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Modeling for Operating Expenses and Time Consumption of High-Speed Railway (HSR)

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Abstract

Transportation plays a significant role in each country's economy and it is critically important to ensure its dynamic harmonious development. Operating expenses and time consumption are important indicators for planning vertical profile of high-speed railway line. The paper presents two models: i) first estimates the effect of stations spacing on operating expenses, and ii) second measures the effect of maximum gradient on time consumption. In this regard, six standard vertical profiles of high-speed railway line have been studied. The results show that operating expenses model is a third-degree function of station spacing, whereas time consumption model is a quadratic function of maximum gradient. Furthermore, it is determined that station spacing has great impact on operating expenses and time consumption of HSR.

Keywords: operating expenses, time consumption, high-speed railway, vertical profile, station spacing

1. Introduction

In the last decade, the world has cherished the rapid development of high-speed railway (HSR). Recent HSR infrastructure is the result of specialized development techniques in this domain,

which results into the expanded the passenger traffic system (Gong, 2010). The passenger high-speed train operates significantly faster (300 km/h) than the normal speed (120 km/h) of rail traffic and has great attraction for passengers (International Union of Railways, 2015). The European Union pays a special consideration for the railway transport development to minimize the undesirable (traffic jams, damage to the environment, noise, accidents) influence of dominating factors in transportation network (Vytautas and Gintaras, 2014). According to the definitions of the European Union, high-speed railway refers to the transformed railway tracks whose operating speed should be 200 km/h or more and the new specialized railway tracks whose operating speed can be 250 km/h or more (International Union of Railways, 2015). The social and economic benefits are one of the important attributes of high-speed railways beside many others like, high-speed, large passing capacity, high efficiency and less pollution. Many studies on efficient energy management have been carried out in metro and rail transit systems (Ennio and Pierluigi, 2014; Ashiya and Yasuda, 1994). The reduction of energy consumption is also seen as one of the key objectives for the development of sustainable mobility by use of HSR. The completion of a HSR project will lead to a huge increase in electricity consumption in spite of the comparatively lower mean energy consumption per passenger kilometer for normal train (High-Level Group, 1995). Moreover, a HSR project requires a very heavy investment for a country mainly due to the cost of civil works. Therefore, high investment must be balanced by a shorter trip time and lower energy consumption.

In recent years, more than ten countries in the world have built HSR, including Spain, Japan, Germany, France, China, and the United States (International Union of Railways, 2015/UIC). The taskforce of high-speed of UIC's wants to reflect this variety of explanation by considering

HSR from many views, such as infrastructure, rolling stock and operations. Nevertheless, HSR is a combination of all the elements that constitute the “system” (Aur lie 2011):

1. Infrastructure: new dedicated lines designed for speeds above 250 km/h; upgraded normal lines, which enable trains to operate up to 200 or even 220 km/h.
2. Rolling stock and operating conditions: special trains that differ from normal rolling stock with an increased power/weight ratio and several characteristics such as aerodynamics, reliability, safety.

Due to the constraints in train routes and other economic and technical reasons, high-speed trains cannot provide the “door to door” service for passenger, so that the passenger distribution of high-speed railway station must be completed by means of urban traffic system. Thus, high-speed railway station is also one joint point between urban external communication and intra-city traffic system, where is the change place of traffic modes and transport properties. The aim of high-speed railway station location is to control trip time of passengers, and reduce the pressure of urban road traffic network and improve transportation energy efficiency (Xiang et al., 2010).

In this context a technique for calculation of time consumption and operating expenses, derived by Wang D. and Wang D.S. (2000), is in the form of mathematical models and graphs. They expected that the theoretical idea and the main procedures could be applied for HSR. Their work was done in cooperation with engineers of the Third Design Institute of Chinese Railway Ministry and was proved satisfactory in practical designs for normal speed railways. By referring to several vertical profiles of railway lines, Wang D. and Wang D.S. (2000) have also suggested six standard vertical profiles between passing sidings or intermediate stops. In this paper, the authors have applied their technique to HSR. It is concluded that when station spacing is small like in mountain areas, operating expenses will be small and time consumption will be larger,

and vice versa.

2. Literature Review

Station is the basic unit of railway transportation, integrating technical equipment relating to transportation. Various passenger traffic service and goods traffic services, such as passengers' boarding and alighting, consignment, loading and unloading etc., can only be gathered at the stations. Various technical operations of railway transportation are all conducted at the stations. Investment on station construction takes up a great part from the total investment of railway construction project. From the view of social economy, a reasonable location of high-speed railway station can significantly reduce the average trip cost of passengers, which is helpful for the growth of social wealth. Reducing time consumption is an important reason for introducing high-speed train (HST) services, e.g. the opening of the Wuhan-Guangzhou, China reduced travel time from ten hours to three hours 16 minutes, (Hang 2011). The ability of HST to reduce travel time is determined by the average speed it achieves, which is affected mainly by the number of stops and the different speed variations along the route. Therefore, HST that has a high maximum operating speed might still achieve a relatively low average speed and limited travel timesaving (Hang, 2011). HSR considers as the main development of international railways transport because of its various advantages. These advantages have obtained more and more recognition by governments and the community around the world (Qiu et al., 2009). Since long access journey to the HST station might cancel the timesaving's the HST service offers, there is an incentive to provide more than one station per city. Yet, more stations/stops mean a lower average speed and thus a trade-off must be made. Large metropolitan cities that are polycentric in nature can justify more than one HST station, e.g. Tokyo has three stations on the Tokaido line (Tokyo, Shinagawa and Shin-Yokohama), which might not generate enough demand to justify the reduction in average speed and the longer travel time (Hang, 2011). A fuzzy control model, proposed by (Hwang, 1998), determines an economical running pattern for a high-speed railway through an optimal compromise between trip time and energy consumption. The simulation results showed that the number of rules identified by the proposed method is smaller without any loss of model accuracy. Levinson et al. (1997) examined the full costs of a HSR system proposed for a corridor connecting Los Angeles and San Francisco in California, USA. The aggregate costs include infrastructure, fleet capital and operating expenses, the time users spend on the system, and the social costs of externalities, such as noise, pollution, and accidents. They found that total travel between the two metropolis would likely increase very little, since the time and cost savings of even non-stop HSR against the existing frequent air service from the three Bay area and five Los Angeles airports are minimal in the United States. Coto-Millán et al. (2011) applied benefit-cost analysis technique to determine the minimum level of demand that makes a HSR project economically viable in Spain. The results showed that the HSR is socially profitable from a traffic volume of 6.5 million passengers and for a social discount rate of 4%. Gong (2010) studied the reasonable scope of station distribution layout and station spacing for high-speed railway in China under different influential factors and conditions

like travel speed, passing capacity and transportation organizational modes. He found that setting the stations in full accordance with the needs of passenger traffic will worsen the passing capacity, the number of running train and travel speed that will caused in more time consumption.

