Optimal Programming of Cyclist Power Allocation Based on Genetic Algorithm

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Abstract. In this paper, we have analyzed the way of bicycle road races. By establishing relevant models, the power curves of different types of athletes are obtained. Firstly, we use the least-squares method to optimize the function, and introduce two different types of passengers and get specific parameters. Then, by constructing the fatigue degree, energy consumption model and cyclic motion model, the genetic algorithm is used to solve the problem, and the optimal energy distribution of different athletes on different tracks is obtained. In addition, considering the influence of uncertain factors brought by the weather and other environments, the scheme that the driver and the directeur sportif would obtain the local optimal solution and actively change the power distribution is analyzed, and the process of the team time trial is studied. Finally, the generality and sensitivity of the model are tested, and the advantages and disadvantages of the model are evaluated.

Keywords: Least squares optimization method, genetic algorithm, greedy algorithm.

1. Introduction

We could appreciate various wonderful moments of a criterium, a team time trial, or an individual time trial in bicycle road races. Apart from the general environmental factors, a rider's chance of success can vary for these contests depending on the type of event, the course, and the rider's abilities. In an individual time trial, the winner is the cyclist who rides a fixed course alone within the shortest time. There is a big difference between multiple riders presented on the power curve, for example, the time trial specialist, the climber, the sprinter, the rouleur, the puncheur, etc. Moreover, different individual riders can produce different levels of power for different lengths of time, and the amount of power and how long a given amount of power a rider can produce varies greatly between riders. Riders always expect that they can reach the finishing line as soon as possible. However, as a race progresses, if he consumes much energy continuously, he may need more time to recover at a lower power, which will slow him down. Furthermore, a rider's power curve also indicates other factors that can influence the result of a game.

Therefore, riders need to apply power while traversing a given time trial course. We wonder if we could summarize a model to determine the relationship between the rider's position on the course and the power the rider applies to help different types of riders to achieve their goals.

In this paper, we improve the model by considering these factors by collecting information from different riders, races, and cycling tracks. On this basis, first, we get the common curve type. In addition, we study the potential impact of weather or other environmental conditions on the model, and take into account the effect of the driver and Directeur Sportif on the model. Finally, we study the proper rotation sequence of six cyclists and the process of the team time trial.

2. Power Curve

2.1. Model Establishment

We gather the detailed data of the different drivers of bicycle road races. To make the result more accurate and reliable, we collect their weights and the average power of 5s, 1 min, 5 min, 1h from

various races [1] available online. We get the function expression between the power to body weight ratio and continuous output time can be expressed as follows:

$$P = a \times t^{-b} \tag{1}$$

Where P is the power to bodyweight ratio; t is the time of the race; a, b is the unknown arguments of the function.

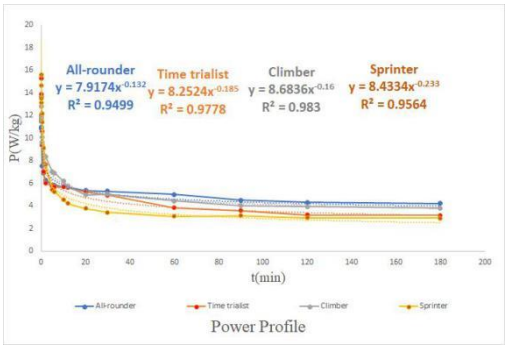


Figure 1. Power profile of four kinds of cyclists

2.2. Results analysis

Although we get the law of the function, there is no apparent difference between any two types of riders, nor can it reflect the characteristics of different riders. In order to verify the reliability and universality of the model, we use the power distribution information method proposed by Dr. ANDREW COGGAN [2]. The advantage of this approach is that it enhances the validity of comparisons across event durations.

To choose the target durations, we refer to the doctor's method [2]. The values provided by Fig. 2, and the index efforts of 5s, 1min, 5min, and at functional threshold power were chosen as those best reflecting neuromuscular power, anaerobic capacity, maximal oxygen uptake (VO_2max), and lactate threshold (LT), respectively. For the reason that a 1 min all-out effort is completely anaerobic, and that a 5 min all-out effort entails exercising at precisely 100% of VO_2max.

