Problem Chosen	2022	Team Control Number
A	MCM/ICM Summary Sheet	2210391

Apply Power Wisely in a Time Trial Course

Summary

With the idea of low-carbon travel deeply rooted in people, the bike and the bike contest have gained great popularity. Take the Tour of France for example, it has attracted more than 10 millions visitors.We will talk about an important project in the bike contests. It is callled the ITT(Individual time trial). In our article, we will discuss how to help athlete get better grade in the ITT with personal power profile.

We choose the CP model to get the power profile or the relationship between the power and the distance. What's more, we will analyse it from macro and micro level. In the macro aspect, we segmented the course according to the climb level based on the energy optimization algorithm. Then we distribute the energy of the athlete according to the road's features and position in the contest. In the micro level, With the energy distribution in the macro analysis, we set up the dynamics formulation to solve specific power of the athlete needs to change between the divided sections.

We define two power profiles of two types of the athletes.Our results show that the relationship between power and position varies among different types of athletes on the basis of general consistency.For example, climbers allocate more energy on the slope.

By applying the model to the specific course we can draw the curve of the relationship between power and position. The result will be displayed in Figure(17).

Based on the above two models, we also conduct sensitivity analysis of some of the factors.First we consider the effects of wind direction and speed and ground humidity, then we consider the case when the athletes' power allocation is out of the scheduled plan. And these have little effect on the overall result which shows the high robustness of our model.The result will be displayed in Figure(18) and Figure(19)

We also make some extension to the model. In the ITT competition, athletes are seldomly disturbed by other athletes, so its model can be used as a basis to solve how the power of each athlete should change with the position in TTT competition.Based on the change of air resistance in team cooperation,we made a more appropriate competition strategy in TTT competition in the extended part.

Keywords: Cycling;Power profile; CP model; Energy distribution; Strategy of game; Dynamical equation

Contents

1 Introduction

1.1 Background

Bicycling was first introduced in the 1800s, and it quickly became very popular. The basic bicycle design can be traced back to 1493, when Gian Giacomo Caprotti sketched out the idea. Another version was built in France in 1791.

Nowadays the cycling events have more and more popular, Like the Tour de France, Giro dItalia, Vuelta a España. Plenty of talented athletes participate in such events. With the scientific training athletes can get the award easier especially in the individual time trial(ITT). If the power of the athlete can be arranged reasonably, he can get better grade.

Scientific method have been introduced into sports field for a long time and there are some relevant work in the marathon, F1 Racing Championship. Related areas of research await our practice.

1.2 Restatement of the Problem

The problem can be simplified to obtain the relationship between the power distribution of the athlete and his position on the track after knowing the basic information of the track and the basic parameters of the athlete. The basic information of the track includes the total length of the track, the distance and slope of each ramp, the angle of each turn and its radius of curvature. The basic parameters of the athlete include weight, age, height, FTP (maximum average power output for 1 hour), CP (The critical power)[3], and sprint power. The main issues to be addressed are as follows.

1. Determine the athlete's power profile based on a number of parameters.
2. Process and apply the data of the contest's maps.
3. Analyze the power distribution of an athlete by applying his specific characteristics to a specific game
4. Sensitivity analysis of factors such as weather and road humidity and athletes being disturbed from their set goals while competing
5. Extend our model to a team time trial

1.3 Our Work

In order to select the exact power output for each athlete according to their position in the specific game situation, we have done the following works:

1. We establish CP model based on the power profile of the actual athlete. It allows us to depict the athletic ability of the athlete with limited parameters.
2. We combine actual terrain with Opencv. And the route is divided according to climbing, altitude drop level and sharp turns. In this way we can give the overall energy allocation for each section of the route.

3. We use classical mechanics to analyze the power versus position curve of the athlete at the turning point of the speed change. And we draw the picture with the specific route derived from the two races given in the question and a track we set ourselves

4. We select unpredictable factors such as wind speed, wind direction, and humidity for sensitivity testing in the competition environment.

5. We analyze the variation of the subsequent power versus position curve when the athlete deviates from the established plan due to various uncontrollable factors in the race

6. We extend our model to a team time trial and give a suitable strategy for the race.

2 Assumptions and Explanations

1. Tire rolling resistance is regarded as a constant value. Because the wind resistance of athletes and tire rolling resistance are close when the speed of the athlete reach 12km/h, while the speed of professional athletes in ITT races is generally above 25km/h.What's more, the speed of professional riders in ITT races is generally above 25km/h.So the tire rolling resistance can be regarded as a constant value during the contest.

2. Our article also does not take into account the differences in cyclists' bikes.And we assume that the athletes' skills are all certain, because the types of bikes vary and there are many uncertain variations on different terrains

3. We assume that the road is not bumpy. Because in some mountain bike races, road bumps can cause considerable energy expenditure

3 Notations

Symbol	Description	Unit
W_{Total}	Total energy required to complete the race	J
W_{i}	Energy distribution for each section in the road	J
W_{ir}	The energy distribution determined by the terrain	J
P_{O}	The power output of the athlete	W
P_{eff}	The actual power consumed by the athlete	W
t_{f}	The time takes to complete the contest	s
m	Mass	Kg
s	distance	m
g	Gravitational acceleration	N/Kg
h	The height of center of mass	m
θ	The angle of slope	rad
C_R	Rolling resistance coefficient	–
μ	Sliding resistance coefficient	–
λ	Cornering resistance coefficient	–
C	Air resistance coefficient	$\mathrm{kg/m^3}$
A	The contact area between the cyclist and the air	m^2
CP	The critical power	W

4 Model Establishment

In our model, we have two submodels, one is designed to solve energy distribution, another is designed to analyse actual pavement under the energy distributed by the first model.They will be introduced in the 4.1 and 4.2

