Research on the Maximum Traffic Capacity in Wuhan Hub of Beijing-Guangzhou Railway

&

Design Solutions for City Express Train in Wuhan

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Abstract

Beijing-Guangzhou Railway extends from Beijing to Guangzhou with a total length of 2,284 kilometers. It is a north-south traffic artery of China. Wuhan Railway Hub is among the busiest and most important hubs. Therefore, researches on its maximum capacity and a good plan can promote the implementation of the Beijing-Guangzhou line planning and optimization so as to optimize the line's capacity. This project aims to study, create and apply the formula of calculating the maximum capacity on the basis of actual conditions. Thus, we can offer valuable advice to the Ministry of Railways with regard to the optimization of Beijing-Guangzhou railway.

We first conduct an operation model of Wuhan hub under a series of hypothetical conditions and explore the ideal maximum capacity. Then we examine the use of CRH EMU trains, speed-type railway passenger trains, ordinary passenger trains, fast freight trains, ordinary freight trains on the Beijing-Guangzhou railway line and explore the effect of the two signal systems LKJ and CTCS-2 on the speed and running capacity of trains. We further put forward the running plan of Wuhan Hub and some advice to improve it and work out the maximum running capacity of Wuhan Hub. We patterned the improved train diagram of Wuhan Hub after the TDCS system, using the commonly used EXCEL software in create ordinate set.

We adopt various solutions to different problems in this project. For example, we define the operating modal under the real lines condition and establish the hypothetical "later parameter" of trains of different speed and use it in the actual train diagram. We use linear programming to design different modals with the real situation into consideration, such as the co-use of CTCS-2 and TDCS signal systems, and different trains equipped with different systems. We adopt "reducing the speed" to calculate the running capacity on the basis of the operation of the 25T passenger train at the speed of 160 km/h.

With the quick development of Chinese economy, railway has become the busiest transportation. Optimizing the train diagram is one of the effective methods to improve the running capacity. According to our estimation, if the optimization is implemented, the flow of passengers can gain 6,000,000 per year, while the flow of freight 9,000,000 tons. In a word, this project is of great use in reality.

Key words: **S-Bahn**, **City-Express, Train Diagram**, **the MAX Train-handling capacity**

Ⅰ Introduction

Wuhan Railway Hub is one of the busiest and most important hubs of Beijing-Guangzhou railway. 25 miles of Beijing-Guangzhou rail line strings Zhengzhou, 52 miles in Wuhan, 10 miles in Zhuzhou [*1]. In the region covered by this railway in Wuhan, there are both Wuchang and Hankou oversize passenger transport stations as well as two top-class freight stations. According to *Medium and Long Term Plan on National Railway Network*, Wuhan Hub is on the list of the four biggest hubs across China. In Wuhan Hub, there are 139 passenger trains, 8 Baggage trains and 186 freight trains [*2] running in different speed through the extent between the west of Yangtze River and southern Wuchang in two directions. As far as the whole Beijing-Guangzhou Railway is concerned, Wuhan Hub is near being a bottleneck because of its complex lines, extremely frequent speed limiting and shunting service, which slows down the trains and as a result the logarithm of maximum of trains handled through the hub.
With our research on Wuhan Hub's largest transport capacity and making a good plan, we can effectively promote the implementation of the Beijing-Guangzhou line planning and optimization so as to release the line's capacity best. These days, Wuhan Railway Bureau was discussing for a city commuter dispatch schedule between Hankou and Wuchang with a maximum speed of 120km per hour, which requires the reasonable modifications more of the running chart. We hope this research can provide a reference for the sound use of main extent between Hankou and Wuchang Station of the existing Beijing-Guangzhou Railway by Railway Sector and municipal traffic department.

Ⅱ **Problems and assumptions in perfect conditions**

ⅰ. Problems and assumptions

a. Problems proposed

Beijing-Guangzhou railway, the existing line along Yangtze River Bridge, extends from Hankou station(1192km+445m) to Wuchang station（1211km+59m）in Wuhan railway hub with a total length of S, equal to 18.614km [*3]
Within a day (T = 24h),There are two EMU trains at the speed of 200km/h , 7.5 (counted as 8 in calculation) [*4] passenger trains at the speed of 160km/h , 18 passenger trains at the speed of 140km/h, 44 passenger trains at the speed of 120km/h ， 4 fast baggage trains at the speed of 100km/h , and 93 general freight trains at the speed of 80km/h going through this extent. In order to ensure the sound travel of the trains as well as to meet the transport needs, we propose to increase such trains as 'n' at the speed of 120km/h and 'm' trains at the speed of 80km/h .We try to work out the MAX (n, m) and then put forward a feasible plan operated in reality.

b. Assumptions on the problems

To address these problems, we make assumptions as follows (The practical situation will be discussed later):

