Research on Optimal Riding Strategy Based on Improved Rider Power Position Analysis Model

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Abstract. How to achieve good results in bicycle road races is a question worth pondering on. we developed a rider power-position analysis model that can be applied to any type of rider to determine the relationship between that rider's position and power on the track. This paper considered extending the model to team time trials. The team maintains a stable pace, maintains different power in different positions, the entire team maintains a distance of 30cm, and the strong and weak are arranged alternately.

Keywords: principal component analysis, differential equations, FNN, genetic algorithm.

1. Introduction

Cycling road racing is a sport that challenges speed and endurance, and it consists of many types: standard races, team time trials, and individual time trials. In individual time trials, each rider is judged on the time it takes to complete a set course. The likelihood of success varies from rider to rider in each event, and this likelihood depends on the type of event, the route, and the ability of the rider [1].

To better improve the rider's individual time trial performance, different riding strategies are developed according to the rider's power curve and the course.

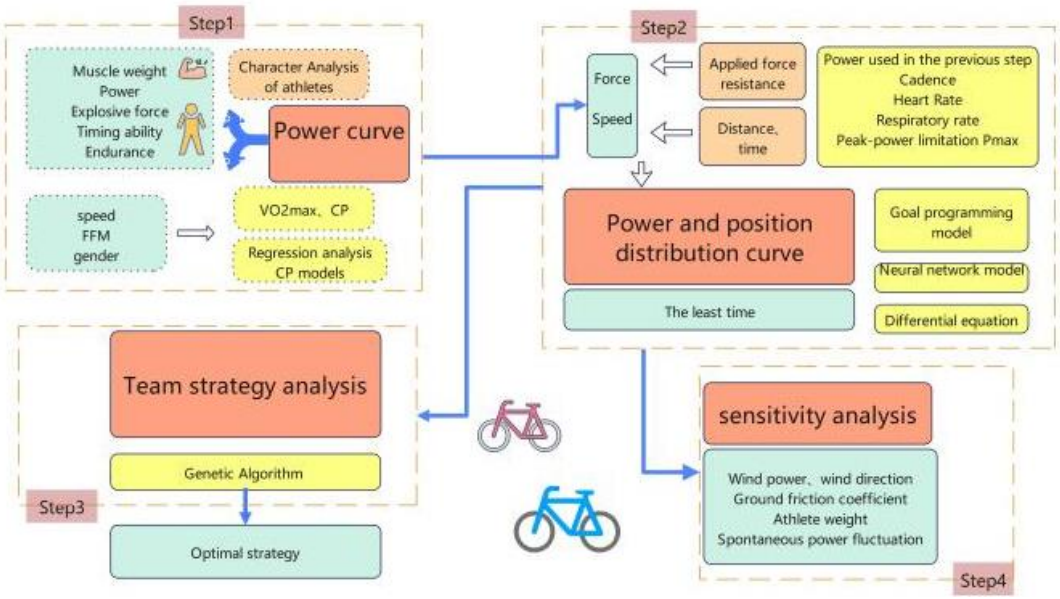


Fig 1. Rider force Position Analysis Model Process

Rider force Position Analysis Model Process is shown in Fig. 1.

Considering the background information and restricted conditions identified in the problem statement, this paper need to solve the following problems:

A model was developed and applied to various time trial courses to show the relationship between the position of the rider and the power applied.

The model is improved to find the optimal strategy for a six-rider team time trial.

2. Model Assumptions and Notation

2.1. Assumptions[2]

It is assumed that the weather during the race will not be very bad and the temperature will be suitable. Since weather conditions can have an effect on a rider's physical condition, and when the weather conditions are bad, the rider's performance can be greatly affected and does not reflect the rider's true condition.

It is assumed that the rider is able to complete the entire race without accidents. The data is only true and reliable if the rider can complete the entire race.

It is assumed that riders in the same category have approximately the same physical fitness. The average fitness of the riders in the same class consider facilitates the analysis of the results and improves the utility of the model.

It is assumed that training values can be used to represent power. The power can reflect the real training intensity, and the power meter detects the muscle firing to do work, which truly responds to the training intensity, ignoring the influence of external factors.