Zeng et al. (2013) introduced variable of comfort levels to calculate the generalized value of travel time. A pricing model, which is based on the value of travel time and bi-level programming, presented to maximize the benefit of the railway agencies and the passengers' utility. Model considered the passenger's mode choice behavior with different income levels. They found that using the model by actual survey and pricing is more acceptable compared with the pricing method in the current condition. Through the actual investigation, the price got by model based on value of travel time and bi-level programming was more reasonable than the existing price. Travel time reliability is a fundamental factor in travel behavior. It represents the temporal uncertainty experienced by travelers in their movement between any two nodes in a network. The importance of the time reliability depends on the penalties incurred by the travelers. Carrion and Levinson (2012) presented a systematic review of the current state of research in travel time reliability, and more explicitly in the value of travel time reliability. To increase the overall benefits of the HST (and decrease its negative effects), it should serve many cities and include many stops, but more stations on an HST line lead to a lower average speed and thus to lower capacity on the route and a longer travel time (Hang, 2011). Recently, Abid and Khan (2015) proposed a MILP model to find the position of stations with sidings on the railway network to minimize the conflict delays.

Various researchers present different social and economic effects of transport projects (Lingaitis, 2009; Robert and Daniel, 2012). Summarizing the authors' suggestions, the passenger transport system's modernization effects can be grouped into the effects of transport systems changes and the effects of social economic changes that measure the interests of passengers, transport companies, regions and countries. The evaluation indicators proposed the following points: the change of travelling time, the changes of technological costs of passenger transport, the changes of traffic and ecological safety, the changes of comfort level, and the changes of a company's cohesion and economic development. According to the experts, one of the most important indicators of passenger transport's economic social efficiency is the value of travel timesaving. 30 to 80 percent of the overall transport project benefit is thought to come from the reduced traveling time during which a passenger does not participate in the formation process of added value (Vytautas and Gintaras, 2014).

3. Research Methodology

In the case of the general route of the railway line is selected, the detailed plan and profile has been not designed, and the type of the motorcar and line standards has not decided yet, the evaluation of operating expenses (E) cannot be prepared by means of conventional methods. Table1 presents the notations used in this paper. Mathematic modeling is an effective approach to optimize the technical controlling factors in planning stage, both for operating expenses and for investment costs. Rational evaluating models of operation expenses are not only valuable in

planning and design stages but also useful for examining the efficiency of existing railways (Yi and He, 2009). In the framework, a method for the calculation of operating expenses and time consumption are derived from Wang and Wang (2000) in the form of mathematical models and graphs. By comparing the large volume of design data, authors found that the vertical profiles between passing sidings or intermediate stops could be classified into six types of simulated designs, mentioned as vertical profiles I, II, III, IV, V and VI (see Figure 1).

Operating expenses modeling has implemented the earlier discussed methodology of normal speed railway for modeling operating expense (E) to high-speed railways. Figure 2 shows the graph for calculating operating expenses of profiles I, II and III. Figure 3 shows the graph for calculating operating expenses of profiles IV, V and VI. Time Consumption Modeling has also adopted a methodology that implies using previously mentioned six types of vertical profiles. We have calculated the maximum gradient values with different maximum speed on HSR, besides getting the value of time consumption.

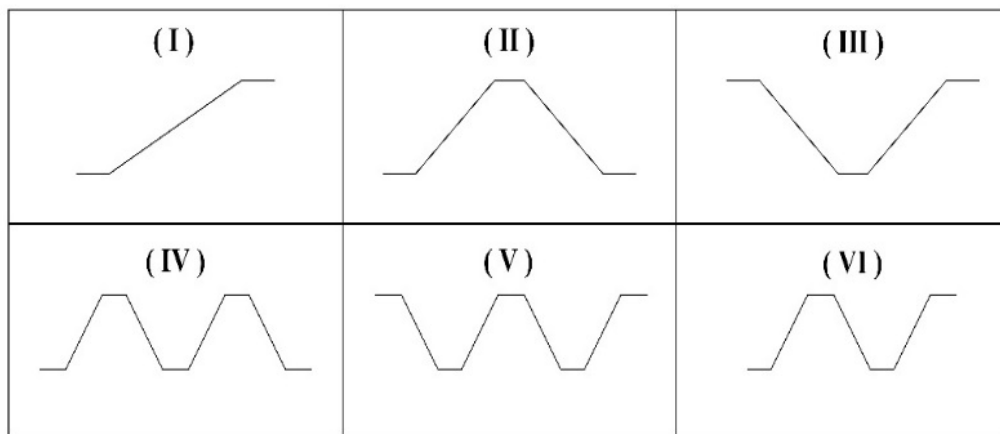


Figure 1: Six types of vertical profiles of high-speed railway

Table 1: Table of Notation

| | |
|-----------|---|
| D | Station spacing (km) |
| λ | Inequality factor of traffic volume in the |
| E | Operating expenses (¥) |
| ¥ | RMB (Chinese Currency) |
| G | Ruling grade ‰ |
| α | Factor of utilization of ruling grade |
| R^2 | coefficient of determination |
| $f(D)$ | Function of station spacing |
| i_{max} | Maximum gradient of slope (‰) |
| P_k | Required power per ton (kW/t) |
| V_{max} | Maximum speed of train (km/h). |
| g | Gravity acceleration ($g = 10 \text{ m/s}^2$). |
| W_0 | Basic resistance of maximum speed of running |
| CRH- EMU | China railway high-speed – electrical motor train |

| | |
|-----------|---|
| $T_{A/B}$ | Time consumption of train running between station |
| t_s | Extra time consumption for starting a train (min) |
| t_p | Extra time consumption for parking a train (min) |
| L_i | Horizontal length of slope (km) |
| t_i | Time consumption per kilometer for a train on a |
| V_i | Balancing speed (km/h) |
| D | Braking distance (m) |
| V | Speed of the train (km/h) |
| a | Deceleration of the train(m/s^2) |
| t | Time consumption (min) |