(1) The hardware facilities in the extent permit trains to run at a speed of ∞.
(2) The length of the sidetrack in all stations of the hub is calculated as 1.2km。Whether passenger trains or freight trains, the length is calculated as 0.4km.
(3) Suppose in the extent, no trains are allowed to stop at any station. Only the ‘n’ newly added trains at a speed of 120km/h will stop at the Hanyang Station (1202km +800 m) for 0.05 hours (3 minutes).
(4) We will not, at the same time, take such things into consideration as the irregular attenuation of kinetic energy caused by stops or deceleration of trains. Additional time for starting or stopping caused by acceleration or deceleration for stops of trains should be calculated as 1/2 of the stopping time. [*5]
(5) No train exerts influence on any other ones and no malfunctions occur to any of the trains.
(6) Space between any two neighbor signalers is fixed and is 3.2km in the hub.
(7) The train diagram in this extent is non-parallel train diagram. [*6]
(8) Lhasa - Guangzhou, T263/4 Train，which travels every other day and is statistically calculated as 0.5 pairs，will be calculated as 1 pair in our paper(160 Speed Standard).
(9) The impact of Wuhan CTCS-2 and LKJ-signal systems is left out in perfect state, while it is taken into consideration in practical situations.

P.S. Physical quantities discussed in this article are uniformly stipulated as: km, km/h, h, N

c. Research ideas

First, we will study the impact of different speeds of trains on their going through, on the basis of identifying the specific numbers of train pairs; then we will make one among them as a standard, other operating models for reference and eventually a mathematical model to work out the maximum number of trains pairs within the daily train-handling capacity in this extent.

ⅱ. Method 1: Computing the maximum train-handling capacity by ‘Direct computing method’

Since trains run at different speeds, we can find get a weighted average speed of the more than 100 trains by weighting. And then we can work out the maximum train-handling capacity in this extent after a whole study and modeling. Some experts at home propose with the direct computing method. (“Railway Transport and Economy" in July 2005)

Based on the assumption above, trains are classified into six categories according to their speeds。The total number is 169+m+n as depicted in the table below.

Speed	Pairs
80	93+m

100	4
120	44+n
140	18
160	8
200	2

We are easy to get the formula as follows

$$V_{average} = \frac{80(93+m)+100*4+120(44+n)+140*18+160*8+200*2}{169+m+n}$$

On the railway, the running trains should maintain a certain distance from the ones before or after for safety. This distance is often 4 times as long as the space between each two neighboring semaphores. This distance is defined as $Lspace$ .The train itself has a certain length, which is defined as $Ltrain$.We can use the known conditions for the establishment of the whole mathematical model.

$$t_{interval} = \frac{L_{space}}{V_{average}} \qquad N_{\max} = \frac{24}{\frac{L_{space}+L_{train}}{V_{average}}}$$

$$t_{pass} = \frac{L_{train}}{V_{average}}$$

So the maximum train-handling capacity is obtained.

Evaluation on this model:

The difference in speeds of express trains and way trains when passing through $Lspace$ ignored in the calculation of average speed, thus time through the interval is variable and shorter. So the maximum capacity obtained here is larger than that in reality, which will cause an error of the result. Given that, 'Direct computing method' cannot be adopted.

ⅲ. Method 2：Original method: CHIZHI(Retardation) coefficient computing method

a. A definition of CHIZHI(Retardation) coefficient [*7]

Because non-parallel train diagram is applied in the existing Beijing-Guangzhou railway line, which means that all kinds of trains are travelling in the mixed way, so way trains are bound to make way for faster train. In addition, In order to ensure the safety of travel on the railway, we must reserve a certain space between trains. In this way, fast and slow trains will disturb each other.

In the perfect conditions, we can treat train-running as a uniform linear motion. On a certain extent of the railway, we make a passenger train at a speed of 160km/h as a model. Suppose now the trains on the line are of the same length and running at the same speed with the minimum space between each other. Here the model train at a speed of 160km/h is called the 'standard rapido'. And then, the number of the trains passing through the line can be shown in the model.

Suppose:

Speed is $V_{\max}$ Length of the train is L_{train}

Minimum space between each two neighboring trains is L_{space}

Number of trains pairs within the train-handling capacity is $N_{\max}$

$$t_{interval} = \frac{L_{space}}{V_{\max}} \quad \text{①}$$

$$t_{pass} = \frac{L_{train}}{V_{\max}} \quad \text{②}$$

$$N_{\max} = \frac{24}{t_{interval} + t_{pass}} \quad \text{③}$$

In our assumption above, there are 6 kinds of trains running in the mixed way. In the formula above, the speed of trains V is inversely proportional to t and t is inversely proportional to N. According to the linear change, N increases along with V. We are easy to conclude: Adding 'k' way trains is equivalent to add 'p' standard express train p.

