Problem Chosen	2024 MCM/ICM Summary Sheet	Team Control Number
A		2215308

Power Allocation Strategies For Cyclists

Summary

Cyclists should allocate their energy appropriately to improve their grades in the course. In our paper, we develop several models to **optimize the cyclist power allocation strategy**.

Firstly, we build the **Power Consumption Model** to estimate the power of cyclists to overcome resistance. Through force analysis, we consider the gravity, rolling resistance and air friction as the components of resistance and derive the formula to calculate them. As a result, we get the relationship between cyclists' power consumption, road situations and motion states.

Secondly, we should properly **define the power curves** of different cyclists. After collecting data of four riders, we acquire their maximum maintaining power for 5s, 60s, 300s and 3600s. Then we use the data to portray the power profiles by means of **local cubic fitting**. By analyzing the result, we're glad to find that the power curves we define can fully reflect the feature of different kinds of cyclists.

Thirdly, aiming to simulate the energy consumption in time trail, we build a model to assess the change of cyclists' energy over time, where we use the state of **"overdraft"** and **energy consuming function** to estimate the influence of tiredness accumulation and power curve limitation. Then we determine the energy consuming function based on actual situation and establish the **motion equation** of the cyclists.

After that, we apply our model to three cycling races(two are really exist, one is self-designed) to test the model. Based on the track and elevation data of these races, we portray the **optimal position-power profile** of each cyclist in each race through **Genetic Algorithm**. The results are shown in Figure 8, 9, 10. By analyzing the figure, we suggest the average speed of cyclists be about 13.5m/s for man and 12.5m/s for woman. Furthermore, we offer some tips for different kind of cyclists to copy with different courses.

Additionally, we extend our model to make it feasible to adapt to team course. Considering that the leader can block the wind for others in team course, we propose a detailed schedule which provides the strategy on the optimal candidate and suggested speed of the **"wind-blocker"** in each time interval of the race in Table 2. Through this strategy, the grade of cyclist can be improved by 18.9% compared with individual course.

The paper also analyze the model's sensitivity to wind and rider's deviation. The headwind or disturbance on rider's speed will cause the result to increase by about 2%. So these two exert impacts on model's stability, for which we offer the strategies to cyclists to minimize the impacts.

Finally we write a guidance for the Directeur Sportif on how to improve the time trial specialist's performance in plat road.

Keywords: Power Consumption Model, Power Curve Fitting, Cyclist Position-Power Profile, Time Trail Course

Contents

1 Introduction

1.1 Background

"Cycling race is so charming. As long as you take part in it once, you will be infected by the atmosphere, thinking about how to become stronger next time." Said by a cyclist. But to get good grades in cycling competition, merely enhancing the body strength is not enough. Actually cyclist should also formulate appropriate strategies to allocate their strength based on their riding abilities in different road conditions.

The amount of power and power allocation strategies vary greatly among riders. Different types of riders may participate in individual time trail, such as time trial specialist, climber, sprinter, rouleur or puncheur. Because of the time limitation, our model only considers the performance of time trial specialist and climber. Before establishing our model, we firstly search the introduction of climber and time trial specialist.

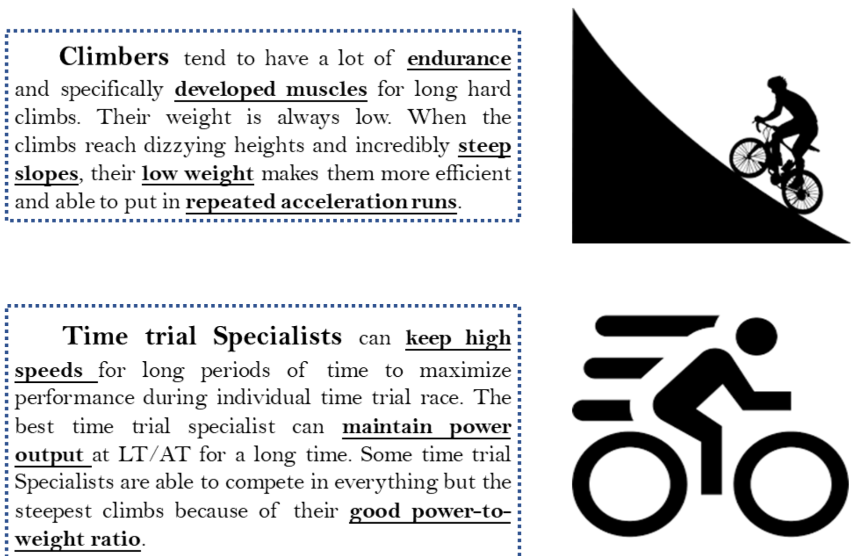


Figure 1: Introduction of climber and time trail specialist[9][8]

1.2 Problem Restatement

Riders always hope to minimize the time to cover a given distance. We're required to guide them on how to allocate their energy properly in the time trial. To achieve this goal, we should

- determine the power curves of different cyclists.
- develop a model to evaluate the power consumption of cyclists in the course.
- Apply the model to offer optimal energy allocation strategies for cyclists in different time trail courses.
- Extend the model to team courses and analyze its sensitivity to wind and rider's deviation.

1.3 Our Work

In this paper, we establish three models to solve the problem. Firstly, through force analysis, we establish Power Consumption Model to estimate how much power the rider uses to overcome friction. Then we develop Power Curve Model and define the power profiles of different kinds of cyclists. Finally based on the estimation of cyclists' energy consumption, we develop Cyclist Power-Position model to determine the relationship between the rider's position on the course and the power the rider applies.

We then apply our models to three time trial courses. Based on the track information, we attain the Power-position Curves of different cyclists. Additionally, we extend our model to team course and analyze the sensitivity of the model. Finally we write a specific guidance for the Directeur Sportif.

The flow chart of model framework is shown in Figure 2.