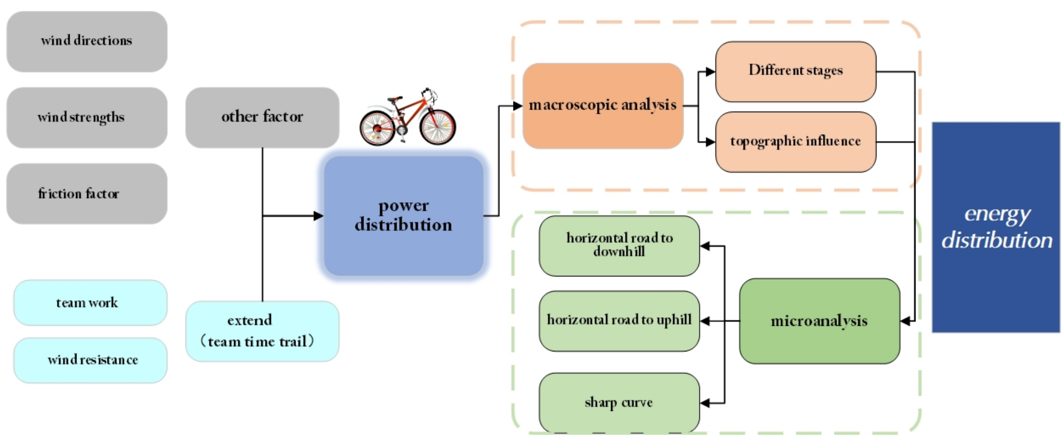


Figure 1: flow diagram

4.1 Global energy distribution

4.1.1 The power profile of the athlete

According to the athletes own parameters, FTP and sprint power, climbing power and other characteristics, we can get the athletes power profile. In the actual situation,coach can test the athletes various sports ability to get a more personal representative power profile about the athlete. In this paper we use the CP model to analyse our model.The detail about CP model is as fellows.:

$$W = (P - CP)t \tag{1}$$

The model is based on the following four assumptions :

1. Power output is a function of two energy sources: aerobic and anaerobic;
2. Aerobic energy is unlimited in capacity but limited in rate. That is, a person could exert power levels CP infinitely;
3. Anaerobic energy is limited in capacity but unlimited in rate. That means the maximum power output is infinite;
4. Exhaustion occurs when W is depleted.

P is the power bigger than CP,The t is the time that the athlete can sustain when outputting W is the energy consumed in this period.

4.1.2 Macroscopic topographic influence

When athlete rides on the slope, the length and the gradient will be the main influence factor for power output. The model can be simplified in this way, choosing the key point to consider the overall slope climb. When the gradient of the slope is fixed,the change of the athlete's speed is slight, for the total power allocated for each part of the road can be decided by the power curve.

We suppose the time for an athlete to complete a race is t_f.Its corresponding power in the power profile isP_f. We can have the equation(2) about the energy that the athlete can use.

$$W_{\text{Total}} = \int_0^{t_f} P dt \tag{2}$$

But the athlete is not a machine.The human's power output and consumption power need to be solved using the model mentioned in the previous subsection.So we can correct the above equation(2) with the equation(3)

$$W_{\text{Total}} = \int_0^{t_f} P_{\text{eff}}\, dt \tag{3}$$

In our hypothesis, the total energy of the athlete is fixed, but we can easily find that if we take a point in the power profile. The result of multiplying its power with its corresponding maintainable time is not a constant value, therefore, combined with the CP model, we can change the output power so that it multiplied with the corresponding maintainable time can be a constant, and the result of the change is the consumed powerP_{eff} :

$$\begin{aligned} P_{eff} &= P_f \cdot \frac{S_f}{S} \\ S_f &= P_f t_f \\ S &= P_0 \cdot t \end{aligned} \tag{4}$$

The final expression:

$$P_{\text{eff}} = \frac{P_f^2 t_f}{W} \frac{P_{\text{O}} - CP}{P_{\text{O}}} \tag{5}$$

According to Newton's laws of motion, we can obtain the dynamics equation for the athlete in the case of a slope with the angle θ (θ is regarded as 0 in the flat)

$$F - mg \sin\theta_i - F_{\text{resistance}} = m\frac{dv}{dt} \tag{6}$$

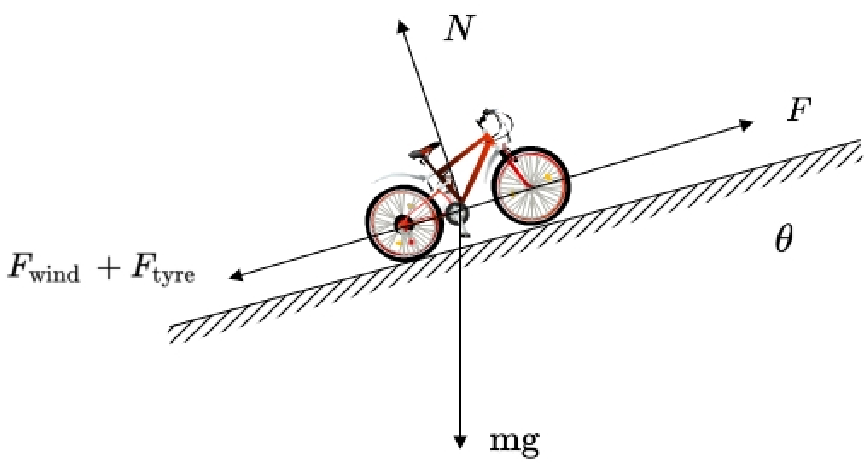


Figure 2: force analysis

The $F_{resistance}$is the resistance to which the athlete is subjected in the process of riding, and the following modeling analyzes the resistance:

$$\begin{aligned} &F_{\text{resistance}} = F_{\text{wind}} + F_{\text{tyre}} \\ &F_{wind} = r \cdot C \cdot A \cdot v_{wind}^2 \\ &A = 1.05 + (m - 30) \cdot 0.02 \end{aligned} \tag{7}$$

A is the frontal area of the people, C is the dimensionless wind resistance coefficient ,r is the density of air in kilograms per cubic meter