In that way, we can regard the proportion of slow trains to standard express trains running on this extent as CHIZHI(Retardation) coefficient. According to our definition, CHIZHI(Retardation) coefficient can be expressed as following:

Suppose CHIZHI(Retardation) coefficient is a, the number of way trains passing by within 24h

is $N_{\max slow}$ while the number of standard express trains is $N_{\max standard}$

Easily we can obtain such formula as follows:

$$a = \frac{k}{p} = \frac{N_{\max slow}}{N_{\max standard}} \quad \text{④}$$

According to ①②③④, this equation can be simplified as:

$$a = \frac{V_{\max slow}}{V_{\max standard}}$$

b. Proof on practicability and simplicity of the CHIZHI(Retardation) c oefficient calculator

According to Ministry of Railways' current 'capacity utilization coefficient of deduction' method [*7], quoted from the former Soviet Union's regional railway system, we can easily find that max train-handling capacity calculated by this method is not the actual average maximum number of trains going through the line within a day. And in the actual calculation process, the 'capacity utilization coefficient of deduction' is only distinguished between single and double-line, without taking into account such factors as the type of trains. For the railway in Wuhan which is terribly tight and on which a wide variety of trains are traveling, it is a critical factor that needs great attentions.

'CHIZHI(Retardation) coefficient calculation method' we obtain from our summary is based on maximizing the potential of rail transportation facilities. And the calculation result is shown in the actual max train-handling capacity. Since the train-handling capacity in Wuhan hub is at peak stably in a whole day. Also we can obtain the operation style of trains in each period separately by simple calculations and modeling.

So the train-handling capacity in Wuhan hub calculated by traditional "capacity utilization coefficient of deduction" method cannot meet the actual needs. And we need to seek a new capacity calculation method which accords with the demand characteristics of Wuhan hub so as to meet demand from the transport market for dynamic train-handling capacity.

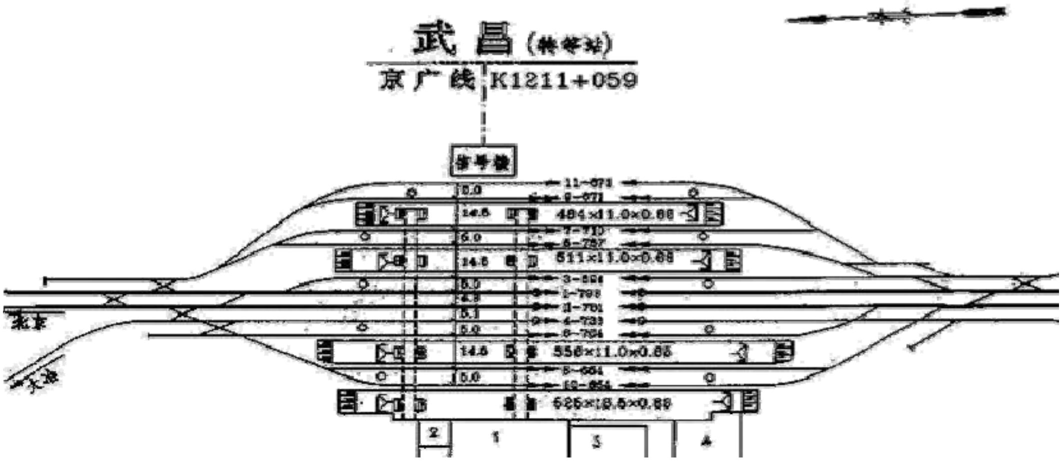
By the careful demonstration of the trains in Wuhan hub, we obtain such "CHIZHI(Retardation) coefficient calculation method". The advantage of this method is that it will turn the minimum train interval when running in existing methods of transportation into the minimum time interval of the trains. And then it will improve significantly the maximum train-handling capacity in our computation. We think there are many manufactured saturated extents when computing the maximum train-handling capacity by the exiting method. If our method is adopted, it can promote the maximum train-handling capacity under the safe conditions by making full use of the existing, non-changed hardware facilities, so as to fully ensure the passage of trains. Besides the calculation process of this method is concise, and anyone with secondary mathematical level can make it.

Ⅲ.Maximum train-handling capacity computing in physical circumstance

ⅰ. Materials prepared

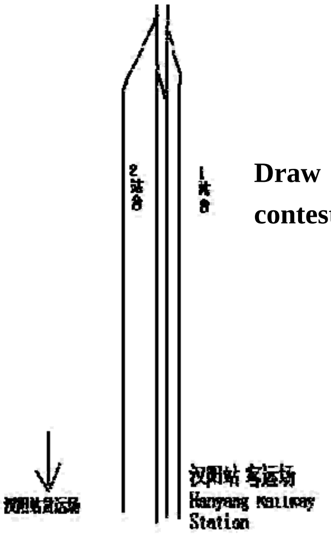
a. Wuchang Staion

Wuchang railway station is located in the Beijing-Guangzhou line 1211 kilometers away from Beijing West station. There are 11 station tracks, of which are two main railways, I Line 739m and II Line 781m. Besides there are nine station lines.