3.1 Operating Expenses Modeling

3.1.1 Assumptions for study

- (1) It is assumed that the distance between two stations is variable: $D = 30, 40, 50, 60$ km, and this distance will divide for each slope section as shown later in each profile, Figures 4, 5, 6, 7, 8, 9.
- (2) Ruling grade of the vertical profile of high-speed railway line is constant: $G = 9\%$
- (3) Utilization factor of ruling grade (α) is calculated by dividing the horizontal distance of ruling grade on the total station spacing for each profile.
- (4) Inequality factor of traffic volume in the two directions (λ). In this research it is assumed that the traffic volume is equal in both directions hence ($\lambda=1$).

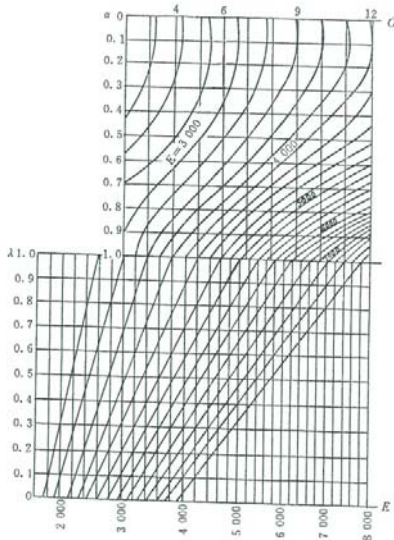


Figure 2: Operating expenses graph for profiles I, II and III

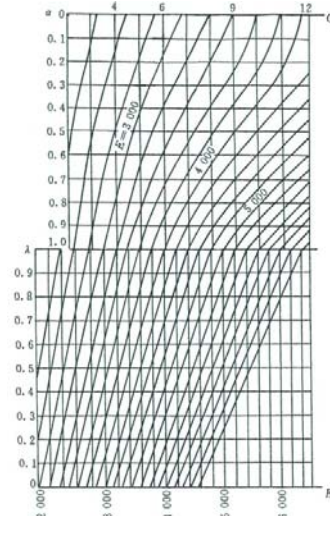


Figure 3: Operating expenses graph for profiles IV, V and VI

3.1.2. Illustration Example for Profile I

When station spacing: $D = 30$ km, then ($G = 9\%$, $\alpha = 27/30 = 0.9$, $\lambda = 1$), therefore the operating expenses can be calculated as follows: the intersection point of ($G = 9\%$, $\alpha = 0.9$) is located on the sub-curve $E = \text{¥}5600$. By tracing along the sub-curve line downward until reaching the abscissa line ($\lambda = 1$), the graph will give the value of the operating expenses (E): $E = \text{¥}5600$.