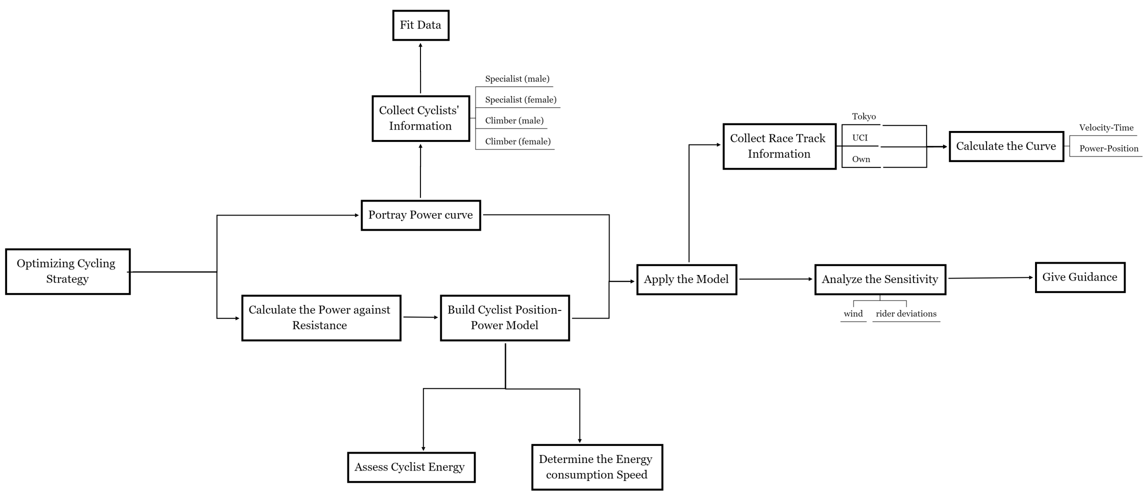


Figure 2: Model Framework

2 Assumptions and Justification

To simplify our problems, we make the following basic assumptions which are properly justified.

- The player's condition is determined only by the wind and is not affected by other environmental factors.

- Road friction factor is a fixed constant which remains the same in the whole race.

- The frontal area of a rider is fixed in the whole race, which is determined by rider's height and weight.

  Justification: Riders always use the best riding postures to minimize the frontal area. Considering the long race, the error caused by posture adjustments can be neglected.

- When considering the impact of turning, we ignore the time spent on turning and only consider the speed of turning has a limitation.

Justification: The time spent in the turning process of all cyclists is almost the same. However, the accelerating and decelerating process may cause excessive energy consumption for cyclists.

3 Notations

Symbols	Descriptions
g	Acceleration of gravity
C_{rr}	Coefficient of rolling resistance
C_d	Drag coefficient
ρ	Density of air
η	Efficiency constant
P_c	The instantaneous power consumption of cyclist
P_w	The power rate on wheels
P_a	The power used to accelerate
F_f	Total resistance
F_g	Gravity
F_r	Rolling resistance
F_a	Air friction
m	Total mass of bicycle and rider
W	Weight of the rider
θ	Slope
A	Frontal Area of the rider
S_A	Surface area of the rider
v	Velocity
R	Radius of turning circle.
T	The total time of the course
$energy(t)$	The remaining energy of the rider at the moment of t
$\gamma(P,t)$	The speed of energy consumption of a rider at the moment t and power P
$\Delta\gamma(t)$	The accumulating rate of tiredness
$Strength_{normal}$	The total strength a rider can use in the state of normal
$Strength_{over}$	The remaining energy a rider can use in the state of overdraft
k	The coefficient to describe the "overdraft" influence on the rider
$l(t)$	Variable to describe the wind-blocker at the moment t
$\alpha(x,t)$	Included angle of the road direction in the position x and the wind direction at the moment t

4 Model1: Power Consumption Model

Considering the main energy expenditure of cyclists is to offset the influence of resistance, we should firstly determine how much the resistance is under different road conditions at different speeds. The total resistance(F_f) can be divided into three component forces, which respectively represent gravity(F_g), rolling resistance(F_r) and air friction(F_a) as shown in Figure 3.

$$F_f = F_g + F_r + F_a$$

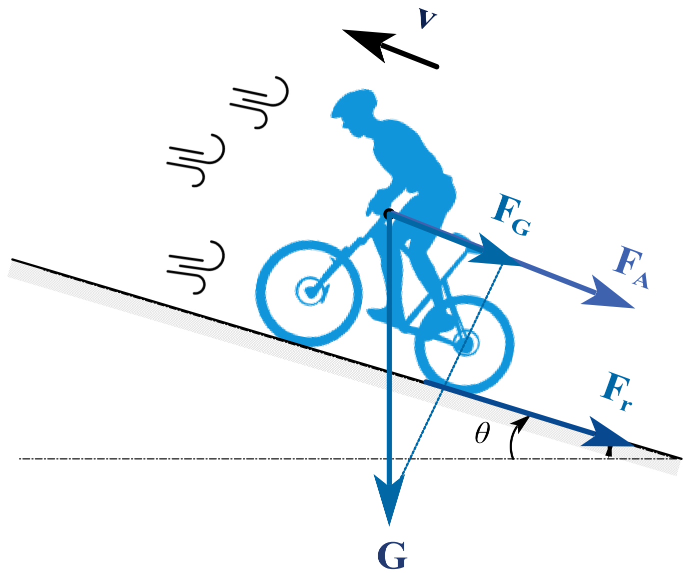


Figure 3: Force analysis diagram of a cyclist

Gravity: We all know that cycling uphill needs more effort because cyclist is fighting against gravity, and this can be expressed as

$$F_g = mg\sin\theta$$

Rolling resistance: Friction between tires and road surface can slow a cyclist down, and this force is proportional to support force N. In this model, N is $mg\cos\theta$. So the expression of F_r is:

$$F_r = C_{rr}mg\cos\theta$$

where C_{rr} is a dimensionless parameter called coefficient of rolling resistance, which is determined by the road condition and tyre pressure.

Air friction: While cycling against wind, the rider needs to push the air around and is resisted by air friction. The faster the rider moves, the larger force the air pushes him or her. Actually we have the formula

$$F_a = 0.5 \cdot C_d A \cdot \rho \cdot v^2$$

to determine air friction, where ρ is the density of air, which is $1.29kg/m^3$. C_d is the drag coefficient and A is the frontal area. In reality C_d changes as A changes. But to simplify our model, we assume C_d is a constant for every rider with value 0.63.