Wuchang station is a top grade passenger station where time interval between two adjacent trains at station is 6 minutes in the same direction. *8

b. Hankou station



Draw by contestants

Hankou Railway Station is a first-class passenger terminal of Wuhan railway hub, the center of which lies in Beijing-Guangzhou line K1192+445m far from Beijing. The railway station has 4 railway platforms and 11station tracks with the up main track as exterior Hankou station. *9 The station is under transformation, after which the station will add 6 railway platforms, 12 parking road of trains, and 1engine road.

c. Hanyang station

Hanyang railway station is a cargo terminal attached to Wuhan Railway Bureau, located in located in Hanyang District, Wuhan City, Hubei Province. And the center of Hanyang railway station lies in the Beijing-Guangzhou line K1208 +381 m. The railway station with 800m length and 1200m goods yard sliding has two railway platforms, two main lines (two lines in middle), and two arrival and departure sidings.

d. Intra-terminal speed limiting information [*10]

Beijing-Guangzhou railway lies in downtown and the minimum curve radius of the line is very small, so the limiting speed of the trains is lower in Wuhan hub. Then in Wuhan hub, the speed of the trains should less than or equal to the permitted speed whatever the type trains are. In this way, our calculation in reality is distinct substantially from the one in theory.

Sector start-stop laction	Allowed speed on the railway	Turnoff speed of stations	
		vertical	side direction
Jiang'an west-Hanyang1187.793-1202.8	100	100（Hankou25）	45
Hanyang-Wuchang 1202.8-1211.1	85	85	45
Wuchang-Wuchang south 1211.1-1216.353	90	90（Wuchang45）	45

After observing the speed limitation table of Wuhan Hub, we can discover allowed speed in sector of Hankou——Wuchang studied in this issue is between 85~100km/h.

e. Clerestory repairs

To ensure the its safe operation, railroad needs routine maintenance every day. During this period, the railway will stop service. And the train skylight time in Wuhan will change with the quarter scheduling requirements.

f. Slow-running point *[11]

The trains will encounter some irresistible factors during daily operation, so dispatch will allow all trains more time when drawing up train diagram. The extra time is “slow point”

In Wuhan, it will need 6-8mins more when the trains move much slower. The reason is that Wuhan is the hub linking north-south and the train coming and going frequently encounters irresistible situations in other lines. To make sure the trains run on time, always the additional operating point is set in Wuhan.

ii. Road map

Firstly, different types of trains can be boiled down to two operation models by means of grouping after knowing passenger trains schedule、the number of passen ger and freight trains passing by. Then discuss and compare the combination of operation models among different types of trains. Thereby, we can build up a ma thematical model to work out the maximum train pairs passing through in reality and optimal travel program separately.

iii. Classify by operational model

It is clear that the max speed is limited between 85km/h and 100 km/h in Wuhan hub after our analysis. But the maximum speed of passenger trains in reality is much larger than this one. Only the speed of freight trains is less than the speed limit for the lines.

Therefore we can classify all the trains based on this. In fact, the train uniformly accelerates when it pulls in and uniformly decelerates when it departures, which should be taken into our consideration in the compilation of the actual operation diagram.

At present, all freight trains are starting from Jiangan West Station or Wuchang South Station and then travel through Hankou and Wuchang stations without stopping. While all the passenger trains that go along this extent will stop at Wuchang station and travel through Hankou station. Then we can divide the movement of the freight trains in the interval into three parts approximately:

Running range	Hankou -- Wuchang	Wuchang -- Hankou

Starting from Wuchang or Hankou station←→the highest speed that the train reaches	An accelerated motion with a muzzle velocity at 25km/h and terminal velocity at 80km/h	An accelerated motion with a muzzle velocity at 45km/h and terminal velocity at 80km/h
Running normally	uniform motion with the speed of 80km/h	uniform motion with the speed of 80km/h
The train is arriving and beginning to decelerate←→going through or arriving at the station	A decelerated motion with a muzzle velocity at 80km/h and terminal velocity at 45km/h	A decelerated motion with a muzzle velocity at 80km/h and terminal velocity at 25km/h

The operation of passenger trains is similar to the freight trains, but there are some differences:

Running range	Hankou --Wuchang	Wuchang -- Hankou
Starting from Wuchang or Hankou station←→the highest speed that the train reaches	An accelerated motion with a muzzle velocity at 0km/h and terminal velocity at 100km/h	An accelerated motion with a muzzle velocity at 0km/h and terminal velocity at 85km/h
Reaching the highest speed ←→HanYang station	uniform motion with the speed of 100km/h	uniform motion with the speed of 85km/h
HanYang station←→The train is arriving and beginning to decelerate	uniform motion with the speed of 85km/h	uniform motion with the speed of 100km/h
The train is arriving and beginning to decelerate←→going through or arriving at the station	A decelerated motion with the muzzle velocity at 85km/h and terminal velocity at 0km/h	A decelerated motion with the muzzle velocity at 100km/h and terminal velocity at 0km/h

From the graphs above, we can see clearly that passenger trains and freight trains run in different ways, so we should discuss respectively. However, the up train is similar to the down train, so here we only discuss the downlink (from Hankou to Wuchang).

In the case of calculating the actual maximum number of trains going through the interval, we will not discuss new-blown trains that stop at the station of Hanyang. Regarding this kind of urban City Express Train berthing at Hanyang, there is no need for additional slow-moving point due to the tiny probability of tardiness. But the additional time generated by the frequent parking at the Hanyang station is less than the slow-moving point (see the calculation in ideal state). Therefore we can deem the actual runtime of urban City Express Train to be the same with the operation of the passenger trains.

