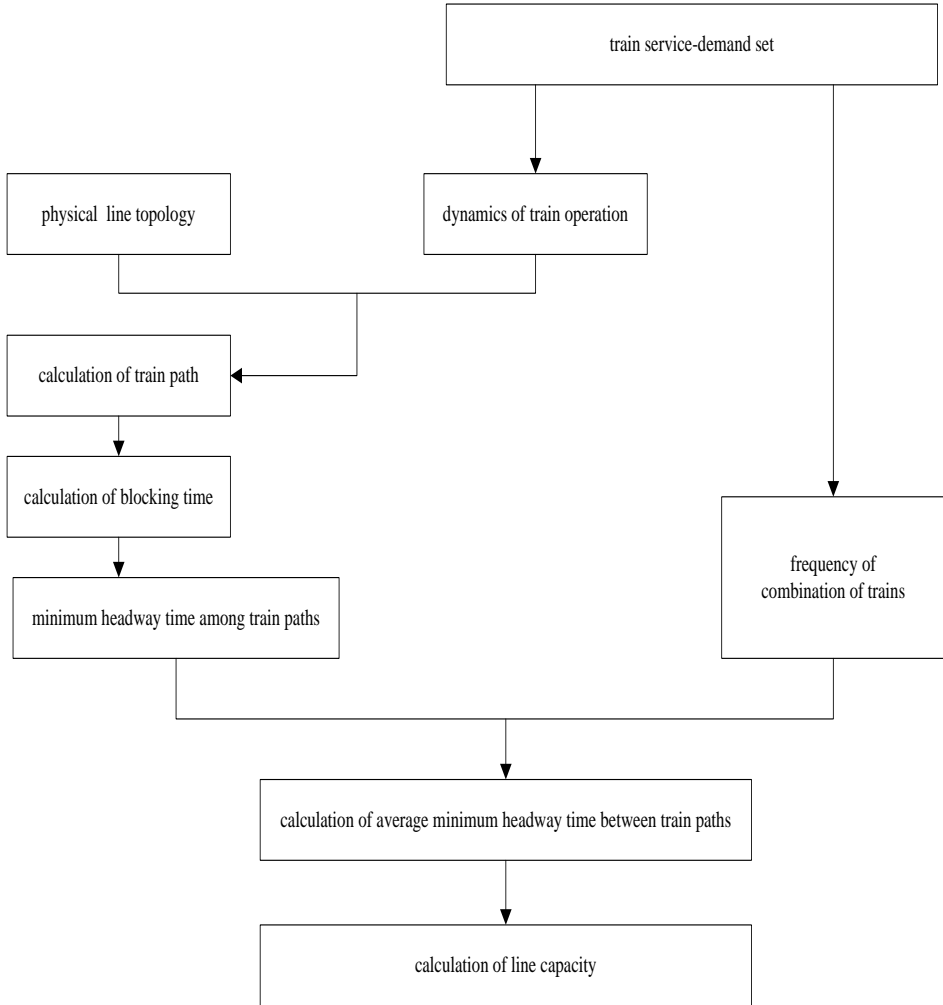Figure 5: framework for CHSR node capacity calculation

Figure 6: framework for CHSR line capacity calculation

Of course, the data in the table still needs to be modified according to the special case of CHSR. And then by optimization method and simulation tool one can obtain more optimized and visualized result.

Table 2: UIC interval for maximum capacity consumption

Type of line	Peak hour	Daily period	Comment
Dedicated suburban passenger traffic	85%	70%	The possibility to cancel some services allows for high levels of capacity utilization.
Dedicated high-speed lines	75%	60%	
Mixed-traffic lines	75%	60%	Can be higher when number of trains is low (lower than 5 per hour) with strong heterogeneity.

7. Assessment for CHSR Network Capacity Based on the Coordination of Nodes and Lines

For the whole CHSR network, the interdependency of one line with other lines in the connected node would be one of the chief factors affect the capacity. The network effect changes the capacity utilization and the train services quality such as the punctuality, because each part of the network has its own individual topology and train operation character. P. A. Farrington (1999) builds the Parametric Capacity Model which is intended to fill the void between simple empirical formulae and detailed simulation models by focusing on the capacity relationship of key plant, traffic and operating factors, and it evaluates the network capacity by predicting the train delay versus volume capacity curve.

Queuing time is generally used to illustrate the network effects for trains, regarding the difference in running time by comparing a single train on a line with a situation with many trains on the line. However, it's also widely admitted that the queuing method can't reflect the controlled random character of train service.

So as to embody the integrity, relevance, dynamics and controllability of the CHSR network fully, this paper advises to take advantage of the coordination techniques of the systems engineering theory by regarding the CHSR network composed of several subsystems (e. g. nodes and lines)as a dynamic system. Though the capacity of the network is hard to evaluate for it's the result of many factors, it might be possible to predict the future punctuality if one knows the capacity consumption of the subsystems from the historical data. It's necessary to define a coordination degree for the evaluation according to the heterogeneity, average speed, punctuality and number of trains.

8. Conclusions and Expectations

The main purpose of railway capacity calculation and assessment is to direct the practical train operation for making best use of the infrastructure. This paper builds the framework for the capacity calculation and evaluation for the developing CHSR as a guideline, which is based on the plan of operation instead of the known timetable and still needed to be validated in the future practical implementation. It's said the best method to estimate capacity is with a complete system simulation involving models of the signaling system, power supply system and train performance. So far, the relatively mature simulation tools (such as Railways and Open Track) have been developed, which may be a good choice for the CHSR capacity calculation and assessment after being made a secondary development according to the particular case of CHSR.

There should be a difference between the capacity calculation and the capacity assessment. Usually the term of capacity calculation means a kind of precision and it will obtain a precise result. While the term of capacity assessment means a kind of uncertainty and it will be closer to the operational reality, for which the dynamic factors should be taken into account. Theory stems from practice. It's important to keep track of the development in the daily capacity consumption and capacity utilization for CHSR, which means that the number of trains, the average speed, the heterogeneity and the stability should be registered as detailed as possible during the practical operation of CHSR.

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