In the macroscopic analysis, we do not consider the acceleration between the sections of the road and the change in velocity on each section, but consider the sudden change in velocity between each section of the road.And the velocity on each section of the road is considered for the time being as constant.

$$\begin{aligned} & F - mg\sin\theta_i - F_{\text{resistance}} = 0 \\ & P_{Oi} = Fv_i \end{aligned} \tag{8}$$

P_{Oi} is the output power in each segment

$$t_i = \frac{x_i}{v_i cos\theta_i} \tag{9}$$

So our work is equivalent to find the $W_i(x_i)$ that can minimum the $\sum_i t_i$

$$\int_0^{t_f} P_{eff} dt = constant$$

After substituting the specific expressions, we need to find minimum the equation(11) in the restrain of equation(10)

$$\sum_i \frac{P_f^2 t_f}{W} \left(1 - \frac{CP \cdot x_i}{\left[C_1 v_i^4 + \left(C_2 + mg\sin\theta_i\right) v_i^2\right]\cos\theta_i}\right) = constant \tag{10}$$

$$\sum_i \frac{x_i}{v_i cos\theta_i} \tag{11}$$

The above expression is complex and involves many variables, so we consider simplifying it. In the formulation (10), we perform a Taylor expansion of the velocity v on θ. And in general, the angle of the bike course is not very large, so we can ignore the higher order minima of θ to obtain the following expression

$$Q_i = \left(1 - \frac{A}{B\theta_i + C}\right) x_i \tag{12}$$

The rationality of the hypothesis can be proved by fitting existing data

The Figure2 is the power of an athlete during a race varies with height

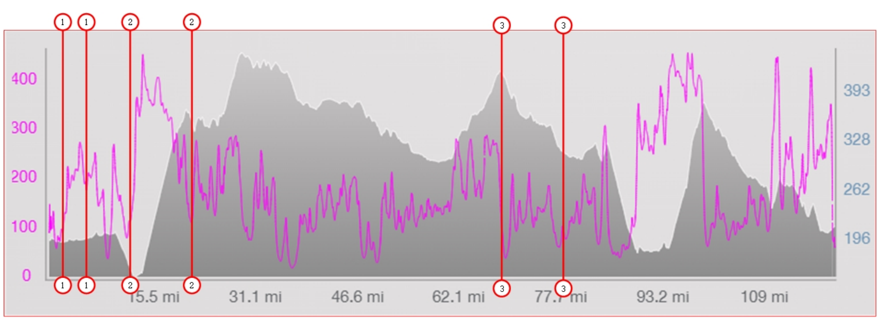


Figure 3: athlete

We climb to its selected fragments calculating the angle and its relationship with the power,then we can use the least squares fitting to get them .

The relationship we get is $\frac{B}{A}Q_i + \frac{C}{A} = \frac{1}{1-\frac{Q_i}{S_i}}$

The Figure3 is the fitting result

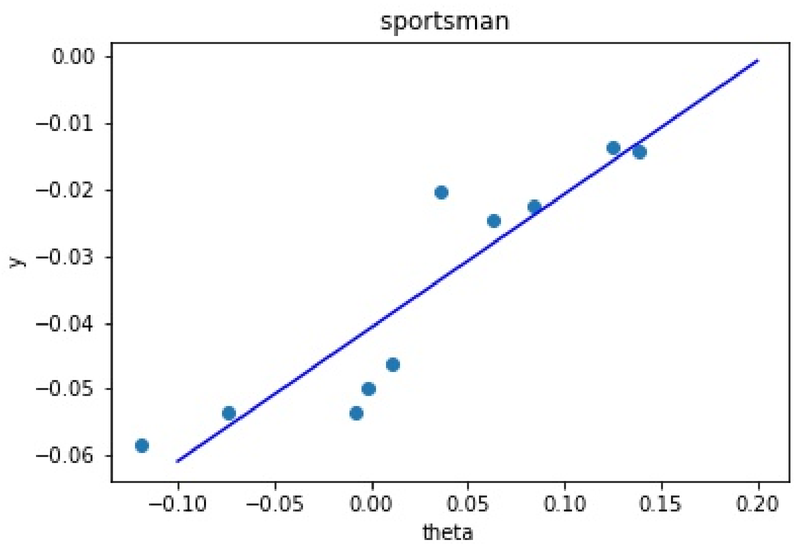


Figure 4: sportman

After calculating the dependency between variables, we can see strong linear correlation between them.We can see it clearly in the Figure4. So our assumption in the formulation(10) is reasonable. We can divide the course into several combinations of uphill, flat and downhill slopes based on slope Angle and length.The energy allocated for each segment is as the formulation below.

$$\begin{aligned} & W_i = (1 - \frac{A}{B\theta_i + C})S_i \frac{P_f t_f}{\sum_i (1 - \frac{A}{B\theta_i + C} S_i)} \\ & A = CP \\ & B = \left(g v_0^2 - 4\alpha k v_0^4\right) m - 4\alpha\beta v_0^4 \\ & C = (km + \beta) v_0^4 \\ & \alpha = 4, k = 1.677 \times 10^{-3}, \beta = 3.7 \times 10^{-2} \end{aligned} \tag{13}$$

Figure 5: The heatmap of varibles

4.2 Power profile of each section of road

4.2.1 Analysis of the ramp

Figure 6: downhill

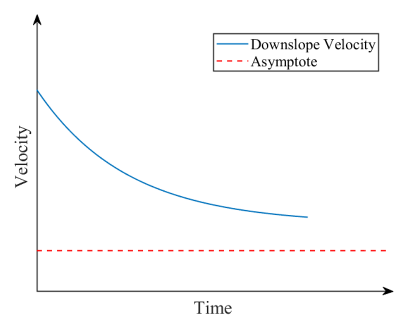


Figure 7: v-t figure of downslope

In the downslope, it takes athlete a few energy, they usually make the bike go by itself. In the downslope, the analysis of forces is as the formulation below.

$$mg(\sin\theta - C_R) - \frac{1}{2}CAv^2 = m\frac{dv}{dt} \tag{14}$$

The θ is the angle of the slope, C_R is the rolling resistance coefficient

When the gradient of the slope is small, the rolling resistance is similar to flat.