In the actual situation, we leave out the space between the two neighboring and running trains. And we suppose the time interval is 0.1 h.

ⅳ. Operational models of trains

According to the actual situations mentioned by the above tables, we can demonstrate the operation of the trains in physical situation.

The traction engines of the freight trains generally adopt the SS6B engine produced by the factory of Zhuzhou Electric Locomotive of China Southern Railway Locomotive. The power rating is 4800KW power rating and the load capacity is 5500t.

Suppose tha the resistance in the operation of the freight trains is f , with power of P, the power of the engine is F1 at the speed of 80km/h, the power is F2 when the speed is 25km/h, the accelerated velocity is A.

$$5500\ t = 5.5 \times 10^{6}\ kg$$

$$80\ km/h = \frac{200}{9}\ m/s$$

$$25\ km/h = \frac{125}{18}\ m/s$$

The resistance is f

$$P = FV$$

$$f = F_1 = \frac{p}{V_1} = \frac{4800000}{\frac{200}{9}} = 2.16 \times 10^{5}\ N$$

$$F_2 = \frac{p}{V_2} = \frac{4800000}{\frac{125}{18}} = 6.912 \times 10^{6}\ N$$

$$F_{\text{force}} = F_2 - f = 6.696 \times 10^{6}\ N$$

$$A_{freight} = \frac{F_{\text{force}}}{M} \approx 0.82\ \mathrm{m}/s$$

The traction engines of the passenger trains generally adopt the SS8 engine produced by the factory of Zhuzhou Electric Locomotive of China Southern Railway Locomotive. The power rating is 3600KW and the carrying capacity is 1500t.

Suppose that the resistance in the operation of the passenger trains is f , it's power is P, the power of the engine is F1 at the speed of 100km/h, the power is F2 when the speed is 25km/h, the accelerated velocity is A.

$$1500\,t = 1.5 \times 10^{6}\,kg$$

$$100\,km/h = \frac{250}{9}\,m/s$$

$$25\,km/h = \frac{125}{18}\,m/s$$

The resistance is f

$$P = FV$$

$$f = F_1 = \frac{p}{V_1} = \frac{3600000}{\frac{250}{9}} = 1.296 \times 10^{5}\,N$$

$$F_2 = \frac{p}{V_2} = \frac{3600000}{\frac{125}{18}} = 5.184 \times 10^{6}\,N$$

$$F_{\text{force}} = F_2 - f = 3.888 \times 10^{6}\,N$$

$$A_{passenger} = \frac{F_{\text{orce}}}{M} = 2.592\,\text{m}/s$$

The operation model of the freight trains is built:

$$t_{\text{acceleration}} = t_{\text{deceleration}} = \frac{v - v_0}{a} = \frac{55}{0.82} \approx 67\text{s}$$

$$S_{\text{acceleration}} = \bar{v}\text{t} = \frac{105}{2} \times 67 = 3517.5\text{m} = 3.5175km$$

$$S_{\text{uniform}} = 18.614 - 3.5175 \times 2 = 11.579km$$

Then we can calculate the runtime of the through freight train in the interval:

$$T = 2t_{\text{acceleration}} + \frac{S_{\text{uniform}}}{V} \approx 0.164h$$

If we take into account the slow-moving point, the actual runtime of the train: $T_{freight}$=0.164+0.12=0.284h

The operation model of the passenger trains :

$$t_{\text{acceleration}} = t_{\text{deceleration}} = \frac{v - v_0}{a} = \frac{75}{2.592} \approx 29\text{s}$$

$$S_{\text{acceleration}} = \bar{v}\text{t} = \frac{125}{2} \times 29 = 1812.5\text{m} = 1.8125km$$

$$S_{\text{uniform}} = 18.614 - 1.8125 \times 2 = 14.989km$$

Then we can calculate the runtime of the through passenger train along this extent :

$$T = 2t_{\text{acceleration}} + \frac{S_{\text{uniform}}}{V} \approx 0.112h$$

If we take into account the slow-moving point, the actual runtime of the train: $T_{passenger}$=0.112+0.12=0.224h.

Ⅴ. Influence of signal system on maximum of train pairs within the daily train-handling capacity

There are two control methods for Wu han Hub of Beijing-Guangzhou railway line, which are called LKJ2000 model for the running of traditional locomotive and CTCS-2 model. LKJ2000 model is installed on traditional passenger trains, at a speed of 80km/h , 100 km/h ,120 km/h ,140 km/h and 160 km/h , while both LKJ2000 and CTCS-2 are installed on CRH EMU at a speed of 200 km/h .

LKJ2000 relies largely on the reasonable adjustment on the line parameter of IC card that exist both in radio communication with 450 MHz and running controller for vehicles, while as for CTCS-2, we control trains by the communication between Analog Carrier circuit on the railway and running control center.