It is assumed that the friction factor of the field to the rider and the weight of the bike are constant values. By determining the two variables, friction factor, and bike weight, the comparison of the other variables can be reflected.

It is assumed that when considering the effect of weather conditions on the results, the weather conditions only consider wind direction and wind strength. Since it is determined that the weather conditions are determined only by wind direction and wind strength, the complexity of the model can be reduced substantially.

It is Assume that in a cycling team time trial, except for the lead rider, the following riders are subjected to the same air resistance. This assumption reduces the complexity of the model and leads to better answers.

2.2. Notations

Important notations used in this paper are listed in TABLE 1.

Table 1. Notations

Symbol	Description
speed	The speed at which the rider is riding in km/h
gender	Rider's gender
CP	Critical power
T	Exercise maintenance time for a given power condition
AWC	Anaerobic work capacity
i-th	means the i-th moment
j	means six-rider numbers
j-th	six-rider numbers at i-th moment
x	Refers to the coordinate position
y	Refers to the coordinate position
h	Altitude
S	Cross-sectional area relative to the motion of the fluid
V	Wind speed of resistance overcome relative to the fluid motion
P_i	Power of the rider at the moment i
$F\mathrm{u}_i$	The force applied to the rider at moment i
f_i	The obstructing force applied to the rider at the moment i
F_i	Force exerted by the rider at the moment i
ρ	The density of the air-fluid
c	Resistance coefficient

fa	Fatigue index
v_i	The instantaneous speed at moment i
fc_i	Turning resistance at moment i
fs_i	Slope resistance at moment i
wr_i	Wind resistance at moment i
ΔK_i	The relative horizontal slope at the moment i
$F_{\max}$	Maximum force
$P_{\max}$	Max. power

3. Model construction and solving

3.1. Rider power-position analysis model

Since the results in bicycle road races are based on the time taken by the rider to travel the entire distance, Riders are always looking to minimize the time required to cover a given distance. Therefore, aim for the shortest time for the rider to travel the whole distance, so allocate and use the maximum power for the rider. So conclude 4 influence factors for rider's power from the problem background, including the degree of fatigue, rider's characteristics, geographical factors, weather factors [3].

3.1.1 Rider power-position analysis model

Based on the requirements of the problem, this paper developed a rider power-position analysis model to reflect the relationship between the rider's power and position. However, since the power consumed by the rider at each position is instantaneous, this paper introduced a differential equation model. Based on the fact that there is power consumption and power recovery during the rider's ride, there is a fatigue level that affects the process, so this paper introduced a feedback neural network model to find out the effect of fatigue level.

3.1.1.1 Differential equation model

Based on the requirements of the question, the model can represent the interrelationship between rider and position. Since the power consumed by the rider at each position is instantaneous, all the variables analyzed below should be used to analyze the power of the rider in an instantaneous situation. So use the differential equation model to turn the actual problem into a fixed-value solution problem for the differential equation [4,5], The model is as follows:

Create physical expressions(Fig. 2),

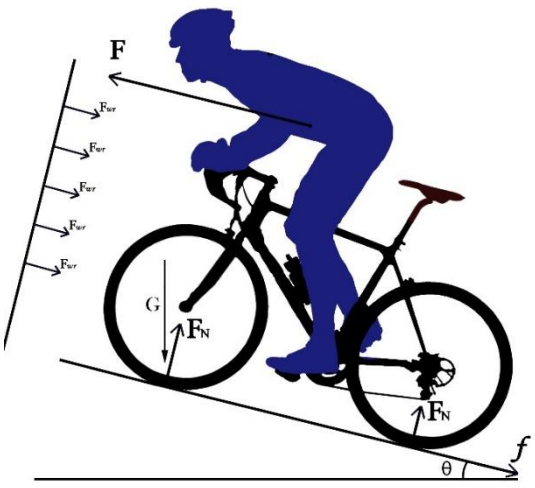


Fig 2. Rider force analysis

Since the problem is a practical physical problem, we establish the physical expression for the instantaneous power:

$$P_i = Fu_i \times V_i + C_1 \tag{1}$$

Then use the physical force balance method, express the useful force:

$$Fu_i = -f_i + a \times F_i \tag{2}$$

Differential method

By differentiating the distance, expanding the distance in 3D coordinate space, then using the equation of instantaneous velocity in physics, to find the instantaneous velocity

$$\begin{aligned} \Delta x_i &= x_i - x_{i-1} \\ \Delta y_i &= y_i - y_{i-1} \\ \Delta h_i &= h_i - h_{i-1} \\ v_i &= \frac{\sqrt{\Delta x_i^{\,2} + \Delta y_i^{\,2} + \Delta h_i^{\,2}}}{T_i} \end{aligned} \tag{3}$$