Solving the equation(14), we can get

$$
\begin{aligned}
&M=\exp\left(\frac{\sqrt{2mgCA\left(\sin\theta-C_R\right)}\cdot t}{m}\right)\\
&P=2mg\left(\sin\theta-C_R\right)-CAv_s^2\\
&Q=mg\left(\sin\theta-C_R\right)-\frac{1}{2}CAv_S^2+\left(\sqrt{mg\left(\sin\theta-C_R\right)}+\sqrt{\frac{1}{2}CAv_S}\right)^2M\\
&V(t)=\sqrt{\frac{2mg\left(\sin\theta-C_R\right)}{CA}}\left(1-\frac{P}{Q}\right)
\end{aligned}
\tag{15}
$$

The M, Q, P is intermediate variables to make the process more clearly

In the equation of V(t), we can see some properties when the angle of downhill is big

1. The process in downhill is mainly acceleration, with the increase of speed, the acceleration will decrease
2. The critical velocity is large but difficult to achieve, so we can assume the downhill is accelerated movement all the time.

If l is the length of the slope, we can get a restriction: $\int_0^t vdt = l$. With this restricted condition, we need to solve the equation below

$$
\begin{aligned}
&l=\frac{2m}{CA}\ln\left[1+\frac{R}{S}(M-1)\right]-\sqrt{\frac{2mg\left(\sin\theta-C_R\right)}{C_A}}t\\
&R=(\sqrt{mg(\sin\theta-C_n)}+\sqrt{\frac{1}{2}CAv_s})^2\\
&S=mg(\sin\theta-C_n)-\frac{1}{2}CAv_s^2+(\sqrt{mg(\sin\theta-C_n)}+\sqrt{\frac{1}{2}CAv_s})^2
\end{aligned}
\tag{16}
$$

After we get the t in the downhill. Take the t into the equation(16), we can get the final speed(also the start speed in the next section).

In the uphill, the athlete always keep a fixed speed. When the speed is too high.It will take too much energy. So we set the speed in the uphill as fixed. By combining force balance, the length of the slope, energy restriction, We can get the v_{up} in different slopes.

$$
\begin{aligned}
&P=(\frac{1}{2}CAv_{up}^2+(C_R+\sin\theta)mg)v_{up}\\
&t=\frac{1}{v_{up}}\\
&w=P\cdot t
\end{aligned}
\tag{17}
$$

4.2.2 Analysis of the bend

When athlete drive in the bend, they usually sidled through the corner to provide enough centripetal force.We can assume the move in bend as uniform circular motion. Then the resultant force provide the centripetal force. According to the stress relationship. We can get [4]

$$P = \frac{v}{1-\lambda}(\frac{C_R mgR}{R - h\sin\theta} + \frac{1}{2}CAv^2) \tag{18}$$

The λ is the coefficient of rotational resistance. C_R is the coefficient of rotational resistance. h is the height of the system centroid when the athlete stand.R is the radius of circling motion. θ is the angle with the perpendicular when the athlete leans. P is the power of the athlete.

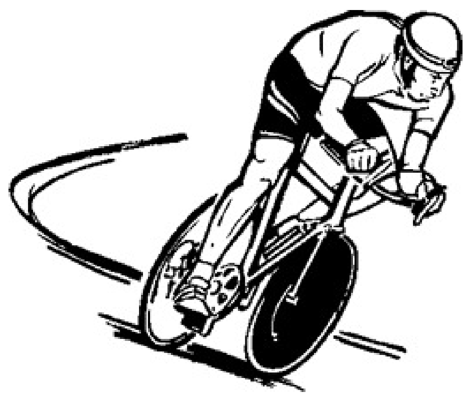


Figure 8: downhill

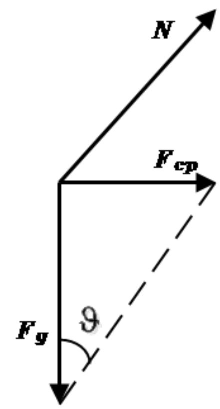


Figure 9: v-t figure of downslope

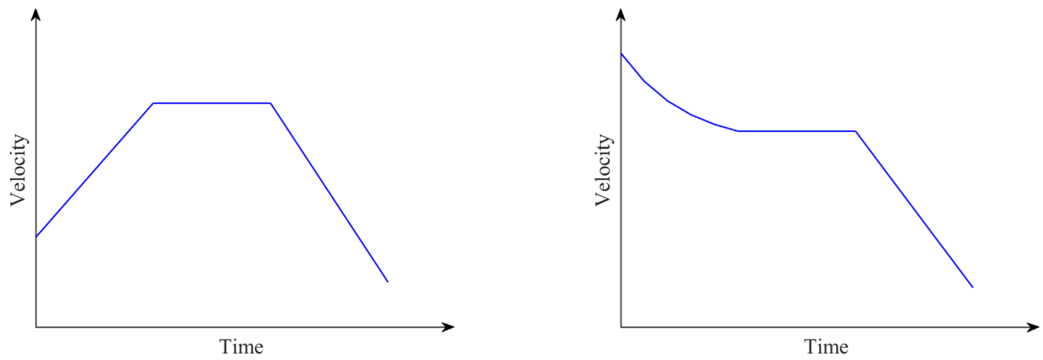
4.2.3 Analysis of the flat

To minimum the time,athlete always choose to keep a fixed speed in the flat.We assume this speed is v_0 they expected, the v_s is the speed when the enter the flat. If the $v_s > v_0$, the athlete will slide for a distance then keep the speed v_0. If the $v_s < v_0$, the athlete will accelerate to the v_0 then keep it. So the v_t(the final speed before entering the next part) has the restriction as below.

$$v_t = \begin{cases} v_0 \text{ the next is downhill or uphill} \\ \sqrt{\mu g R} \text{ the next is bend} \end{cases} \tag{19}$$