Compared with the earlier developed LKJ2000 system, the block manner---containing an artificial distance set between trains to ensure security that adopted in CTCS-2 system is called Quasi-Moving Block Control Mode. An appropriate safe distance is left to the start end of block division occupied by the pre-trip train which is related to the target point that tracked by Move Block, while the across high-speed train from the beginning point of a braking curve calculation is based on target distance, target speed and the train's own performance computing decisions. The trains in the same block division do not affected by the first trains running in the front, however, the train’s emergency brake on their own starting point with the line parameters and the performance of the train itself, varies .Due to distinguish with the moving block and the

space interval length is not fixed, we call it as quasi-moving block. Obviously the track running intervals is smaller than the fixed occlusion's that used by LKJ2000 system. [*12]
However, in the practical application of EMU, Carrier Division has become increasingly complicated compared with the original insulated rail joints, since the number of motor train unit accounts for only 1% of the volume of traffic through the whole day, and people generally adopts ultra-long seamless rails in the Wuhan area. Furthermore, because of the adoption of rail carrier, Carrier Division could be easily misused so that error codes are made which may pose serious threats to road safety. In particular, the error will more easily lead to false-control thus affecting the traffic safety performance on account of the complex electromagnetic environment in the city of Wuhan. Besides, the dispatching center of Wuhan Railway Bureau adopts a unified model to control trains so that the workload of the railway sector can be reduced. Unfortunately, after our estimation, there is extra capacity for only one CRH if it's arranged separately.
The above-mentioned speed limit is almost under 100km/h in the hub of Wuhan, so that the actual running time interval would not be substantial increase in. But CTCS-2 system can be manually shut down and we can run the LKJ2000 Operation Monitoring System with highest speed limit of 160km/h under the CRH EMU's "part of the monitoring model".
Therefore all the trains in Wuhan hub will focus on using the same operation way, so that the operation cost will be reduced, and the safety factor will increase without affecting the maximum capacity.

ⅵ. Maximum of train pairs within the daily train-handling capacity in physical circumstance by the method of CHIZHI(Retardation) Coefficient Calculator

In the motion model above of the passenger and freight trains, we have worked out the actual traveling hours along this extent. Then we can show the traveling speed under the actual circumstances based on the practical running hours. Thus, we can work out the train pairs of these two types with the help of the method of CHIZHI(Retardation) coefficient calculator mentioned above.
According to the ① ② ③ in Ⅱ.3, we can describe the daily maximum capacity in real situations:
Suppose that the speed of train is $V_{\max}$, the length of train is L_{length} and Number of train pairs within the train-handling capacity is $N_{\max}$

$$t_{interval}=\frac{L_{space}}{V_{\max}}\cdots\cdots\cdots\cdots\cdots\cdots \quad ①$$

$$t_{pass}=\frac{L_{length}}{V_{\max}}\cdots\cdots\cdots\cdots\cdots\cdots \quad ②$$

$$N_{\max}=\frac{24}{t_{interval}+t_{pass}}\cdots\cdots\cdots\cdots\cdots\cdots$$

③

We can come to the conclusion easily that

Suppose that total train-handling capacity is $\sum N$, maximum number of passenger trains within this capacity is $N_{passenger\max}$, maximum number of passenger trains within this capacity is $N_{freight}$.

Here the CHIZHI(Retardation) coefficient is $a_{freight}$

$$[N_{passenger}]_{\max} = \frac{24}{\frac{0.4}{\frac{18.614}{0.224}} + 0.1} = 228$$

$$a_{freight} = \frac{v_{freight}}{v_{passenger}} = \frac{t_{freight}}{t_{passenger}} = \frac{0.284}{0.224} = \frac{71}{56}$$

So we can obtain an indefinite equation

$$\sum N = N_{passenger} - \frac{1}{a_{freight}} N_{freight}$$

Easily it can be simplified as

$$\sum N = 226 - \frac{56}{71} N_{freight}$$

$$71(N_{freight} + N_{passenger}) + 56N_{freight} = 16046 \qquad N_{freight},\ N_{passenger} \in Z$$

Here are these integral solutions:

$N_{passenger} = 226$ $\qquad N_{freight} = 0$

$N_{passenger} = 224$ $\qquad N_{freight} = 1$

……

$N_{passenger} = 81$ $\qquad N_{freight} = 81$

Judging from our calculations, we can draw a conclusion that the maximum pair within the daily train-handling capacity in reality is 226.

Ⅳ Design solutions for City Express Train in Wuhan

ⅰ. An introductory survey

We have examined the maximum train-handling capacity per day in the ideal and physical situations in Wuhan hub of Beijing-Guangzhou railway. Capacity in reality is slightly smaller than in theory.

However, we should notice that the speed in practice environment is far smaller than what we have set in the theory. According to the Linear Changes Theory, speed and traffic capacity was positively correlated in the formula of hysteresis coefficient. The number of passed trains will be far smaller than that in the theory. But from our final conclusions, we find that the daily maximum capacity of Wuhan hub is 20 trains or so less than that in theory.