Since drag has an effect on the power consumed by the rider, And the resistance is a combination of the resistance generated by the turn, the resistance generated by the slope and the expression is:

$$f_i = fc_i + fs_i \tag{4}$$

Since the resistance is different in different positions, so we fit the relationship between the turning resistance and the instantaneous slope using the differential equation, and the relationship between slope resistance and the rider's weight and the slope's gradient, and the expression is:

$$fc_i = b \times \Delta K_i \tag{5}$$

$$\begin{aligned} fs_i = {} & Mg \times \Delta h_i \times \sqrt{1 \div (1 + \Delta h_i^{\,2})} \\ & + 0.04Mg \times \sqrt{1 \div (1 + \Delta h_i^{\,2})} - \mu Mg \end{aligned} \tag{6}$$

Among them is the horizontal relative slope, Δh_i is Relative slope, μ is Friction coefficient, the value of is 0.04.

Cumulative summation

Because of the micro-unitization of the distance, the time obtained by the micro-unit is the time consumed by that short distance, so the time consumed by the entire distance should be accumulated at each moment to get.

$$T = \sum T_i \tag{7}$$

Since the total capacity that a person can consume is a constant value, after normalization:

$$W = \int_0^T P_i dT = \begin{cases} 1 + l \\ 0.75 + l \end{cases} \tag{8}$$

Among them is the Recovery factor. Assuming a recovery factor of 1 for men,0.75 for women, however, due to the small value of the recovery factor, does not make a big difference to the results, So the recovery factor is negligible.

3.1.1.2 Feedback neural network model

As the rider's past fatigue level will affect the current play, a new level of fatigue will follow, therefore we use feedback neural networks to solve this dynamic influence problem.

Since the applied force is always less than the maximum force, then.

$$F_{\max i} = 100 P_{\max} \div (V_i \times f_a) \tag{9}$$

By searching the fatigue index data, we concluded that the fatigue index corresponds to the basic body mass of the human body, and we combined the basic body mass with the fatigue index and listed the following expression:

$$\begin{aligned} fa &= 0.3934B_1 + 0.365B_2 + C_2 \\ B_1 &= 0.3468Cadence + 0.2834P_i \\ B_2 &= 0.6289HeartRate \end{aligned} \tag{10}$$

fa is the formula used by fa Fatigue Index, B_1 is Limb fatigue index, B_2 is Physiological fatigue index.

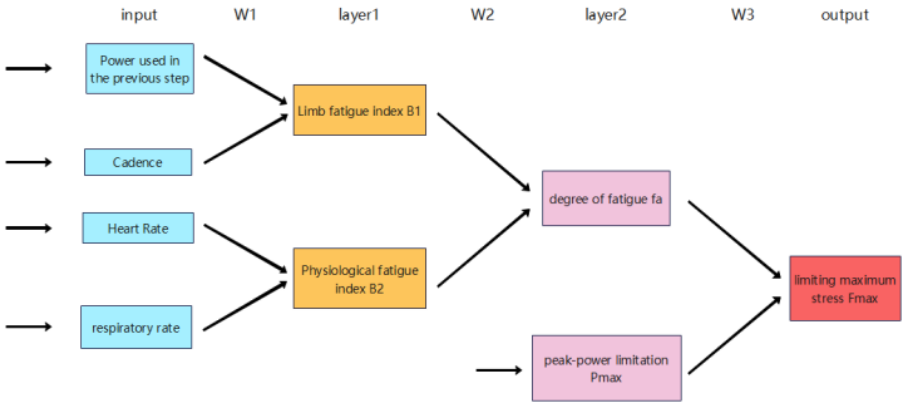


Fig 3. Structure diagram of the feedback-based neural network model

Structure diagram of the feedback-based neural network model is shown in Fig. 3. Finally, the data is then fitted by a differential equation to derive the values of Table 2.