If $v_s \leq v_0$, We need to maximize the acceleration in the restriction[1]

$$s.t \begin{cases} P = (\frac{1}{2}CAv^2 + C_R mg + m\frac{dv}{dt})v \\ \int_0^t Pdt = W + CP \cdot t \end{cases} \tag{20}$$



(a) (b)

Figure 10: The v-t figure for two of all cases

The athlete can always adjust their speed in a short time. So we can regard the accelerated motion as uniformly accelerated motion. After applying the law of uniform linear motion, we can solve the equation below to obtain the acceleration.

$$
\begin{aligned}
& W+CP\left(\frac{l}{v_0}+\frac{2v_0^2+v_s^2+v_t^2-2v_0v_s-2v_0v_t}{2av_0}\right) \\
=& \frac{CA}{8a}\left(4alv_0^2-3v_0^4-v_s^4+2v_s^2v_0^2+2v_t^2v_0^2\right)+\frac{C_Rmg+ma}{2a}\left(2al-3v_0^2+v_s^2+2v_t^2\right) \\
& +\left|\frac{CA}{8a}\left(v_0^4-v_t^4\right)+\frac{C_Rmg-ma}{2a}\left(v_0^2-v_t^2\right)\right|
\end{aligned}
\tag{21}
$$

After solving it, we can get

$$
\begin{cases}
t_1=\frac{v_0-v_s}{a} \\
t_2=\frac{l}{v_0}+\frac{v_s^2-2v_0v_s+v_t^2}{2av_0} \\
t_3=\frac{l}{v_0}+\frac{2v_0^2+v_s^2+v_t^2-2v_0v_s-2v_0v_t}{2av_0} \\
x_1=\frac{v_0^2-v_s^2}{2a} \\
x_2=v_0\left(t_2-t_1\right)+x_1 \\
x_3=l
\end{cases}
\tag{22}
$$

The power in three situations can be expressed as below

$$
P=\begin{cases}
\left(CAax+\frac{1}{2}CAv_s^2+C_Rmg+ma\right)\sqrt{2ax+v_s^2}, x\le x_1 \\
\frac{1}{2}CAv_0^3+C_Rmgv_0, x_1<x\le x_2 \\
\left|\frac{1}{2}CAv_0^2-CAa\left(x-x_2\right)+C_Rmg-ma\right|\sqrt{v_0^2-2a\left(x-x_2\right)}, x_2<x\le x_3
\end{cases}
\tag{23}
$$

If $v_s > v_0$, it will slow down until reach the v_0, then we can use this model to solve it. The equation in this stage is

$$
C_Rmg+\frac{1}{2}CAv^2=-m\frac{dv}{dt}
\tag{24}
$$

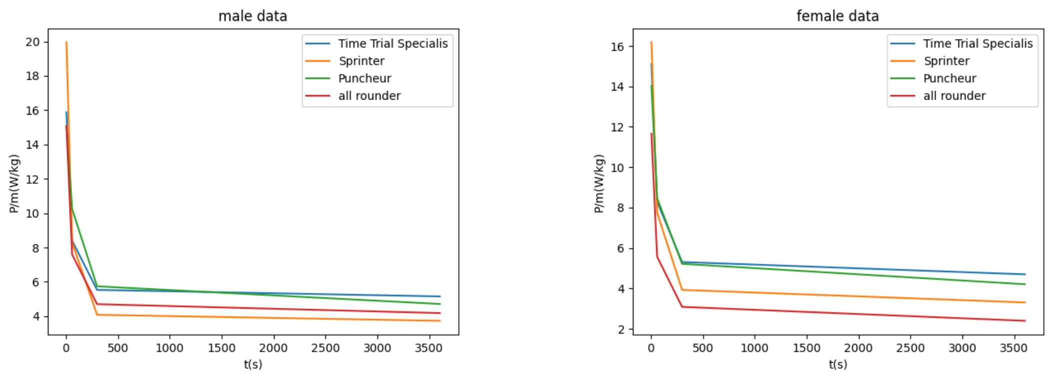
After solving this equation, we can get $v(t)=\sqrt{\frac{2mgC_R}{CA}}\tan(\tan^{-1}(\sqrt{\frac{CA}{2mgC_R}}v_s)-\sqrt{\frac{gC_RCA}{wm}}t)$

The t_0,x_0 is the time and the distance in the moderating process. The P is 0 all the time.

5 Implement

5.1 Power profile

We obtain the power profiles of several athletes of different types, as shown below



(a) all types of the male athletes (b) all types of the female athletes

Figure 11: The contest maps

We have developed a CP model to facilitate our analysis of the actual problem.

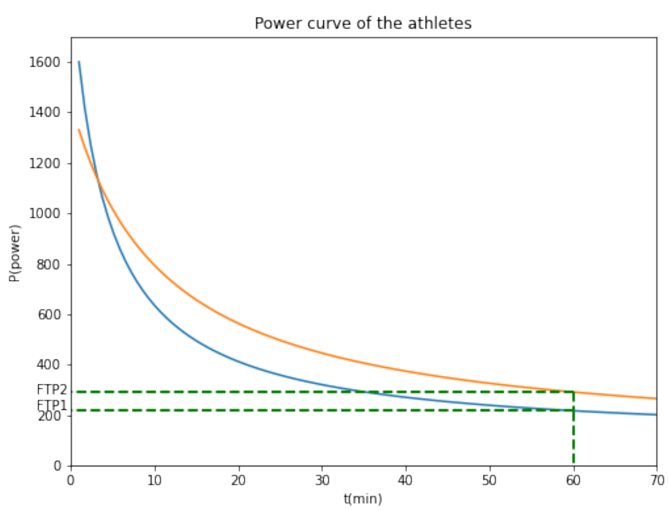


Figure 12: CP model

The following table shows the power profiles of athletes we defined.