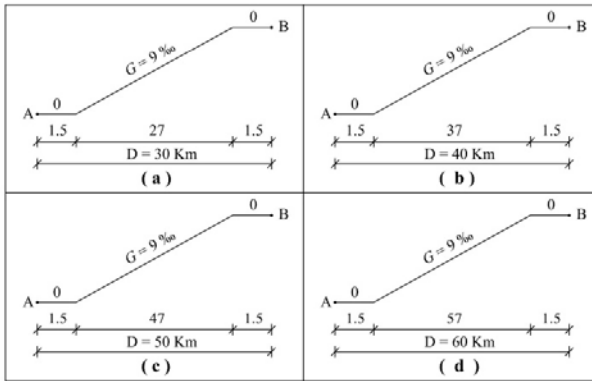


Figure 4: Vertical Profile I with different station spacing

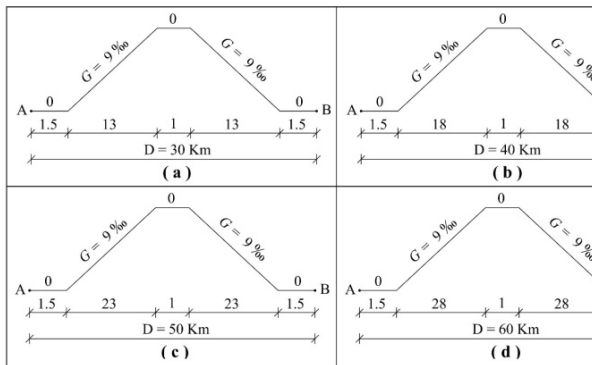


Figure 5: Vertical Profile II with different station spacing

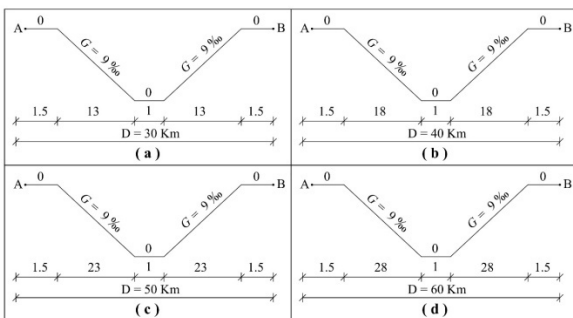


Figure 6: Vertical Profile III with different station spacing

3.2 Time Consumption Modeling

3.2.1. Gradient of Slope

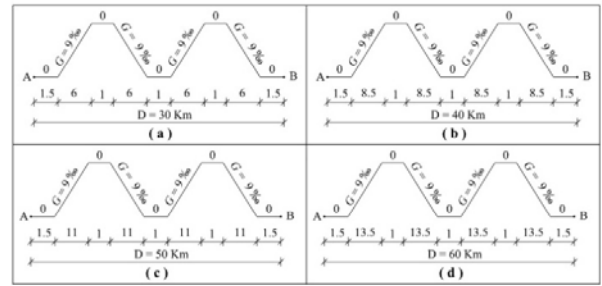


Figure 7: Vertical Profile IV with different station spacing

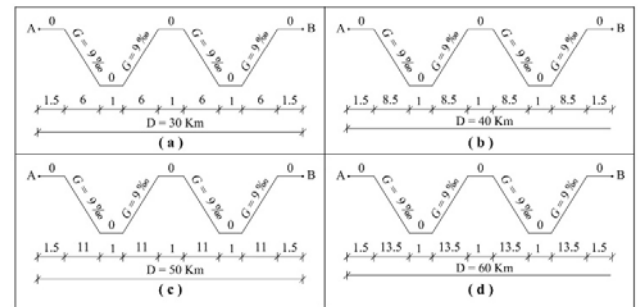


Figure 8: Vertical Profile V with different station spacing

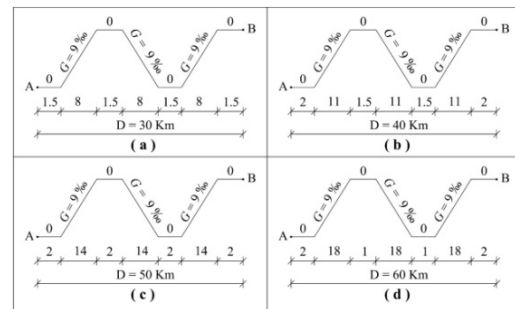


Figure 9: Vertical Profile VI with different station spacing

The maximum gradient of slope (i_{max}) is calculated by using formula (1), (Yi 2008; Yi and He 2009):

$$i_{max} = \frac{3600 \cdot P_k - \omega_0 \cdot g \cdot V_{max}}{g \cdot V_{max}} \quad (\%) \quad (1)$$

Where, P_k : required power per ton (kW/t)

V_{max} : Maximum speed of train (km/h)

g : Gravity acceleration ($g = 10 \text{ m/s}^2$)

ω_0 : Basic resistance of maximum speed of running train (N/kN)

For calculating basic resistance for China Railway High-speed (CRH) Electrical Motor train Unit (EMU), this research will use formula (2) by (Yi 2008; Yi and He 2009):

$$w_0 = 0.66 + 0.00245V + 0.000132V^2 \quad (2)$$

Table 3 shows the values of maximum gradient of the vertical profile of HSR when maximum speed of CRH3 (EMU) is varying from 350 km/h to 200 km/h.

3.2.2. Time Consumption

Time consumption of train running between station A and station B is calculated by using formula (3), (Yi 2008; Yi and He 2009).

$$T_{A/B} = \sum(t_i \cdot L_i) + t_s + t_p \text{ (min)} \quad (3)$$

Where: t_s , t_p : Extra time consumption for starting and parking a train. In general, for electric traction and diesel traction: $t_s = 1 \sim 3 \text{ min}$; $t_p = 1 \sim 2 \text{ min}$.

L_i : Horizontal length of slope (km)

t_i : Time consumption per kilometer for a train on a slope section (min/km), for ascending train, $t_i = 60 / V_i$ where V_i is the balancing speed and can be calculated from unit force graph. But as the braking system of high speed train is activated by using computer-controlled comprehensive braking mode, and it doesn't has the concept of train converted braking ratio and brake lining converted friction coefficient which is in general referred as train brake calculation, and also doesn't need to consider the train basic resistance and gradient resistance, so the effective braking distance can be directly calculated by a given deceleration, (Zhang and Ma 2006). When the train is getting off a slope, t_i is calculated from the formula (4):

$$D = V_{max} \cdot t \quad (4)$$

Where, D : Braking distance (m)

V_{max} : Maximum speed of the train (km/h)

t : Time consumption (min)

However, when the train is getting off a slope and there is a station at the end of the gradient section, the running time is calculated according to formula (5) of uniformly variable motion:

$$D = V \cdot t + \frac{1}{2} a \cdot t^2 \quad (5)$$

Where, D : Braking distance (m)

V : Speed of the train (km/h)

a : Deceleration of the train (m/s^2)

t : Time consumption (min)

3.2.3. Conventions

1- It is assumed that the distance between two following stations is constant ($L = 30$ km) and this distance will divide for each gradient section as shown later in each profile, (Figures 4-a, 5-a, 6-a, 7-a, 8-a, 9-a).

2- The additional time for starting and parking of the train is considered to be 3 min: $t_s + t_p = 3$ min.

3- This research chooses the CRH – EMU type-3 and Figure 14 shows its unit force curve, (Yi 2008).

Table 4 shows main technical parameters of five types of China Railway High-speed (CRH) Electrical Motor train Unit (EMU), (Yi and He 2009). From main technical parameters of CRH3 – EMU (Table 4): $P_k = 21.05$ kW/t , $V_{max} = 350$ km/h. Figure 14, shows Unit force curve of CRH3 – EMU

3.2.4 Illustration of Calculation Process for Profile I

When high-speed train pass through an area imitated as profile I between station A and station B, time consumption is calculated by using the formula (3):

$$T = \sum(t_i \cdot L_i) + t_q + t_t$$

$$T_{A/B} = \left(\frac{60}{V_1} \cdot L_1 + \frac{60}{V_2} \cdot L_2 + \frac{60}{V_3} \cdot L_3 \right) + t_q + t_t$$

As shown in profile I (Figure 4-a) and by using first value of maximum gradient (Table 3):

$$i_1 = i_3 = 0, \quad i_2 = i_{max} = 3.96 \text{ ‰}$$

From unit force curve of CRH3 – EMU (Figure 14), associated speed value of CRH3-EMU for each gradient is as follow: $V_1 = V_3 = 341.44$ km/h , $V_2 = 340.69$ km/h

Now, by replacing in formula (3):

$$T_{A/B} = \left(\frac{60}{341.44} \times 1.5 + \frac{60}{340.69} \times 27 + \frac{60}{341.44} \times 1.5 \right) + 3 = 8.28 \text{ min}$$

By repeating previous calculation for all values of maximum gradient (Table 3) and drawing the graph, this research is getting time consumption model for each profile as shown later.