Table 2. Table of parameter values for differential equation fitting

Parameters	Value
a	15.0724169
C_1	365.48546
b	-31.89978946
C_2	16.47567

After finding the equation fitting parameters, thus finding the relationship between each position and the power consumed by the rider [6,7], After finding the relationship, this paper bring in the test data and compare it with the actual data, The model was found to have good accuracy, the accuracy rate is 90.1%, Details can be seen in Fig. 4.

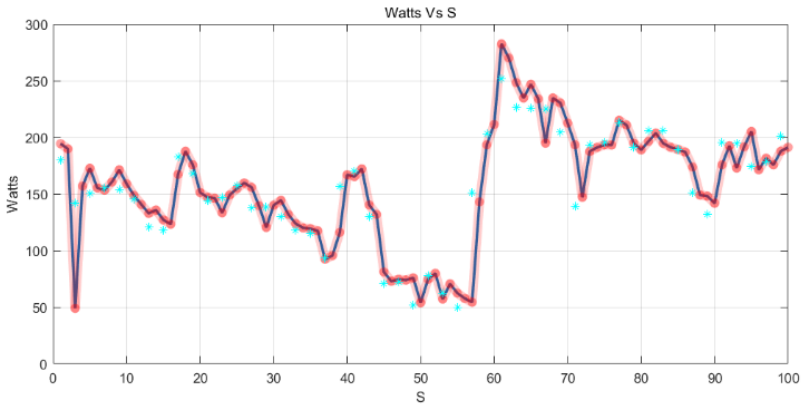


Fig 4. Comparison of equation prediction results with the actual situation

The cyan scatter is the real data, the red line is the result of the equation.

3.1.2 Combination of track and model

3.1.2.1 Race Track

Accurate track location data via Google Maps, use the NASA satellite database [8] to find the corresponding elevation data and convert the latitude and longitude into two-dimensional x, y coordinate information through ArcMap.

According to the characteristics of the Tokyo Olympics bicycle time trial track, this paper took about 5,000 points equally spaced from the starting point to the finish line. These points are enough to express the position of the entire track, and record its position information, x, y, h, denoted as S(s, y, h), through the above-established model, This paper bring in the position information of the track, and then through the limitations of the characteristics of different types of riders, can get the power position information images of different types of riders(Fig. 5).

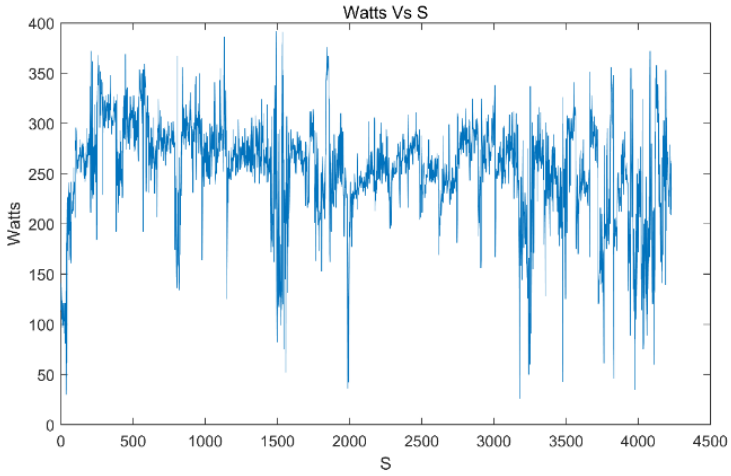


Fig 5. Position power curve of male sprinters in Tokyo, Japan in 2020

Similar to the handling of the Tokyo Olympics cycling time trial, the power position information image of the riders in the 2021 UCI World Championships time trial is shown in Fig. 6 and Fig. 7 below.