To calculate front area A, we get the relationship between surface area(S_A), height(H) and weight(W) of the rider through research.

$$S_A = 0.0061H + 0.0128W[7]$$

And while cycling, the front area can be roughly defined as

$$A = \frac{1}{4}S_A$$

, for we assume that the height of the rider when cycling can be regarded as half of the real height. Moreover, only the front surface of the rider suffers from air resistance.

As soon as the fore-mentioned three components are determined, the power rate on wheels can be presented as:

$$P_w = F_f v + P_a$$

where P_a represents the power to accelerate. Considering the practical situation, accelerating needs additional energy$P_a = mv\frac{dv}{dt}$, but decelerating cannot recycle any energy. So P_a can be defined as

$$P_a = \begin{cases} mv\dfrac{dv}{dt} & \text{if } \frac{dv}{dt} > 0 \\ 0 & \text{if } \frac{dv}{dt} \leqslant 0 \end{cases}$$

The power P_w is provided by cyclists' legs, but not all the power from cyclist's legs can make it to the bicycle. Actually we have

$$P_w = \eta P_c$$

to consider the energy loss of bicycle ,where η is the efficiency constant. In our model, we define η as 0,97.

[5]

5 Model2: Power Curve Model

5.1 Introduction

Power curve is a valuable tool for analyzing strengths and weaknesses of a cyclist and further giving appropriate training plans. Specifically, the curve can reflect the maximum power a rider can maintain for a particular length of time.[6] We can estimate different ability of a cyclist through the value of the power profile to different lengths of time. Usually, short-time part of the curve corresponds to sprint power and long-time part of curve corresponds to endurance.

The x-axis of the curve is time while the y-axis has two forms. One is the maximum power(Unit: W) a cyclist can maintain in t seconds, which reflect the energy and strength of the cyclist. But considering that the resistance and the power may both increase with the raise of weight, P/W (can be represented as power per unit mass) may be a better way to estimate the physical quality of a cyclist. So the other form of y-axis is maximum power per unit mass (unit: W/kg) which can better describe the physical quality of the cyclist.

5.2 method

In our Power Curve Model, we select four cyclists(2 male and 2 female, 2 time trial specialist(TTS) and 2 Climber(C)), and collect the data of their maximum powers for 5s, 60s, 300s and 3600s respectively. The data is listed in Table.

Table 1: Four Cyclists' Information

Cyclist 1			
Type: TTS		Sex: Male	
Weight: 75kg		Height: 1.77m	
Maximum Power			
5s	1752W	300s	562.5.5W
60s	828W	3600s	473.25W

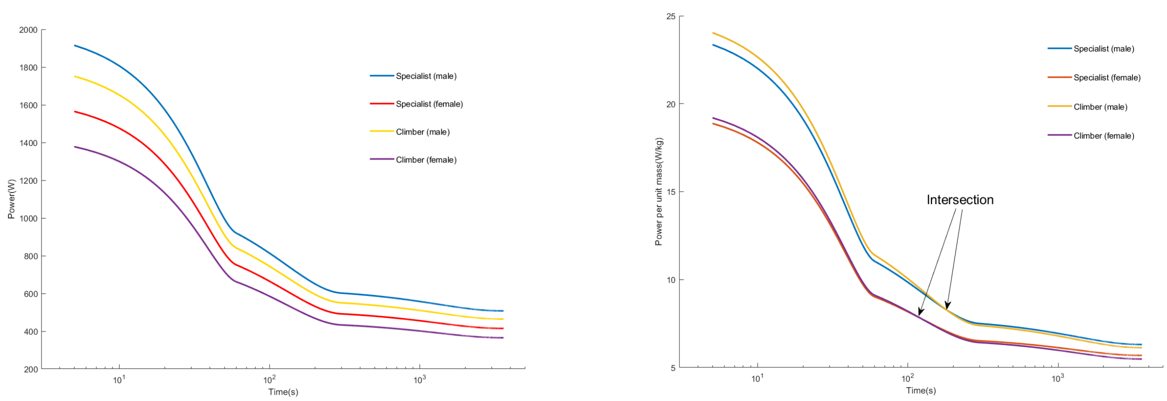
Cyclist 2			
Type: TTS		Sex: Female	
Weight: 59kg		Height: 1.75m	
Maximum Power			
5s	1113.3W	300s	384.5W
60s	531.9W	3600s	335.5W

Cyclist 3			
Type: C		Sex: Male	
Weight: 59kg		Height: 1.74m	
Maximum Power			
5s	1418.4W	300s	436W
60s	672W	3600s	361.7W

Cyclist 4			
Type: C		Sex: Female	
Weight: 54kg		Height: 1.68m	
Maximum Power			
5s	1036.3W	300s	346.5W
60s	491.7W	3600s	296W

Using the method of local cubic fitting, we define the power curves of four cyclists. The results are shown in Figure 4.

5.3 Results and analysis



(a) Relationship between Power and Time (b) Relationship between Power per Mass and Time

Figure 4: Two types of Power Curve

As shown in Figure 4a), the curve of the climber is absolutely dominated by the specialist's. That's because climbers are lighter than the specialists so they cannot compete with specialists in terms of producing power. However, their curves become extremely close when their weights are divided. And the climbers' advantages are emphasised especially when the value of power is large, which is corresponded to their fitness to high-intensity climbing training.

6 Model3: Cyclist Position-Power Model

6.1 Introduction

In this section, we are required to define a power-position curve that can be applied to any type of rider. But when establishing the model, we find it hard to provide strategies simultaneously for different cyclists, because the power curves and strengths of different cyclists vary widely. So we decide to determine the position-power curve for each cyclist respectively, which means portraying four different curves. Further we can accurately consider the physical quality of cyclist and our strategies can be more specific and detailed.

6.2 Cyclist Energy Assessment

When we determine the change of energy of a cyclist over time, we should consider the following items.