data	athlete1	athlete2	athlete3	athlete4
Rider type	TTer	TTer	CHer	CHer
gender	male	female	male	female
height	1.84	1.68	1.67	1.62
weight	75	57	58	52
Maximum power in 30 seconds	1400	870	1204	780
FTP/w	305	275	290	270
CP/w	278	260	273	263
$\alpha_{1,2,3}$	0.95/0.98/1.1	0.96/0.97/1.1	0.96/1/1.05	0.99/1/1.05

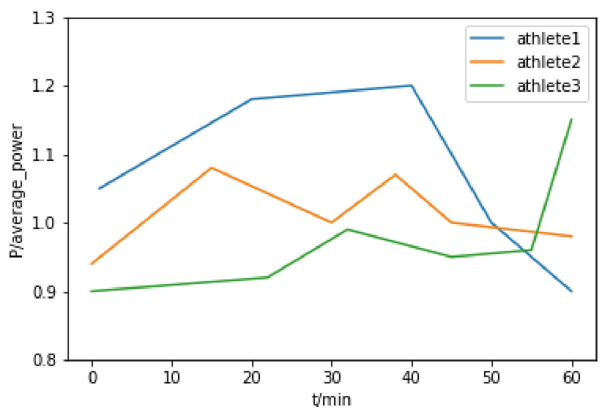
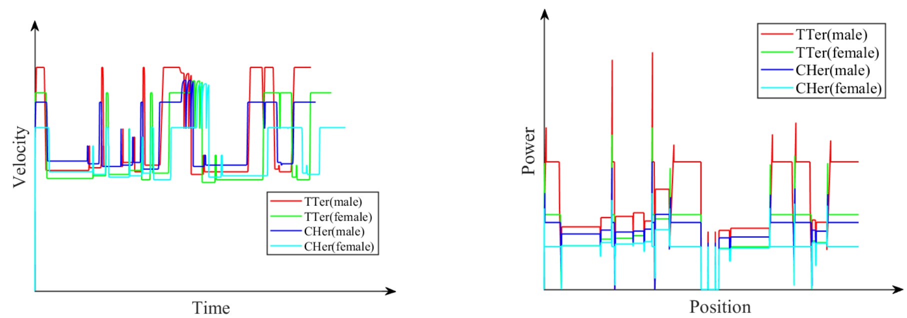


Figure 13: α of different athletes

TTer is time trial expert while CHer is Climbing hand, α is $\frac{P}{\text{The average power}}$

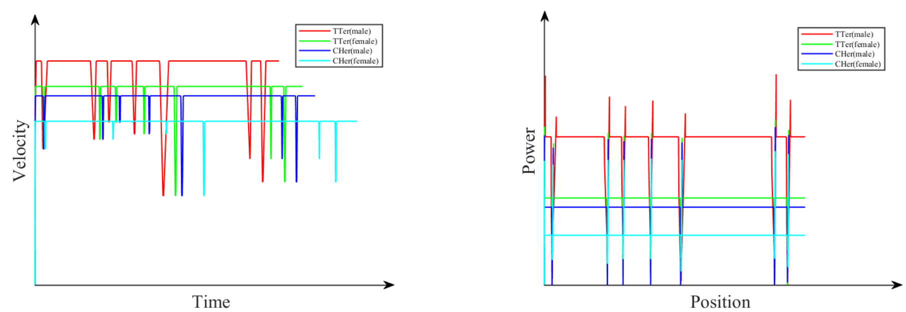
5.2 The P-x and v-t curve in the contest

The maps of these contests are in the appendix B.The figures below are the P-x or v-t curve of them.



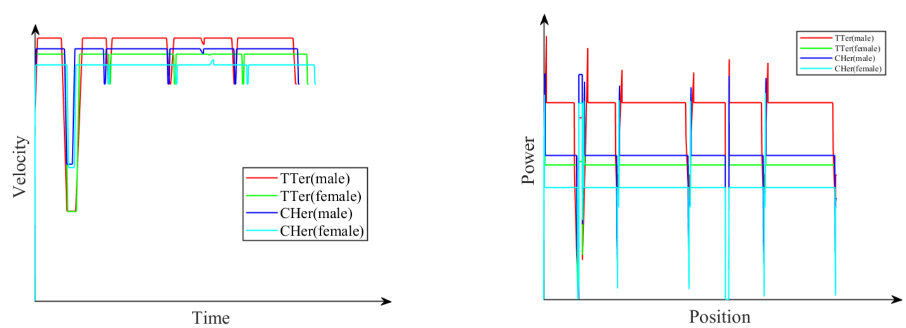
(a) v-t (b) P-x

Figure 14: 2021 Olympic Time Trial course



(a) v-t (b) p-x

Figure 15: 2021 UCI World Championship time trial course



(a) v-t (b) p-x

Figure 16: The map made by ourselves

According to the above figures,we find the TTer (Time Trial Specialist) can finish the contest in the shortest time and CHer(Climber) perform better in the uphill, which is consistent with their characteristics in energy distribution.The overall performance of men was slightly better than that of women, which is consistent with the difference in physiological differences between men and women. Therefore, our model fits the actual situation very well.

6 Sensitivity Analysis

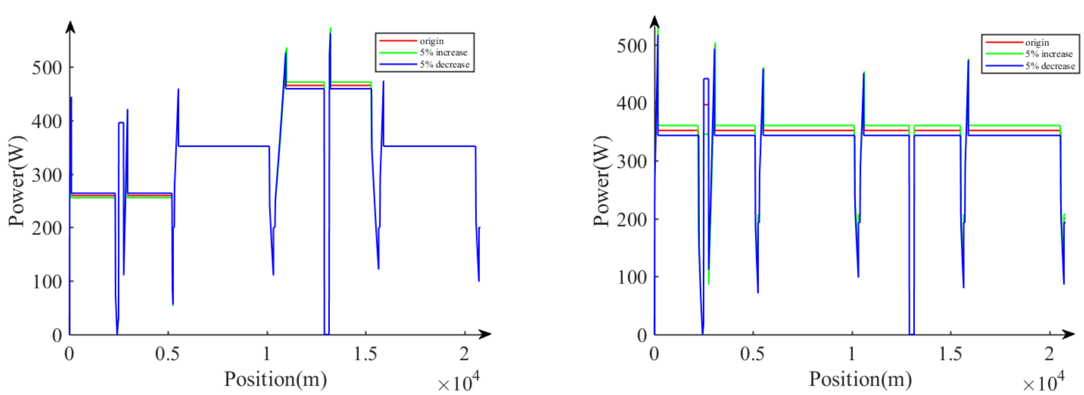
6.1 Weather sensitivity

In the actual competition, the weather factors affect the performance of the athletes.The bad weather will limit the players' strength. So we will discuss the sensitivity of the model to wind and moisture in this part.