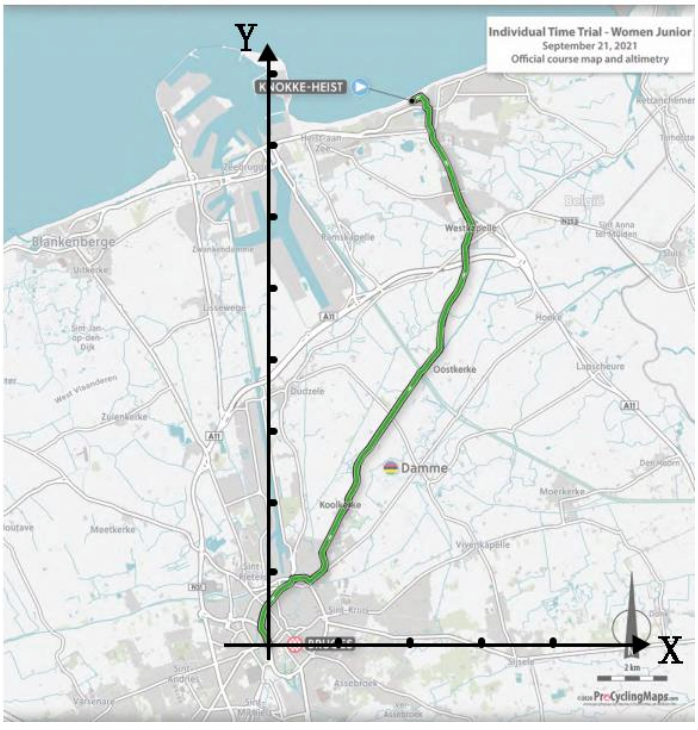


Fig 6. 2021 UCI World Championship time trial course in Flanders

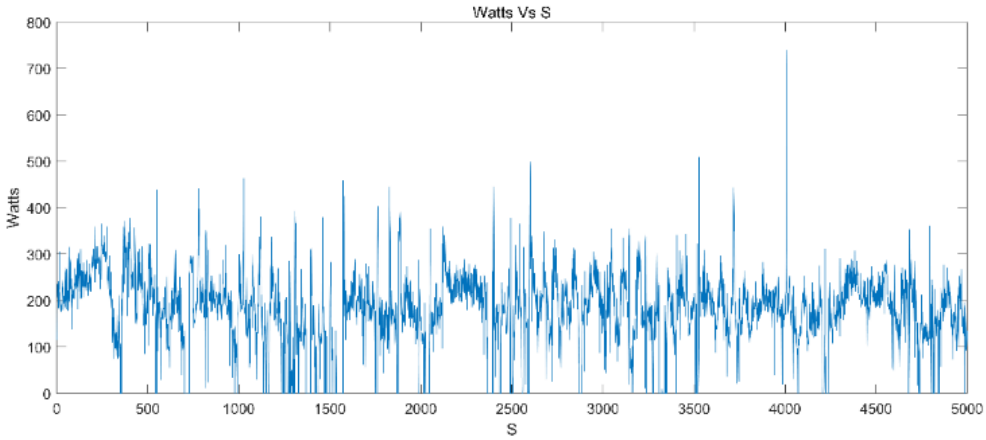


Fig 7. 2021 UCI Male Sprinter Position Power Curve

3.1.2.2 Self-built track

Due to the complexity of the race track and the uncertainties during the race, this is likely to have a certain impact on the measurement of the model parameters, so built a corner with 4 different angles and a steeper ramp composition of the track.

By processing the data of the track, this paper took out 200 points to study the positional power curve of male sprinters. Through the position information of the track, this paper established the following Fig. 8 and Fig. 9.