- The rider has a limitation on the total energy.
- The strategy of rider's power consumption is better to fit the power curve.
- If the accumulating power consumption reaches a threshold, then the rider will be in a state of overdraft, which means the rider may consume more energy than as usual at the same speed. The accumulation from past aggressiveness or exceeding the power curve limits for a long-time may induce overdraft.
- The rider's energy can recover if the rider rides in a slow speed.
- The tiredness of the rider will accumulate with time, which means at the same speed, the energy consumption increases over time.

To better describe the state of "overdraft", we divide the rider's energy into two parts as shown in Figure 5. If the energy is higher than threshold, we call that the rider is "normal".If the energy is lower than threshold, then the rider is in a state of "overdraft".The energy consumption functions of "normal" and "overdraft" are different.

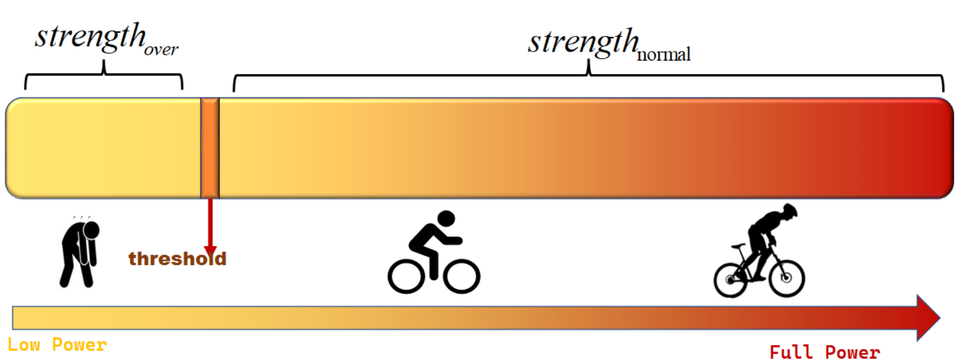


Figure 5: The composition of rider's energy

We apply variable $energy(t)$ to describe the remaining energy of the rider at the moment t. At the beginning of the race, the energy satisfies:

$$energy(0) = strength_{normal} + strength_{over}$$

, where $strength_{over}$represents the threshold of energy. And it's obvious to get

$$energy(t) \in [0, energy(0)], \forall t \in [0, T]$$

And the energy consumption process can be expressed as

$$\int_0^T \gamma(P,t)dt = energy(0) - energy(t)$$

where $\gamma(P,t)$ is a parameter which describes the speed of energy consumption by a rider at the moment t and power P. Considering that the rider can recover when the power P is relatively small, we suppose the value of $\gamma(P,t)$ can be negative. The negative $\gamma(P,t)$ means energy recovery while positive $\gamma(P,t)$ means energy consumption.

The relationship between P and the rider's velocity v is given by Model 1 which is

$$P = \frac{mgv(t)\sin\theta + C_{rr}mgv(t)\cos\theta + 0.5C_d A\rho v(t)^3 + P_a}{\eta}$$

Then we should properly determine $\gamma(P,t)$. Aiming to reflect the combined influence of rider's state and accumulation of riding time on power consumption, we define $\gamma(P,t)$ as

$$\gamma(P,t) = \begin{cases} \gamma(P,0) + \Delta\gamma(t), \text{ energy } (t) > \text{ overdraft} \\ k(\gamma(P,0) + \Delta\gamma(t)), \text{ energy } < \text{ overdraft} \end{cases}$$

where $\Delta\gamma(t)$ reflects the accumulating rate of tiredness and k is the coefficient to describe the "overdraft" influence on the rider. In our model, we take k=2.

Additionally, we can make use of the information in power curve and get the formula

$$\int_0^{t_{\max}(P)} \gamma(P,t)dt = \text{strength}$$

where $t_{\max}(P)$ is the maximum duration of the rider at the energy consumption P.

Finally, we have

$$\int_0^T v(t)dt = s$$

, for the rider who successfully completes the race. And our objective is to find the minimum T.

6.3 Parameter Determination

Firstly, we roughly determine the proportion of $strength_{over}$ and $strength_{normal}$ as 1:5 considering the remaining energy when we feel overdraft.

By now the only thing remaining to be determined is $\Delta\gamma(t)$. To make it adapt to real situation, it should satisfy:

- :$\Delta\gamma(t)$ can be negative and $\Delta\gamma(0) = \frac{1}{350}$. The negative value can reflect the process of energy recovery. Quantitatively, we assume that a rider may spend 350s to fully recover at the beginning of the race when remaining motionless.
- :$\Delta\gamma(t)$ monotonically increases with t. Because as the time accumulates, the energy consumption speed increases.
- :$\Delta\gamma(t)$ increases fast when t is small, and becomes flat as t increases. That's because the energy consumption may boom rapidly at the beginning of the race, then tend to be stable for a long period of time.