We use the least quadratic optimization method corresponding to fit the value of a and b, shown in table 1 below. From the graph, we could see that a Rouleur is a generalist and can do well in races with a wide variety of terrains, while a Time Trial Specialist is a rider specializing in individual time trial events, which has high credibility and universality.

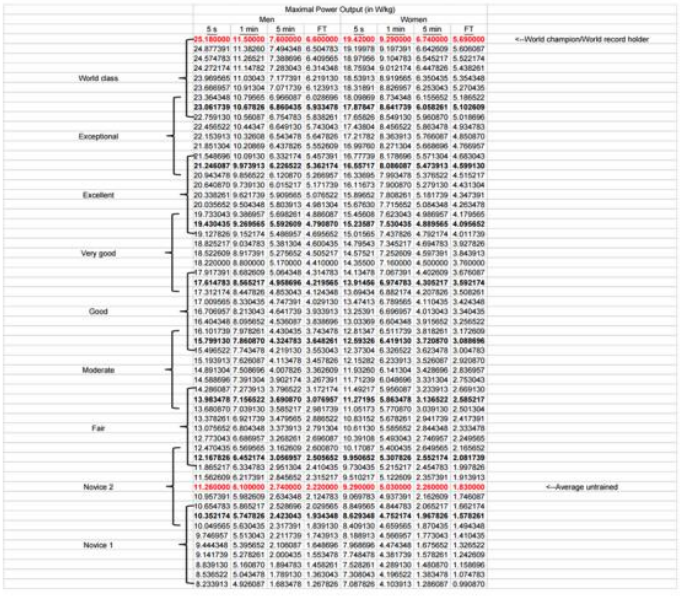


Figure 2. Power changes of riders with different professional levels

Table 1. Power profile parameters of different types of athletes

	a	b
Rouleur	8.0294	0.2468
Time trial specialist	9.0258	0.2183

3. The Fatigue Degree and Energy Consumption

3.1. Model Establishment

Muscle performance will decline due to the prolonged exercise, defined as fatigue. Critical Power (CP) is the boundary between anaerobic and acrobic exercise [3]. The limited energy is named Anaerobic Work Capacity (AWC). The CP and AWC can be expressed as [3]:

$$CP = \frac{P_p(T_a)T_a - P_p(T_b)T_b}{T_a - T_b} \tag{2}$$

$$AWC = P_p(T_a) \times T_a - CP \times (T_a - T_b) \tag{3}$$

The AWC energy expenditure equation can be expressed as:

$$\frac{dAWC}{dt} = \begin{cases} CP - P & P \geq CP \\ CP - P_{adj} & P < CP \end{cases} \tag{4}$$

Where P is the applied power to the bicycle by the rider and P_{adj} is the adjusted recovering power as determined by experimental data. However, empirical formula of P_{adj} also can be expressed as:

$$P_{adj} = 0.0879P + 204.5 \tag{5}$$

The maximal power can be expressed as:

$$P_{\max}(t) = 7 \times 10^{-6} W^2(t) + 0.00234W(t) + CP \tag{6}$$

Therefore, the Fatigue degree model is established to limit the output power of cyclists. With the simple limited maximum consumption Wmax, the question proposed can be solved. In the process of riding, the rider and the bicycle as a whole. The whole system will be subjected to frictional resistance and support from the ground and gravity and air resistance [4]. The bicycle model, which is obtained by Newton's third law, is applied to our cyclist motion model:

$$m\frac{d}{dt}v = F_t + F_a + F_{rr} + F_g \tag{7}$$

Where m is the total weight of the cyclist and bicycle, v is the velocity of bicycle, F_t is the pulling force provided by the cyclist, and F_a, $F_{rr,}$ and F_g are the aerodynamic, rolling resistance and gravity, in proper order. The force analysis is shown in Fig. 3.