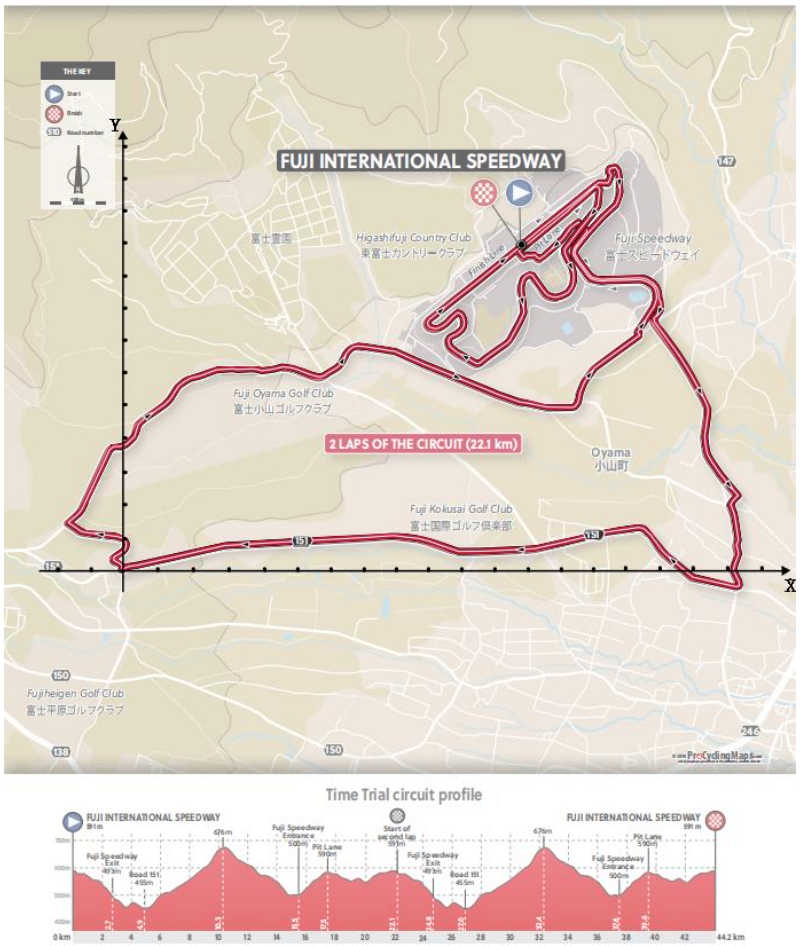


Fig 8. Belgium,2021 Olympic Time Trial course in Tokyo, Japan

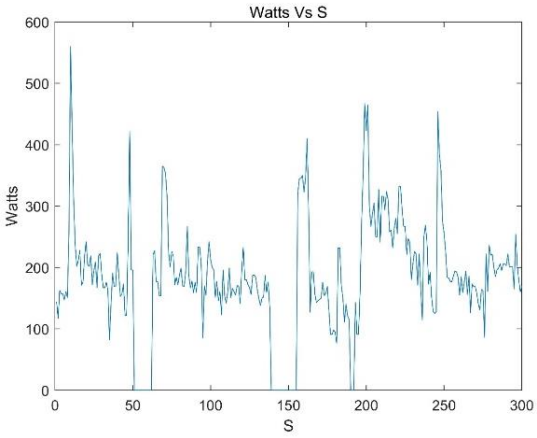


Fig 9. Position power curve of the male sprinter on the selfbuilt track

3.2. Genetic Algorithm-Based Goal Programming Model

This part is essentially an extension of the model of before, extending the rider's individual power curve and influencing factors of before to the team time trial. The results of the cycling team time trial are based on the time taken by the fourth team rider to cross the finish line as the standard, and the teams start with a gap of 2-3 minutes. In order to minimize the time taken by the team to complete the whole process, use a genetic algorithm to find the appropriate combination of rider movement positions, so as to obtain the best strategy for the cycling team time trial.

3.2.1 Genetic Algorithm-Based Goal Programming Model

In order to determine the combination of positions each rider is in in a cycling team time trial, it is necessary to base them on the rider's power curve and the resistance they experience. Assuming that the position order of the team riders is changed, the purpose is to reduce the total power consumption of the team members by air resistance as much as possible and reduce the time it takes for the team to reach the finish line. This paper use the letters I II III IV V VI to replace the number of the six people, denoted as j (I II III IV V VI) rider number.

The ranking of each person is recorded as, judged by the size of the distance S.

The distance traveled by the jth driver.

If S (I II III IV V VI)-S (I II III IV V VI) <0.3 and not equal to 0.

Then there is the case of follow-up. Except for the follow-up coefficient $\alpha=1/2$, the others are all 1[9,10].

In order to easily calculate the combination of positions that the rider moves, the optimal strategy for the cycling team time trial is derived. Do the calculation by genetic algorithm. Flowchart of Genetic Algorithm is shown in Fig. 10.