Through trial and adjustments, we finally determine $\Delta\gamma(t)$ as

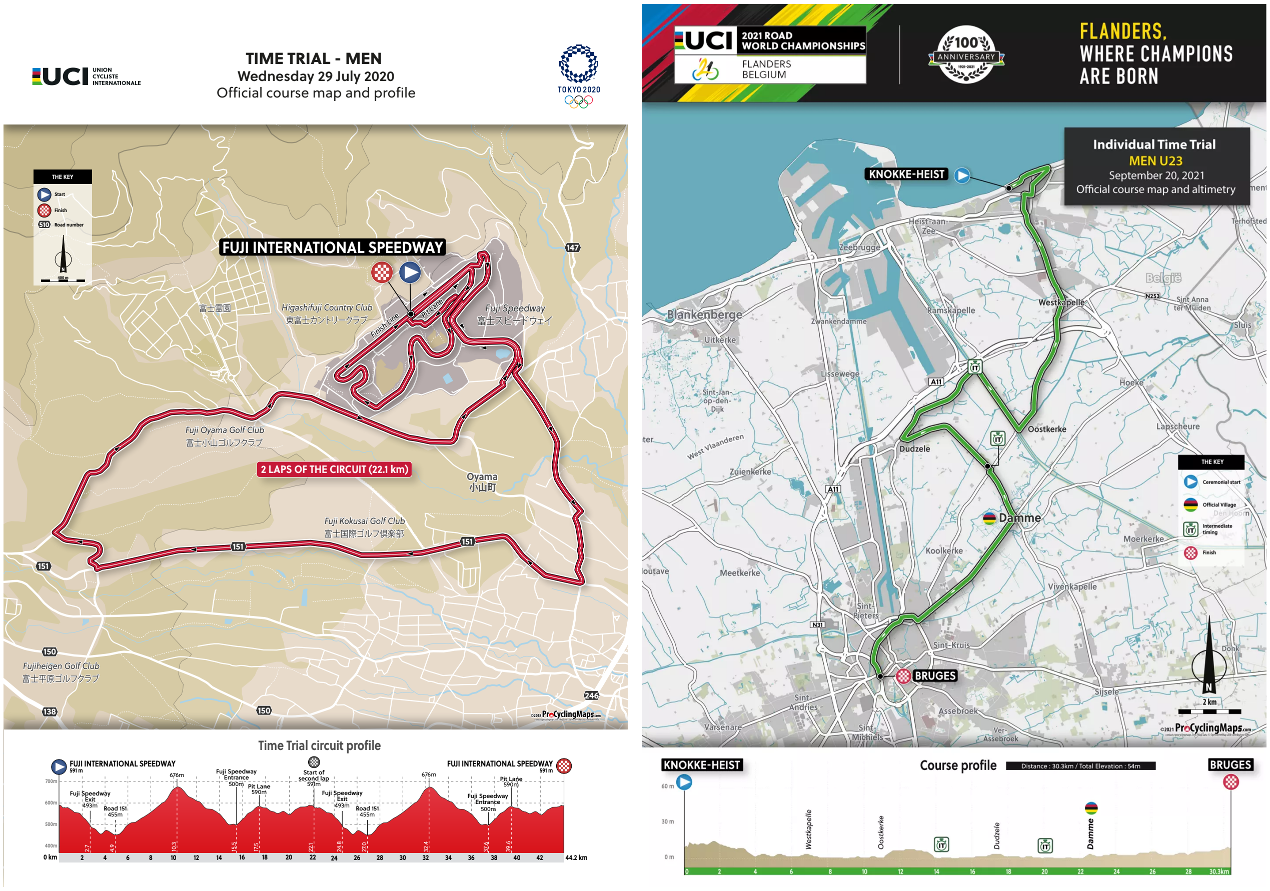
$$\Delta\gamma(t) = -\frac{1}{x+350} + \frac{1}{350}\ln(x+1)$$

7 Model Application

Using the Cyclist Position-Power model, we design the feasible strategies for riders in different competitions. Here we take the 2021 Olympic time trial course in Tokyo and 2021 UCI World Championship time trial course in Flanders to test our model. Additionally, we design a brand-new race track in Liptovský Mikuláš, Slovakia, for the sake of generalizing our model to different race situations.

7.1 Basic Information of the Courses

The route information and elevation data of two courses are collected through their official websites and are shown in Figure 6.



(a) Tokyo Olympic game[2]

(b) UCI World Championship[1]

Figure 6: Track and Elevation Graph of Two Time Trial Course

Comparing the two different race tracks, we can discover that the racing track of UCI is trivial because it is plat and almost straight with few climbing road segments. So to simplify the model, we neglect the energy consume of turning and climbing in this track and assume that the cyclist rides in a straight plat line. (Actually that's the general case of the cycling competition and is worth studying)

The track in Tokyo is much more complex, for it has frequent sharp turns and climbing roads. So we must take slope and turns into consideration when formulating Position-Power profiles for cyclists in this competition. To get the slope data, we calculate the slope of each point in the elevation graph with formula

$$\theta = \arctan \frac{\Delta x}{\Delta h}$$

. Then we determine that the maximum speed of the turns v_m, v_m can be determined by formula

$$m\frac{{v_m}^2}{R} \leqslant \mu m g$$

, where R is the radius of turning circle and μ is the coefficient of static friction. In our model we suppose $\mu = 0.5$ and $R = 10m$, further calculating the $v_m = 7.1m/s$. We then locate the turning in the graph of Tokyo and calculate its distance to the starting point.

In our own-designed track, we choose an area which is half in the mountain and half in the flat ground to stimulate the compound road situations that a rider may experience.