4. Computational Experiments

This section presents the application of the proposed methodologies with real world case study of HSR from Guiyang – Guangzhou China.

4.1 Case Study

For theoretical methodology mentioned earlier, this research has applied operating expenses model to the case study, between cities from Guiyang – Guangzhou Railway track in China. Guiyang-Guangzhou Railway line is an important interregional railway corridor, connecting the southwest regions with the coastal areas of South China, which passes through three major provinces from Guizhou, Guangxi and Guangdong. The main railway line is 857.300 km long. Guiyang-Guangzhou Railway Line is a convenient, rapid and large-capacity new passage for the southwest and northwest area to get to Pearl River Delta District and economic zones in Fujian and Taiwan Districts. The construction of Guiyang-Guangzhou Railway can complete the interregional passenger and freight assignment rapidly with large capacity, which will become a bridge for interregional economic cooperation, promoting the rapid, even and harmonious

economic development along the line is of great meaning for implementation of the western development strategy and sustainable development and construction of harmonious society.

4.2 Results

4.2.1 Operating Expenses

Figures 10, 11, 12, and 13 shows the relationship between operating expenses value and station spacing for profiles I, II/III, IV/V, and VI respectively. Table 1 shows operating expenses model for each standard vertical profile. Based on the implicit analysis mentioned earlier, the following results are established.

- (1) Operating expenses model is a third-degree function for all profiles. The R-square values for all models are equal to one, as shown in the figures 10, 11, 12, 13.
- (2) The results show that operating expenses are similar for the profiles, which have symmetrical sketch with a horizontal axis, whereas unsymmetrical sketch of different profiles have different values of operating expenses.
- (3) Both profiles II and III have equal values of operating expenses, consequently they have the same model of operating expenses; additionally the profile IV and V accept the same effect.
- (4) Operating expenses upsurges with the increasing of station spacing for each profile.
- (5) The percentage of increasing of operating expenses between the first and the last value of station spacing for each profile is 5.36% for profile I, 7% for profiles II and III, 6% for profiles IV and V and it is 6% for profile VI.

Table 1. Operating expenses model for six standard vertical profiles of high-speed railway

| | | |
|---------------------------------|--------------------|---|
| Operating Expenses Model | Profile I | $E = f(D) = 0.02D^3 - 3D^2 + 154D + 3140$ |
| | Profile II | $E = f(D) = 0.0033D^3 - 0.7D^2 + 54.667D + 4320$ |
| | Profile III | |
| | Profile IV | $E = f(D) = 0.0047D^3 - 0.84D^2 + 55.533D + 3614$ |
| | Profile V | |
| | Profile VI | $E = f(D) = 0.0257D^3 - 3.22D^2 + 137.43D + 2732$ |

Result of the Case Study "Guiyang – Guangzhou Railway", China

Theoretical study has applied to few sections of case study railway line. Table 2 shows the operating expenses for stations spacing of the case study (Guiyang – Guangzhou) according to the sixth profiles. From Table 2, the following results are established:

Table 2. Operating expenses values for stations spacing of case study

| Operating expenses E (RMB) | Profile I | Profile II | Profile III | Profile IV | Profile V | Profile VI |
|-----------------------------------|------------------|-------------------|--------------------|-------------------|------------------|-------------------|
| | | | | | | |

| | | | | |
|---|---------|---------|---------|---------|
| <i>LingTian–NanYu</i> <i>D = 31.8 km</i> | 5646.63 | 5456.66 | 4681.65 | 4672.53 |
| <i>NanYu–GongCheng</i> <i>D = 47.56 km</i> | 5829.95 | 5691.60 | 4860.72 | 4749.45 |
| <i>GongCheng–Lian’an</i> <i>D = 37.57 km</i> | 5751.87 | 5560.78 | 4763.95 | 4713.08 |
| <i>Lian’an–West ZhonShan</i> <i>D = 21.44 km</i> | 5259.85 | 5202.81 | 4464.82 | 4451.63 |
| <i>West ZhonShan–Hezhou</i> <i>D = 24.45 km</i> | 5404.22 | 5286.38 | 4538.32 | 4542.88 |

- (1) The smallest station spacing is 21.44 km between (Lian’an – West Zhongshan), and when the vertical profile is shifting from plain area (like profile I) to a mountain area (like profile VI), the operating expenses will decrease about 15%.
- (2) The largest station spacing is 47.56 km between (Nanyu – Gongcheng), and when the vertical profile is shifting from plain area (like profile I) to a mountain area (like profile VI), the operating expenses will decrease about 18%.
- (3) When the station spacing is increasing from the smallest one (Lian’an – West Zhongshan) to the biggest area, (Nanyu – Gongcheng), the operating expenses is also increasing whether it is plain area (like profile I, increasing percentage is about 10%) or it is mountain area (like profile VI, increasing percentage is about 6%).