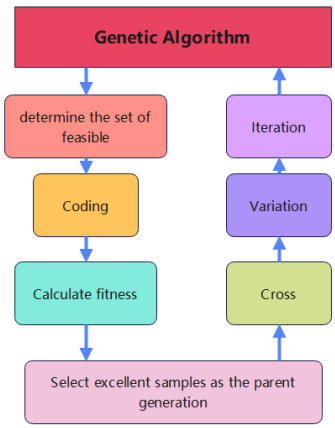


Fig 10. Flowchart of Genetic Algorithm

Through a genetic algorithm, this paper get the optimal strategy of cycling team time trial:

1. The team maintains a steady pace:52-54km, the pace of the leader is 55km/h.
2. The power of the front rider is 600W, the second is 430W, the third is 380W, and the fourth to sixth are 370W.
3. Keep a distance of 30cm from the rider, Since the wind resistance at this time is 62% of the normal wind resistance, and more than 30cm wind resistance should be fully borne.
4. Riders with strong physical strength and weak physical strength are arranged in a cross, staggered and alternately walking: after the 20s for a rider with stronger physical strength, switch to a rider with weaker physical strength for 10s.

4. Sensitivity Analysis

In the above parts, paper discussed the relationship between the power consumption and the position of the rider and established the rider motion model, by comparing it with the actual data, this paper found that the model has good practical value. Therefore, based on the above model, this paper conducted a sensitivity analysis on its important variables to test whether the established model has high stability. Since the third and fourth questions have considered the influence of wind resistance and the fluctuation of the rider's own power on the model parameters, here this paper analyze the stability of the model by considering the influence of the percentage change of rider weight and ground friction factor on the optimal time solution of the model. Sensitivity analysis curve of important parameters is shown in Fig. 11.

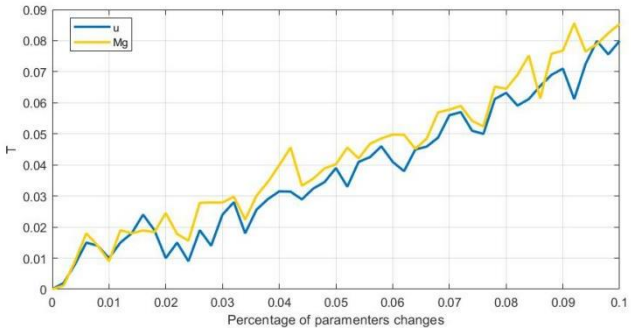


Fig 11. Sensitivity analysis curve of important parameters

μ and the rider's weight each fluctuate from a range of 0% to a range of 10%, The two of them are not affected by each other. Through the fluctuation of the parameters, this paper obtain the fluctuation percentage of the optimal solution to verify the accuracy of the model.

Through the above-established fluctuation percentage line chart, it can be seen that the influence of the maximum fluctuation of parameter Mg on the optimal solution does not exceed 9%, the influence of the maximum fluctuation of parameter on the optimal solution does not exceed 8%, and does not exceed 10% are all within the allowable range. In the process of parameter fluctuation, the fluctuation to the optimal solution is very small. It can be seen that the model this paper established has very good robustness, that is, the model has good stability.

It can be seen from the above analysis that the model not only has good practicability but also has strong stability.

5. Conclusion

This paper built a rider power analysis model, which was used to determine the relationship between the power expended by the rider and positional conditions. And found several important factors that affect the rider's power: fatigue level, rider's characteristics, geographical factors, and weather conditions. Using basic physical models and building new models with differential equations and feedback neural networks, this paper succeeded in finding the relationship between the power

consumed by the rider and the position information. and apply it to three tracks to get the power profile of each rider.

Then, the sensitivity of the model is analyzed. According to the requirements of the title, we have studied the sensitivity of the wind force, wind direction, and rider's own power fluctuation to the model, and found that the model has good stability within a certain range. In addition, this paper conduct sensitivity analysis on the important variable Mg in the model and find that the model has good robustness.

Finally, this paper comprehensively analyze the advantages and disadvantages of the built model and try to extend the built model in depth.

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