Why? In fact, as the actual train speed is only classified into two levels, this is far fewer than that in ideal situation with six levels. But the daily capacity in the real situation can be maximized when there are only passenger trains running on the lines ($N_{passenger}$ = 226 and $N_{freight}$ =0).Therefore, City City Express Train should be categorized to the same speed level so that the line can achieve the maximized utilization.

ⅱ. Social factors in consideration

a. Demand from city commuter

Wuhan city is divided into three parts- Hankou Hanyang and Wuchang by the Yangtze River and Han River. The pressure on cross-river traffic has been a bottleneck in the city of Wuhan. The Yangtze River Bridge (road section)、Yangtze River Tunnel and The Second Yangtze River Bridge are congested and overloaded every day.

Rapid development of the city boomed strong cross-river traffic demand. In June 1995, before the Second Bridge over the Yangtze River is open to traffic, the number of cars traveling across the Yangtze River Bridge per day is about 75,000, rising to reach 270,000 in 2007, with an average annual growth rate of 12%.

Statistics show that the proportion of the traffics across the Yangtze River to the total of vehicles maintains 1:2 for a long-term. 80% of traffic crossing the river is concentrated on the central city bridge. The Central area of the bridge is overloaded while the external bridge has not yet saturated.

According to the survey of passengers across the river in 2007, about 100 million passengers traveled cross the Yangtze River per day, the number of passengers by ferry is no more than 3 million per day and the number of passengers by bus is about 65 million, the rest 32 million passengers crossed the river in companies', communities' cars or in private cars. The vehicles traveling across the Yangtze River Bridge and the Second Yangtze River Bridge traffic are mainly cars, the proportion of which accounting for about 90%. From the purpose of the cars to cross the river, about 35% of people are on work shift or on business in working days; about 30% of people are shopping, visiting friends or entertaining. People usually go to work between7 o'clock and 9 o'clock and they go shopping or have entertainment between 6 and 9 pm. The traffic flow reach its highest level of a day at about 7 pm because it' the time for people to go off the work, go shopping and entertaining. In the weekends, people on work shift accounts for 13%; people on business accounts for 15% and the people shopping or entertaining accounts for the rest 72%. [*13]

Based on this aspect, the Director General of Wuhan Railway Bureau, Yu Zhuomin said in an interview that "bus trains"- urban City Express Train, will be started between the Wuchang and the Hankou station.

From the data above, the traffic pressure mainly lies between 7 and 9 am and 6 and 9 pm. So we believe that the number of inter-city trains should be increased in these two periods.

b. Demand from transit

As one of the four railway junction cities, Wuhan has the biggest number of starting trains in the central area of china. There are few trains starting from the Provinces such as Hunan, Jiangxi, Guangdong and Fujian to the North areas, so the corresponding ticks are scarce. Furthermore the trains speed is very slow and the trains are not so comfortable, so the contradiction of supply and demand is salient. The starting trains from Wuhan where road bureau is located are plenty, the speed is faster and there are more ticks allocated. Many tourists take Wuhan as their transit city when they travel from the north to south or from the south to north.

Currently, owing to the division of tasks for the junctions, Wuchang Station is mainly responsible for trains traveling to the south or passing by mainly while Hankou Station is mainly responsible for dispatching trains to the north. The tourists have to travel by bus between these two stations sometimes. It is not convenient for the travelers and it also increases the city's traffic pressure.

When the inter-city trains are open to traffic, it will become more convenient for travelers to transit and strengthen the role of Wuhan as a railway hub. It will improve the utilization of the trains without increasing any other pressure.

In addition, it will be convenient for people from other cities of Hubei Province to transit in Wuhan. People from the south of Hubei usually arrive at Wuhan at the Hongji or Hanghai Passenger Transport Station which are near to Wuchang Station. If they want to travel to the south of china, they have to go to Hankou Station by bus with their heavy baggage. If they can take inter-city trains, it will be convenient.

c. Demand from railway workers on/off duty

At present, there are about one hundred thousand railway workers in Wuhan. About 20% of them have to travel across the Yangtze River for work, most of which are the front-line workers such as the passenger section workers, the locomotive depot workers and the former workers in Wuchang south station. If the Wuhan Station starts the inter-city trains, it will work with the existing of the Heliu – Liufang and the He'an – South Wuhan City Express Train. Thus it can be beneficial for the stability and development of the stations' staff itself and relieve their pressure from the commute.

ⅲ. An initial actual train diagram [*14]

Train diagram is to demonstrate the train operation with the help of coordinate principal in graph.

Based on this definition, we think on a planar coordinate system. In this approximate S-T coordinate system, we show the train track in the images of piecewise function. That means we add a macro in the Microsoft Excel program and form a function by imputing the coordinate, thus the train track in reality is depicted in the functions.