The effect of wind on athletes is mainly reflected in air resistance. In the air resistance formula, $F = \frac{1}{2}CAv^2$ can be revised to $F = \frac{1}{2}CA(v_{cyclist} + v_{wind})^2$ Because the wind direction only affects the wind speed in the direction of the athlete's forward speed.So we only analyze the sensitivity of the model to size.

The influence of moisture on athletes is mainly reflected in rolling resistance,so we will discuss the sensitivity of the model about the rolling resistance coefficient.

Take the the road designed by ourselves and the male athlete for example,by changing the v_{wind}, C_R, we can the get the picture below



(a) change the $_{wind}$ (b) change the of C_R

Figure 17: The change of parameter

According to the figure(15), our model is not sensitive to the change of the parameter

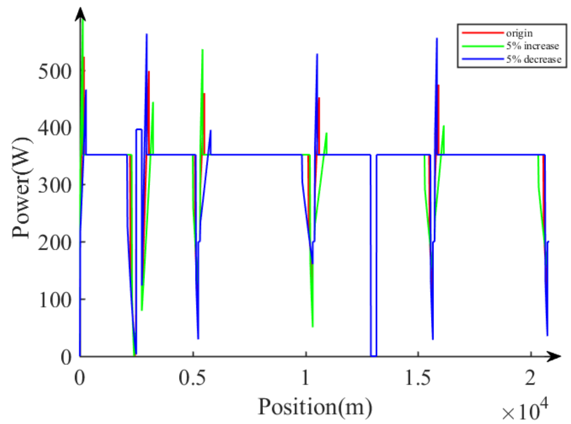


Figure 18: change the distribution

6.2 Disturbance sensitivity

Since athletes may fail to compete according to the planned power due to various accidents that may occur in actual competitions, we need to consider the power distribution of athletes when part of the power deviates from the planned power.We select several routes randomly and increase or decrease the energy of this part while keeping total energy constant. After changing the distribution of the contest, we can get the figure below.

It can be seen from the above figure that athletes deviating from the established power allocation by 5% has little influence on the subsequent energy allocation.

7 Expansion

The above model can also be applied to team time trial (TTT). According to the study on air resistance of two people riding behind in TTT (cited in the paper),we can know that if there are people riding in front (breaking wind) and people riding behind (following) in a team, the riders behind can save energy.

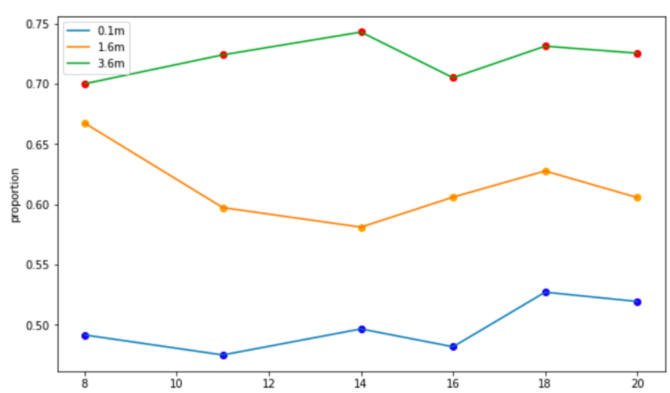


Figure 19: The f_{wind} relation with distance

The biggest difference of ITT and TTT is caused by the energy change above. The most appropriate strategy is to start the team cycling in the same line.The player1 starts breaking the wind first,after arriving at x_1, The player 1 abandons breaking the wind, and relaxes until the end of the game, by its behind the player 2 starts breaking the wind.After arriving at x_2, the player 2 also gives up breaking the wind and relaxes.In the remain distance,four players take turns to break wind and finish the sprint.

The specific allocation plan is as below

1. Suppose there is a ITT contest same as the TTT contest, with the same starting point but its destination is x_1 in the itt games, Player 1's power distribution in TTT is same to the one in ITT contest.
2. Suppose there is a ITT contest same as the TTT constest, but it's destination is x_2,starting point is x_1 in TTT, Player 2's power distribution in TTT is same to the one in ITT contest.
3. Suppose there is a ITT contest same as the TTT contest, but it's starting point is x_1 and the player 3,4,5,6 have some energy consumption.The energy distribution of them in TTT is same to the one in ITT contest.

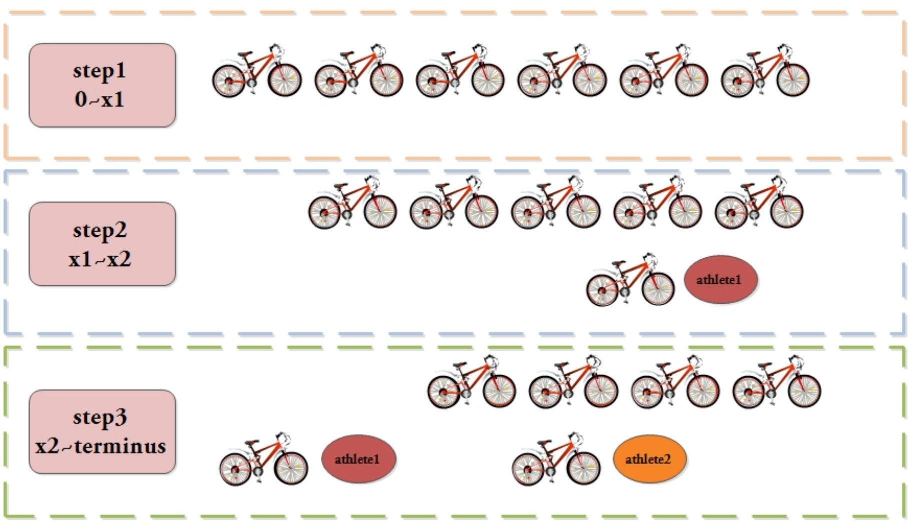


Figure 20: The f_{wind} relation with distance

The specific energy consumption is relate to the characteristic of athletes.We will not discuss it detaily in this article.We just provide a reasonable team strategy in this place.