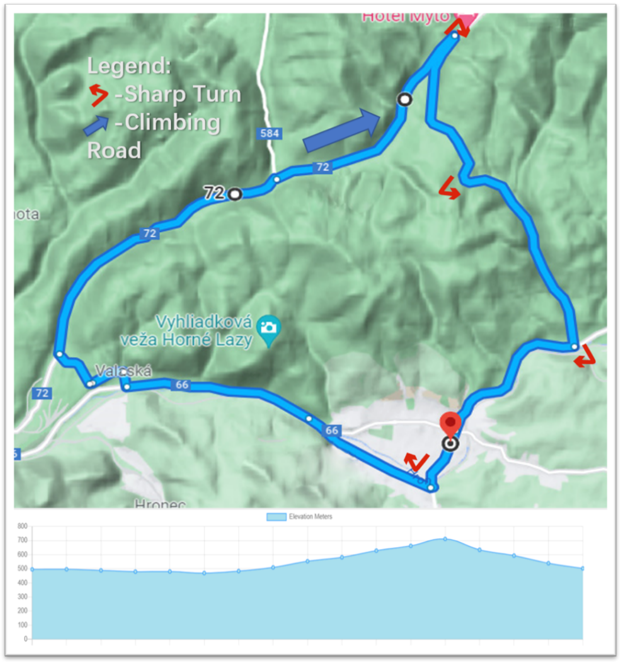


Figure 7: A new route map of cyclist

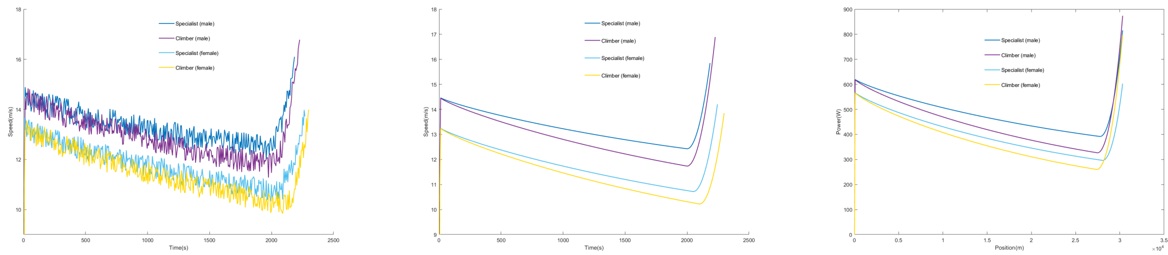
7.2 Model Implementation

The Genetic Algorithm is to determine the optimal Position-Power curve. The steps are as follows.

1. Discretize the curve into 720 points. Each of the point represents the average speed in the 5 seconds.
2. Randomly determine a set of feasible solutions.
3. Determine the fitness function. The fitness function of each state is -T, which means the state with less time is better.
4. Select excellent samples as parent generation and perform the operation of cross and variation to determine the state of offspring.
5. Repeat the step 3,4. Through iteration, the result can finally reach the optimal state.

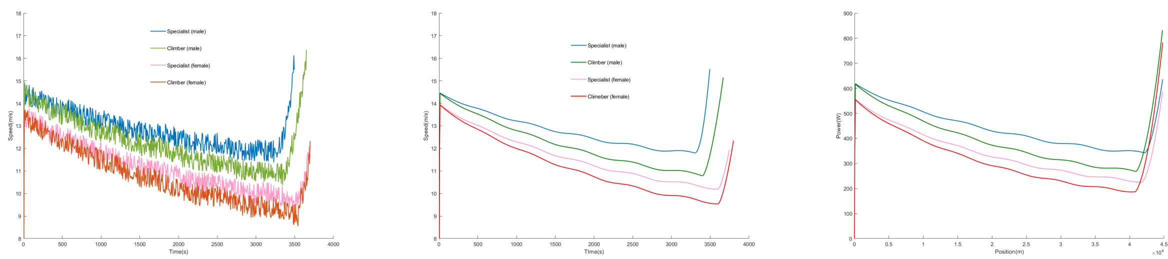
7.3 Results

With the assistance of MATLAB, we get the results of our model, which are shown in Figure 8,9,10. The curves in Section a is the original curve. Giving the randomness of Genetic Algorithm, the curves undulate rapidly and are not feasible in real training. So we fit them by smooth curves in section b. The parameters of these curves are time and speed as mentioned in our model, and we transform it into power-position curve to describe another form of strategy.



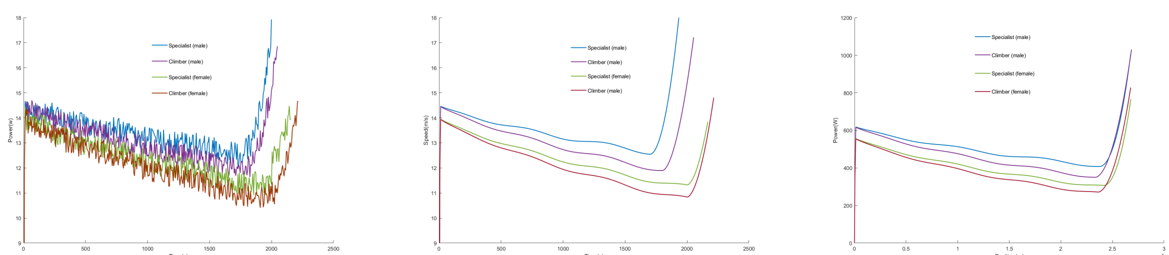
(a) Original Curve (b) Velocity-Time Relationship (c) Power-Position Relationship

Figure 8: Results of 2021 UCI World Championship Time Trial Course



(a) Original Curve (b) Velocity-Time Relationship (c) Power-Position Relationship

Figure 9: Results of 2021 Tokyo Time Trial Course



(a) Original Curve (b) Velocity-Time Relationship (c) Power-Position Relationship

Figure 10: Results of Time Our Own-designed Trial Course

7.4 Results Analysis

In this section, we're going to interpret the common points and differences of each curve. Through common points we can find the generic rule of the optimal energy allocation, while through differences we can formulate specific strategies for different kinds of riders.

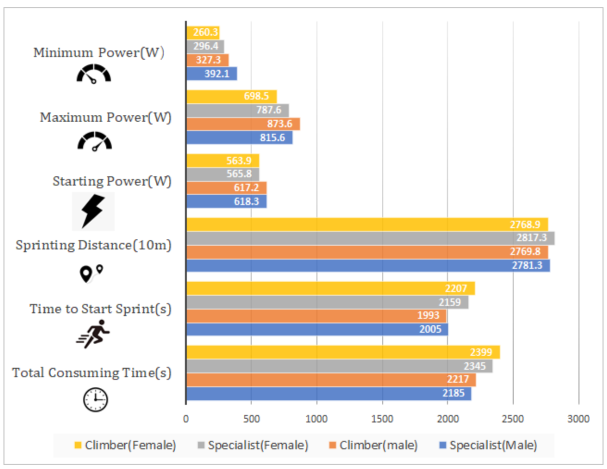
7.4.1 Common points

General trend The general trends of the power-position curves are the same. At the beginning of the course, the riders accelerate to a relatively-large speed. Then they gradually slow down their paces. This process can maintain for a long time, until they reach the sprint point and start to accelerate.