We come up with the train diagram (during 8 am to 8 pm) of up track of Wuchang

–Hankou extent in Wuhan hub on Beijing-GuangZhou railway. This plan takes full accounts of the balance among the existing trains、the new opened trains and the freight trains. More freight trains can run in the mid-day when the bridge is not crowed. More City Express Train should be on running in the rush hours. (To see the details in Appendix 1: *Train Diagram of the inter-city trains.xls*)

We cannot achieve the curve fitting function of the train diagram because of our skill limitations. So we cannot show the train tracks when the trains stop at Hanyang Station. Though the operation can be improved by hand sketching, it's a pity that we cannot finish it due to the limitations of print and scan.

In the train diagram, inter-city City Express Train' number begins with CS and the freight trains' number begins with H.

ⅳ. Suggestions on city trains

With regard to the application of the inter-city trains, we propose withthe SS9G, SS7E, DF11G speed locomotives in the Wuchang south locomotive terminal of the Wuhan railway station, and the HXD3 mixed traffic express locomotive in the Jiang'an west locomotive depot. These types of locomotives are featured with high power rating, high toggle speed, steady continuous operation, low energy consumption and small carbon emissions.

We can share the railway carriages with such existing trains as the Wuchang-Shenzheng T95、T67、T175(25K), Wuchang-Hangzhou Z45(25T), Wuchang-NingboZ31(25T) and Wuchang-East LianYungang 2614（22、25B mixed. In this way, we can not only promote significantly the utilization rate of carriages but also cut cost.

The other trains can be combined according to the mixed marshalling prepared by the Wuchang passenger train depot of Wuhan Railway Bureau, 25G (AC380V Power support system) and the 25T（Power support system DC600V. It is necessary that the mixed unit trains should adopt the same power support system and it is better for a small marshalling of 6-8 carriages to operate, the running chart of which can be obtained with reference to our standard one with 16 carriages.

We sincerely hope that our paper can bring some useful ideas to the railway administration and contribute a little to the economic and social development of Wuhan. Also we hope Wuhan hub of Beijing-Guangzhou railway (the extent in our discussion) could be fully utilized. We wish the city trains will travel in Wuhan as soon as possible.

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Ⅶ Appendix and note

1. From *http://www.tieliu.com.cn.*
2. *Zhengzhou Railway Bureau Statistics Yearbook*，2007.
3. *National Railway Timetable*: People's Railway Press, 2008.
4. Lhasa——Guangzhou T263/4 starts every the other day, so it is counted as 0.5 pair
5. *Regulations on the Management of Railway Technology: Chapter 2*, 1984.
6. Unparallel Routes refers to railway routes where trains run on the same route at different speeds.
7. Based on *Capacity calculation of Railway Section*, 1984.
8. Station interval refers to the minimum。。。
9. This conclusion is based on the participants' observation. There may be some errors. During the transformation of Hankou station, the stop line outside the station may have been canceled.
10. From http://www.whrailway.cn/
11. There may be a one-minute error with the slow point.
12. From *Occlusion and Train Control Overview,* delivered by **Bo Shishan**, Beijing Railway Communication Signal Research Institute, 2008.
13. Cited from *Cross-river Traffic Studies of Wuhan*, delivered by City Comprehensive Transportation Planning and Design Institute of Wuhan, 2003.
14. From www.hasea.com. Designed by **Chen Zhou**, Xi'an Jiaotong University, 2007.

Ⅷ An brief introduction to contestants

Chi Hao

Chi Hao, was born in October, 1993, in Wuhan, Hubei Province. He is now studying in Hubei Wuchang Experimental High School, a well-known key high school of the province. He is very innovative and is endowed with comprehensive practical ability and much talent at railway transport and social investigations. Also Chi Hao is keen on traveling, photographing and writing in his spare time.

He in intensively interested in mathematics and has won prizes in such national math invitation contests as "Innovation Cup", "Hope Cup". He usually ranks top in math examinations at school and came out first in the Entrance Examination of Mathematics to High school. In particular, he is excellent at solving practical problems by mathematical methods. More, he teaches himself mathematical modeling.

Furthermore, he has greater enthusiasm for the unknown and challenges. He usually tries his best to contemplate, practice until the final resolution comes out.

He is also the key member of the “train fans” community. He had been reported by the "Chutian Daily", "Wuhan Evening Newspaper" and his reports about railway had been published in "Guangming Daily", "Market News", "Chutian Metropolis Daily".

He is always keeping an eye on social problems. In 2007, he went to Guangzhou for investigation and wrote the report *Make the Journey Home More Harmonious.* In 2008, he traveled all the way to Shanghai, Hangzhou, Zhengzhou and Suizhou for an investigation and wrote the report *Rain or shine, big love counterparts*. Both of these two investigations have been awarded first prize, which wins him awarding marks in the entrance examination to high school. Chi Hao has also been highly praised by leaders in Hubei province and Wuhan Railway Bureau, experts in Wuhan University for these investigation reports.

In addition, he is experienced in social practice, and has ever worked as a trainee in Hubei Radio, Hubei Daily Media Group, and other news media. Thus lots of useful experience is obtained from these experiences.

He often reads newspapers such as *21ST Century Business Herald*" " *Caijing Magazine*" serious newspapers or magazines as *South Weekend*, *South Window* and other mathematical journals as *science garden*, from which he benefits a lot.