8 Evaluation of Strengths and Weaknesses

8.1 Strengths

1. First of all, this paper analyzes the whole race, so that the athletes can understand the overall power distribution strategy, so as to adjust the power deviation from the established goal due

to accidents.

2. At the same time, we consider how to deal with the details of power distribution when the rider encounters terrain changes in the process of moving, so that the athlete can pass the curve and steep uphill and downhill with the optimal strategy.

3. The strategies discussed in this paper are not sensitive to changes in most other parameters and can be extended to a wide range of races.

4. This paper focuses on the characteristics of power profile of athletes, which has strong correlation.

8.2 Weaknesses

1. In our model, we ignore the change in the athlete's energy consumption in changing the pose of riding and the windage change.

2. We ignore the extreme situation like the slope with the big angle.In the contest with plenty of slope, it may have some bad impact on the energy distribution.

3. Normalized Power (NP) is generally used to reflect the actual power value, since the uncertain factors in the cycling process make the power erratic and difficult to analyze.

4. Our model is a simplified model because the difference in the bicycle will also effect the result,but we do not consider these factors.

References

[1] Jenny de JongOn.the optimal power distribution for cycling a time trial[D].Utrecht:Utrecht university 2015.

[2] VOGT, S., L. HEINRICH, Y. O. SCHUMACHER, A. BLUM, K. ROECKER, H-H. DICKHUTH, and A. SCHMID. Power Output during Stage Racing in Professional Road Cycling. Med. Sci. Sports Exerc., Vol. 38, No. 1, pp. 147151, 2006.

[3] Qiao J. Application of power-maintenance time curve and critical power in predicting cycling performance[J]. Sports Research,2021,042(003):99-104

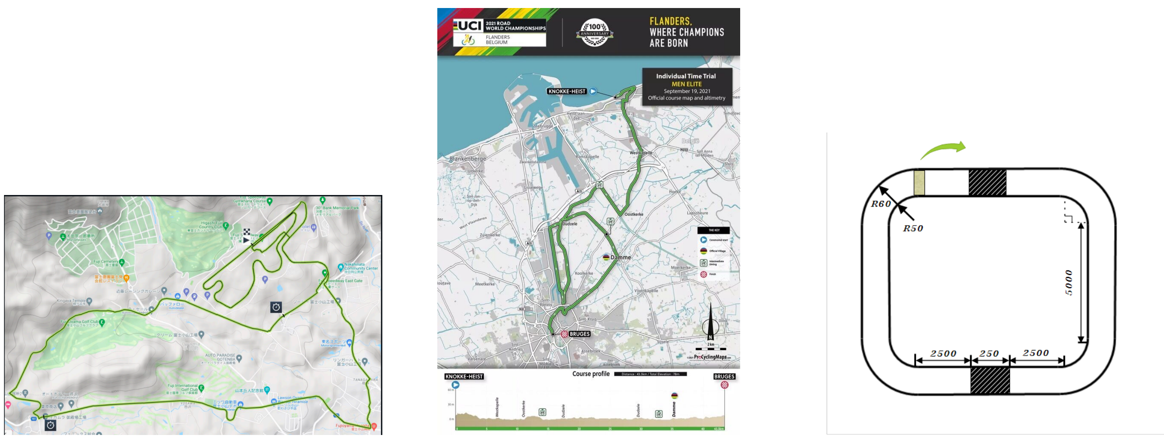
[4] Len Bos , Michael A. Slawinski , Raphaĺel A. Slawinski , Theodore Stanoevğ [J] Modelling of cyclists power for timetrials on a velodrome 2022

Appendices

Appendix A Tools and software

Paper written and generated via LATEX, free distribution.
Graph generated and calculation using MATLAB R2019a.
Data processing and diagramming using Python 3.9 and visio

Appendix B Contest maps



(a) 2021 Olympic Time Trial

(b) 2021 UCI World Championship time trial

(c) The self made map

Figure 21: The contest maps

The shaded part is slope.The direction is along the white line,and the angles are both 12.7°.

Guidance to improve cyclist

To: Directeur Sportif

From: Team 2210391

It is no doubt that you are eager to improve your cyclists contest results.In this guidance,we will give you some advice so that you can better understand how to display your cyclists capability.These suggestions are based on our model.

Every cyclist has his pros and cons.For a time trial expert,he will focus on overall speed,which enables him to achieve shorter time.For a climber,he is good at climbing up a slope while others may climb slow.Before the contest,you should analyze your cyclists concrete characteristics,so that he can achieve better grades.

Energy distribution is also significant.According to our model,the higher power the cyclist exerts,the shorter time he can maintain.If the cyclist exerts too high power at some situations,he will lose much energy and ought to restore in the rest contest.So you can conduct your cyclist to rationally allocate energy during the game.

Take different strategies in different terrains.On flat,the cyclist has more chances to adjust,but should maintain high speed.On the upslope,keep a lower speed in case of consuming too much energy.On the downslope,take a break and let the bicycle run by itself.

Last but not least,there are some tricks which might help.Adjusting a lower posture can reduce the resistance of air.Leaning while turning can save energy.

Hope our suggestions can help your cyclist improve.We sincerely wish your cyclist a better grade.