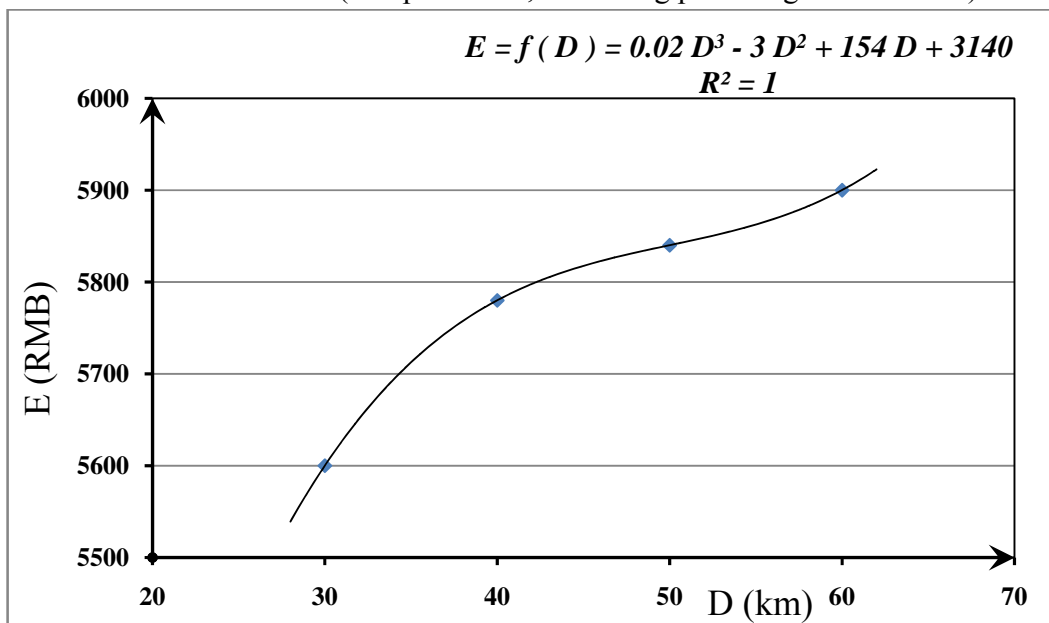


Figure 10: Operating expenses model of profile I

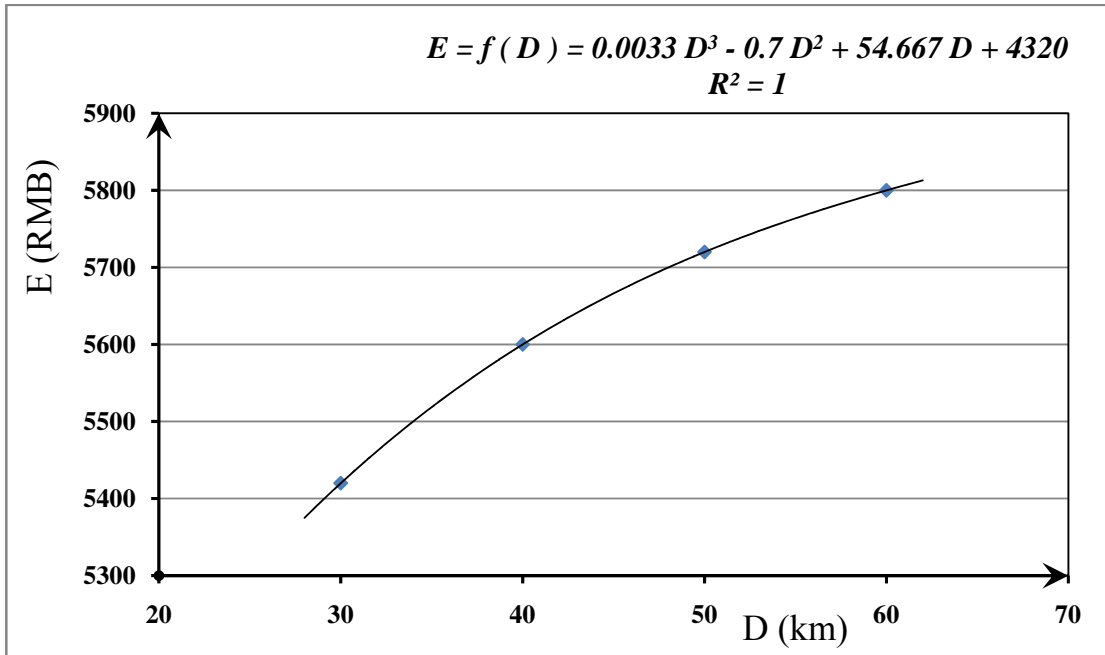


Figure 11: Operating expenses model of profile II/III

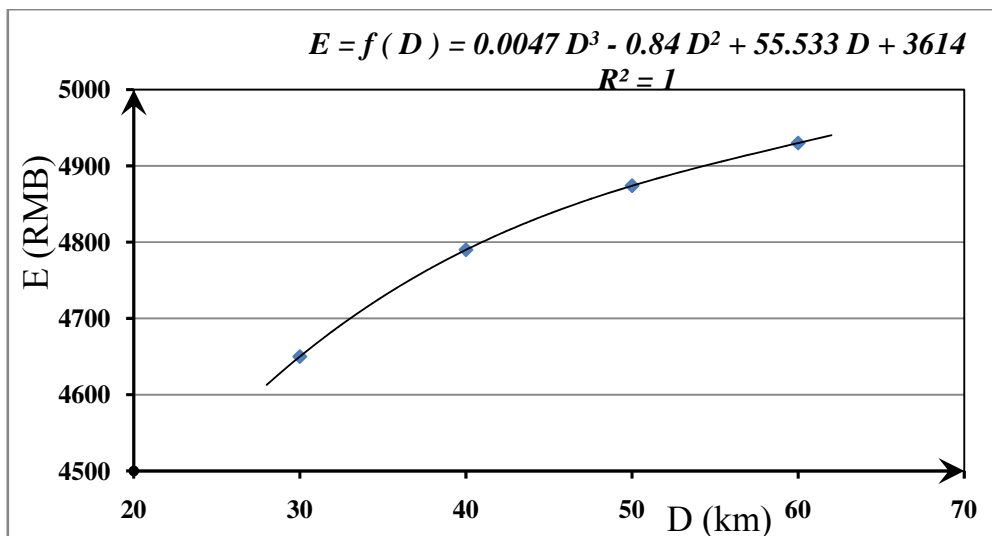


Figure 12: Operating expenses model of profile IV/V

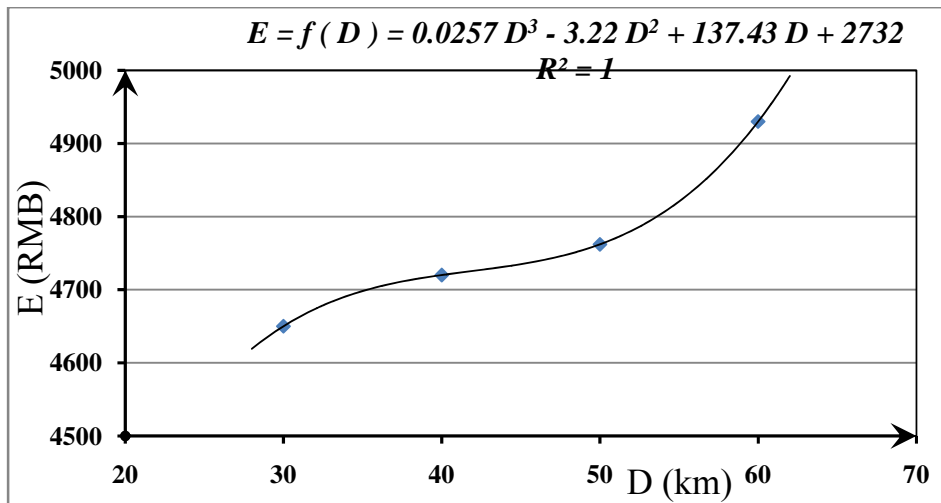


Figure 13: Operating expenses model of profile VI

4.2.2 Time Consumption

Figures 15, 16, 17 and 18 show the relationship between time consumption and maximum gradient for profiles I, II/III, IV/V, and VI respectively.

Table 5 shows time consumption model for each standard vertical profile mentioned previously. Based on the implied analysis mentioned earlier, the following results are established:

- (1) Time consumption model is a quadratic function for all profiles. The R-square values for all models are more than 99% as shown in the figures 15, 16, 17, and 18.