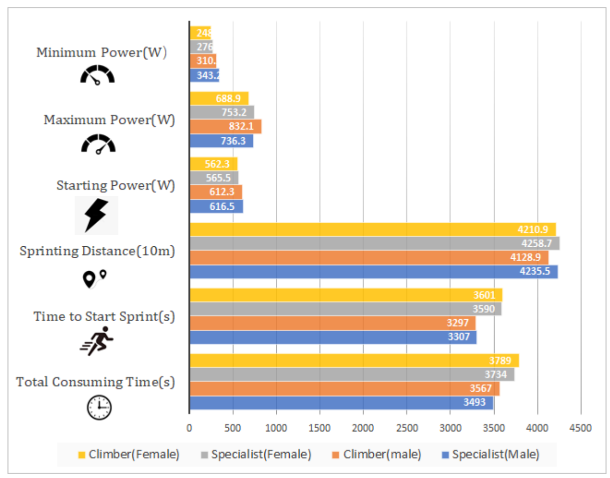
Average speed The average speed of the cyclists can be calculated for the reference. By anlyzing the velocity-time graph, we get the average speed of 13.5m/s for man and 12.5m/s for woman.

7.4.2 differences

Here we choose six features of the cyclists (total consuming time, time to start sprint, sprinting distance, starting power, maximum power, minimum power) and put them together in a bar chart for comparison and analysis.



(a) 2021 UCI World Championship Time Trial Course



(b) 2021 Tokyo Time Trial Course

Figure 11: The differences between cyclists in two races

In figure , we can find that for the same rider in different race,

- The proportion of sprint time and sprint distance in UCI race is larger.

  Interpretation: Cyclists have more remaining energy in the process of sprint in plat-ground race. So they're better to start sprinting earlier.

- The power ratio of maximum and minimum is smaller in UCI.

  Interpretation: In the complex track, the cyclist should change their power consumption flexibly to adapt to the road condition, while in the plain track they should keep their energy consumption more stable to maximize the energy using efficiency.

And in the same race and for different riders,

- The proportion of sprint time and sprint distance for climber is larger.

  Interpretation: The explosive power of climber is larger so they're better start sprinting earlier than the specialist.

- The power ratio of maximum and minimum is larger for climber.

8 Extension of the Model

Actually the result of a cyclist is not only determined by his competence, but is considerably influenced by other cyclists. Research shows that when moving behind another cyclist, the air resistance can be reduced by 37%. In this section we discuss the optimal power allocation of a team trial course. In team trial course, six riders take turns to become "wind-blocker", which means that he or she leads the team and is 100% forced by the air resistance, while the air resistance of 5 teammates behind him or her is reduced by 37%. We assume that the team moves in a straight line with same speed.

8.1 Model Modification

The rule of the team course stipulates that team's time is determined by the moment the fourth rider crosses the finish line, which means two cyclists can stop in a certain position on the route so they can consume all power to lead the team before stopping. So we divide the full race into three parts. Suppose cyclist 1 drops out of the team at the moment t_1 and cyclist 2 drops out of the team at the moment t_2.

The most important feature of the team trial is to determine the order of wind-blocker during the all team. We define $l(t)$ to describe the wind-blocker of time t, which satisfies:

$$l(t) \in \{1, 2, 3, 4, 5, 6\}, t < t_1$$

$$l(t) \in \{2, 3, 4, 5, 6\}, t_1 \leq t < t_2$$

$$l(t) \in \{3, 4, 5, 6\}, t \geqslant -t_2$$

and the power consuming rate of ith cyclist $\gamma_i(P, t)$ can be defined as

$$\gamma_i(p, t) = \begin{cases} \gamma(p, t), & l(t) = i \\ 73\%\gamma(p, t), & l(t) \neq i \end{cases}$$

. The energy of ith cyclist $energy_i$ satisfies

$$energy_1(t) \geq 0 \quad t \leq t_1$$

$$energy_2(t) \geq 0 \quad t \leqslant t_2$$

$$energy_{3,4,5,6}(t) \geq 0 \quad forallt$$

8.2 Results

With the assistance of MATLAB, we finally formulate a detailed strategy for a team consist of 6 male specialists in 2021 UCI World Championship course. The result is shown in Table.

Table 2: The Strategies for a Team

Time(s)	Windblocker	Speed(m/s)	Remarks
1-145	1	16.12	
145-224	2	15.83	
22-369	3	15.68	
369-489	4	15.44	
489-633	5	15.23	
633-742	6	14.99	
742-835	3	14.82	
835-927	4	14.68	
927-1005	5	14.54	
1005-1099	6	14.38	
1099-1344	1	14.29	Cyclist 1 drops off the team at 1344s
1344-1568	2	16.55	Cyclist 2 drops off the team at 1568s
1568-1772	3-6	18.99	Cyclists 3-6 lead in turn for every 17 seconds
Final Result: 1772s			
saved time compared with individual result(2185s): 413s			

Note: The speed is the instantaneous speed of the right point of each time interval.

9 Sensitivity Analysis

9.1 The Influence of Wind

At racing speeds of about 40 km/h, the aerodynamic resistance drag of a cyclist is about 90% of the total resistance. [3]So in the competition, accurately evaluating the air resistance is of great importance. The initial model of evaluating the air friction does not take the impact of wind into consideration. In view of the wind, we merely need to replace the velocity v by $v+w(t)\cdot cos\alpha(x,t)$, so

$$F_a = 0.5 \cdot C_d A \cdot \rho \cdot (v + w(t) \cdot \cos\alpha(x,t))^2$$

where $w(t)$ is the air speed at the moment t. $\alpha(x,t)$ represents the included angle of the road direction in the location x and the wind direction at the moment t.

After that, we collect the weather data on Sept.20,2021 in Damme, Germany [4], where the 2021 UCI World Championship held. Based on the collected weather data and route information, we calculate $w(t)$ and $\alpha(x,t)$. Substituting them into the new formula, we can receive a wind-oriented position-power curve of male specialist in 2021 UCI World Championship as shown in figure 12.