- (2) The results show that the time consumption is similar for the profiles that have symmetrical sketch with a horizontal axis, whereas unsymmetrical sketch of different profiles have different values of time consumption.
- (3) Profiles No.2 and No.3 have the same model of time consumption. Correspondingly, Profiles No.4 and No. 5 have the same model, (Table 5).
- (4) Time consumption increases with the increasing of maximum gradient value for each profile.
- (5) The percentage of increasing in time consumption between the first and the last value of gradient for each profile is 33.6% for profile No.1, 16.3% for profiles No.2 and No.3, 14.9% for profiles No.4 and No.5 and it is 20% for profile No.6.

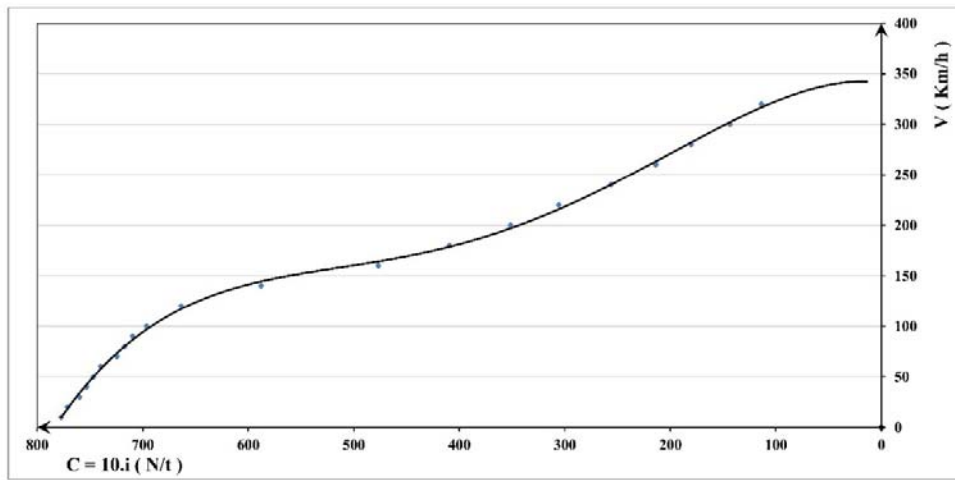


Figure 14: Unit force curve of type 3 China Railway High-speed (CRH) Electrical Motor train

Unit (EMU)

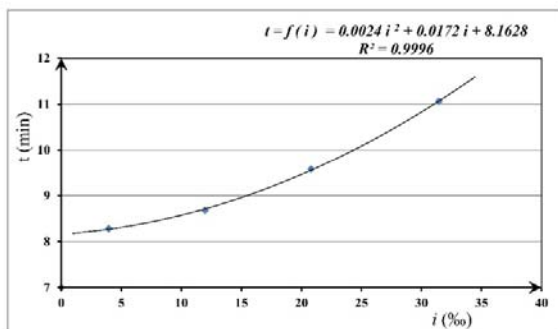


Figure 15: Time consumption graph for profile I

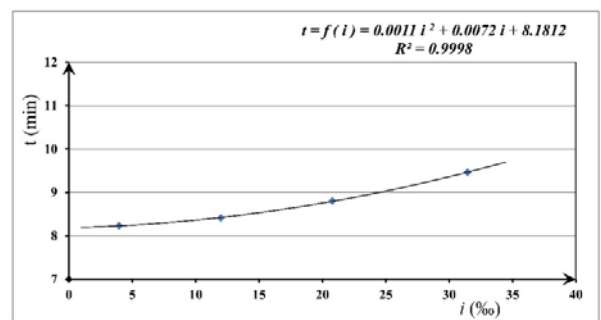


Figure 17: Time consumption graph for profile IV/V

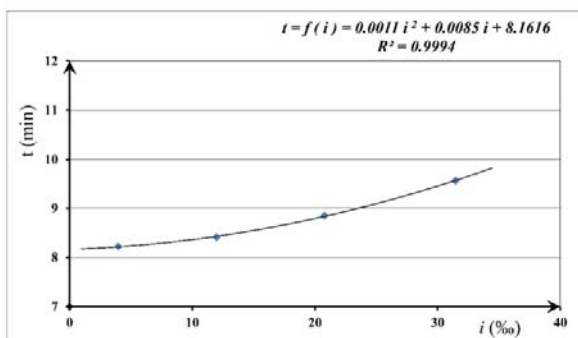


Figure 16: Time consumption graph for profile II/III

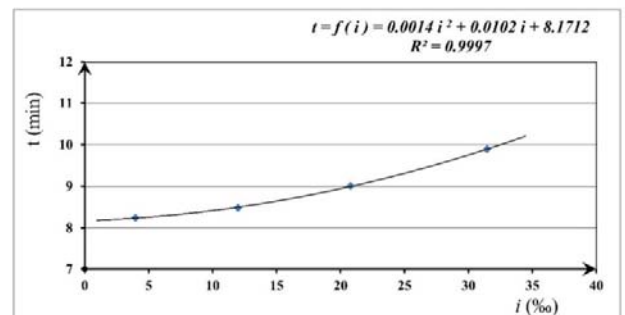


Figure 18: Time consumption graph for profile VI

Table 3: Maximum gradient values for different maximum speed of CH3 – EMU

| V (km/h) | 350 | 300 | 250 | 200 |
|---------------|-------|-------|-------|-------|
| w_0 (N/kN) | 17.69 | 13.28 | 9.52 | 6.43 |
| i_{max} (‰) | 3.96 | 11.98 | 20.79 | 31.46 |

Table 4: Main technical parameters of five types of CRH-EMU

| Locomotive model Item | CRH 1 | CRH 2 | CRH 3 | CRH 4 | CRH 5 |
|--|------------------------|-----------------------|---------------------|------------------|---------------|
| | Marshalled form | 2×[2M+1T] +[1M+1T] | [4M+4T] /[6M+2T] | 2×[2M+1T] +2T | 6M+2T |
| Capacity (person) | 668 | 610 | 610 | 610 | 620+2 |
| Group mass (t) | 420.4 | 359.7 | 380.0 | | 451.0 |
| Group length (m) | 213.5 | 201.4 | 200.0 | 201.4 | 451.0 |
| Operation speed (Km/h) | 200 | 200/300 | 350 | 330 | 200 |
| Length of front of motorcar (mm) | 26 950 | 25 700 | 25 675 | 25 700 | 27 600 |
| Length of middle of motorcar (mm) | 26 6000 | 25 000 | 24 775 | 25 000 | 25 000 |
| Motorcar width (mm) | 3 328 | 3 380 | 2 950 | 3 380 | 3 200 |
| Motorcar height (mm) | 4 040 | 3 700 | 3 890 | 3 700 | 4 270 |
| Dynamic axle type | $B'_o - B'_o$ | $B'_o - B'_o$ | $B'_o - B'_o$ | | $B'_o - B'_o$ |
| Bogie fixed wheel base (mm) | 2 700 | 2 500 | 2 500 | 2 500 | 2 700 |
| Bogie center distance (m) | 17.500 | 17.500 | 17.375 | 17.500 | 17.500 |
| Bogie wheel diameter (mm) | 915 ~ 835 | 860 ~ 790 | 860 ~ 790 | 860 ~ 790 | 890 ~ 810 |
| Axle load/readiness weight (t) | ≤ 16 | ≤ 14 | ≤ 14 | | ≤ 17/16 |

| | | | | | |
|--|---------|------------------|--------|-------|---------|
| Total traction power (KW) | 5 500 | 4 800 / 7 200 | 2 400 | | 5 500 |
| Single motor power (KW) | 275 | 300 | 500 | 300 | 550 |
| Average power per ton (KW/t) | 13.08 | 13.34 | 21.05 | 19.67 | 12.19 |
| Starting tractive force (KN) | 325 | 237 | 300 | | 300 |
| Starting acceleration (m/s²) | 0.5 | 0.406 | 0.406 | | 0.6 |
| Emergency braking distance (m) | ≤ 2 000 | ≤ 1800 | ≤ 1800 | | ≤ 2 000 |

Table 5: Time consumption model for the sixth profiles

| | | |
|--------------------------------------|--------------------|---|
| Time Consumption Model t(min) | Profile I | $t = f(i) = 0.0024 i^2 + 0.0172 i + 8.1628$ |
| | Profile II | $t = f(i) = 0.0011 i^2 + 0.0085 i + 8.1616$ |
| | Profile III | |
| | Profile IV | $t = f(i) = 0.0011 i^2 + 0.0072i + 8.1812$ |
| | Profile V | |
| | Profile VI | $t = f(i) = 0.0014 i^2 + 0.0102 i + 8.1712$ |

5. Discussions

Based on the normal railway schemes for calculation of time consumption and operating expenses, this study implied the models and graphs, as presented in Figure 2 and Figure 3, for HSR. The study has assessed the effect of stations spacing on operating expenses. In this regard, six standard vertical profiles of HSR line have been studied. The results reported that operating expenses model is a third-degree function of station spacing. These models have applied to a case study. The study shows that when the distance between stations is small like in mountain areas, the operating expenses will be lower. Whereas when the distance between stations is large like in plain areas, the operating expenses will be higher.

Travel time consumption has adopted a methodology, which implies using previously mentioned six types of vertical profiles. It is found that the maximum gradient values with different maximum speed on HSR, besides getting the value of time consumption. The study draws the conclusion that when a high-speed train passes through mountain areas, each passenger travelling on railway line will be suspended because of many intermediate stations and the time

consumption will be higher. Meanwhile, when the high-speed train passes through flat or plain areas, there will be less number of intermediate stations.

6. Conclusions and Future Directions

This paper have studied the relationship between operating expenses of HSR line with the station spacing depending on six standard vertical profiles and keeping other indicators constant. We studied the relationship between time consumption and maximum gradient of high-speed railway, but in fact there are few more indicators that can be considered for calculation. Comparison of several times with the vertical sections of existing HSR lines, the intended graphical method shows high degree of veracity among standard profiles. Therefore, future studies can be concentrated on operating expenses, extending time consumption models and including other indicators.

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