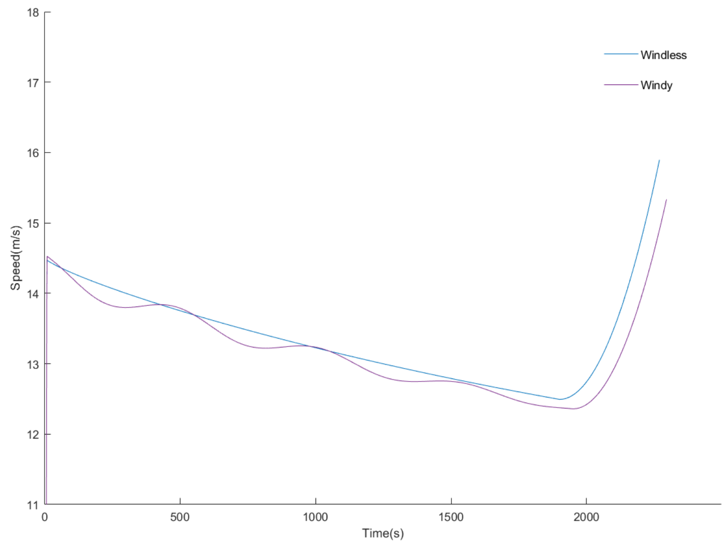


Figure 12: The relationship between wind and speed

The cyclist rides against the wind for most of the time on that day so the cyclists have to slow down their speed. The total time of the cyclist is 2309s, which is increased by 124 seconds comparing with the windless situation(2185s). The influence of wind is non-negligible in real situation, and cyclist must be prepared for adjusting the speed according to the wind direction in the race.

Given the fact that the wind direction changes over time, the curve fluctuates along with the transformation of wind direction. Specifically, by comparing the changing point of wind direction and speed, we further discover that a cyclist should keep a constant speed or even accelerate when riding following the wind, and slow down the pace when riding against the wind. In conclusion, the cyclist should keep their energy consumption steady during the whole race by means of adjusting their speed to minimize the impact of wind to their energy consumption. This phenomenon is similar to the influence of slope. And when we compare Figure 9b with Figure 12, we can find that their curves fluctuate in the same way.

9.2 The Rider's Deviation

Considering the practical situation, the cyclist cannot perfectly perform the pre-arranged schedule. So we should consider the rider's deviation from the target power distribution. To simulate this process, we add a disturbance on the velocity of the rider. For every minute, we assume the velocity v as

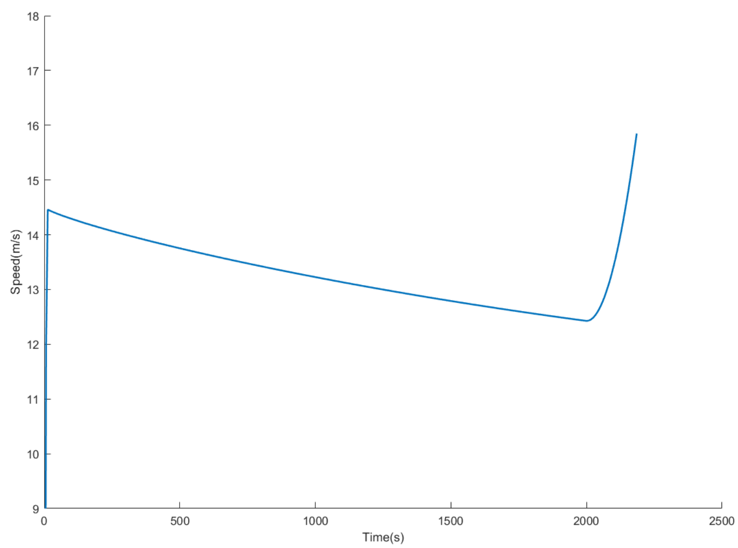
$$v' = v + 0.5 * Rnd$$

where Rnd is a random number which falls in $[-0.5, 0.5]$ and v is the scheduled velocity in the plan. Finally, we run the disturbing model for a male specialist in 2021 UCI World Championship course. The result is 2238s with 2.4% deviation to our original plan(2185s). This shows that the disturbance of cyclists' speed can slightly influence the results. So in practice, the cyclist should try their best to accord with the plan, at least avoid abrupt change of their speed which may consume much power.

10 Guidance for 2021 UCI championship Bicycle Race

Any athlete who does not aim at the championship is not a good athlete. In bicycle road races, there are many factors that determine the final record of a cyclist. It's undeniable that the basic physical quality accounts for a large proportion, but it is also essential to have the customized strategies for a specific race.

To come up with the best strategies, we firstly build a model to calculate the relationship between the player, the racing track, the speed and the corresponding grade. Then we make use of the computer to simulate all strategies of players and then choose the best one, which is shown in the picture below.



As indicated by the result, it's better to reach 15m/s or so at the start of the race and ride at very very low deceleration for about 33 minutes, reaching about 13m/s at the time of 33th minute. It's normal to feel tired in the first 8 minutes because the racer's energy is running out fast. But the racer needs to grit his teeth through the first 8 minutes, and once he passed the eighth minute, the racer will feel his strength returning as the speed drops to 14m/s. By 33th minute, he will have recovered more than half of his strength. At this moment, he should spare no effort to sprint, accelerate and reach 16m/s in a relatively short period of time. With this strategy, the racer can cover this racing track within 37.5min, which is a fairly excellent grade.

Of course, the weather on the day of the match, especially the wind, will also affect the final score. Tailwinds will improve the performance and headwinds will lower the performance. So it's quite critical to pay attention to the wind direction on race day. If it's possible to get detailed information about wind, our model can adjust the strategy according to the weather. If not, there is no need to worry too much. According to our research, as long as the player keep his energy consumption steady during the whole race, you are highly likely to follow the optimal curve, which means you should adjust your speed according to the wind.

It's also taken into consideration that the racer can't exactly follow the optimal strategy, because he may have ideas himself at some certain points of time. However, as our model has strong disturbance resistance, errors, no more than 5s per minute and no more than 0.5m/s per error, is tolerable and won't exert too much influence on the final score.

The above strategy will certainly help the racer to better compete for the champion. In addition to being familiar with the strategy, the player also needs to practice day after day to improve his physical strength and exercise his indomitable will to implement the strategy.

All in all, practice makes perfect and where there's will, there's a way. Best wishes for the 2021 UCI championship Bicycle Race!

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