The air resistance F_a is defined as:

$$F_a = -\frac{1}{2}\rho A C_d (v + v_{wind})^2 \tag{8}$$

Where ρ is the air mass density, A is the cyclist and bicycle's effective frontal area, C_d is the resistance coefficient, v is the speed of the bicycle, and v_{wind} is the speed of the wind. The rolling resistance F_{rr} is defined as:

$$F_{rr} = -mgC_{rr} \tag{9}$$

Where g is the gravitational constant and C_{rr} is the rolling resistance coefficient which depends on the type of tyre, the pressure of the tyre, and the quality of the road. The gravity force F_g is defined as:

$$F_g = -mg\sin(\alpha) \tag{10}$$

Where α is the incline of the road.

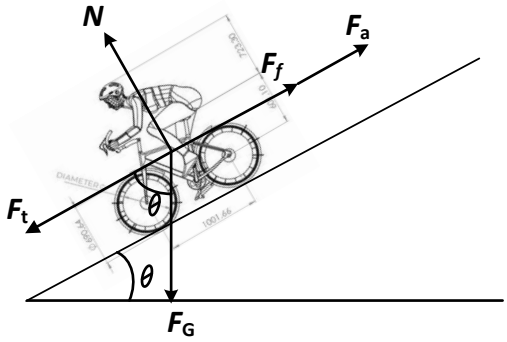


Figure 3. The force analysis of the athletes

3.2. Results analysis

In order to find the optimal power profiles of driver power allocation, the model of the fatigue degree, energy consumption, and cyclist motion are combined. The state of cyclists in the whole race is discretized at equal distance Δx, and the speed v_i is taken as the independent variable. The objective function is formulated as:

$$\min J = \sum_{0}^{n-1}\left(\frac{2\Delta x}{v_i + v_{i+1}}\right) \tag{11}$$

The discrete state quantity can be obtained in the following way:

$$\begin{aligned} P_i = [m\frac{v_{i+1}^2 - v_i^2}{2\Delta x} + mg\sin\theta_i + mg\cos\theta_i\mu \\ + \frac{1}{2}Cd\rho A(\frac{v_{i+1}^2 + v_i^2}{2} + v_{wind})^2]\frac{v_{i+1} + v_i}{2} \end{aligned} \tag{12}$$

$$AWC_{i+1} = \begin{cases} AWC_i - (P_i - CP)\dfrac{2\Delta x}{v_{i+1} + v_i} & P_i > CP \\ AWC_i + (CP - P_{adj})\dfrac{2\Delta x}{v_{i+1} + v_i} & P_i < CP \end{cases} \tag{13}$$

$$W_{i+1} = W_i - P_i\frac{2\Delta x}{v_{i+1} + v_i} \tag{14}$$

$$P_{\max i} = 7\times10^{-6}W_i^2 + 0.0023W_i + CP \tag{15}$$

After considering the power curve P_p-T, the constraint equations include limits on output power, left anaerobic work capacity, left energy, and velocity are shown as follows:

$$\begin{cases} 0 \le P_i \le P_{\max i} \\ 0 \le AWC_i \le AWC_1 \\ 0 \le W_i \le W_1 \\ 0 \le v_i \le v_{\max} \\ W_1 - W_i \le P_p(t_i)t_i \end{cases} \tag{16}$$

Where the value of the v_{max} is 22.3 m/s, W_1 is equal to FPT multiply 1h, about 1423 KJ.

Furthermore, we have designed a time trial course that includes at least four sharp turns and at least one nontrivial road grade as shown in Fig. 4(a) and Fig. 4(b), designed according to individual time trial standards and realistic geographical conditions. Similarly, the map set by our team is configured with a reasonable altitude, and then we use a genetic algorithm to solve the problem. The power distribution is shown in Fig. 4(c).



(a) (b) (c)

Figure 4. The Result of the course designed (a) the altitude and length data (b) vertical view of the course designed by our team (c) power profile of rouleur

4. Affect Factors

4.1. Analysis on the Influence of Wind Force and Wind Direction

To study the impact of the environment on cyclist's competition, we added the conditions of wind force and wind speed based on the original model. In order to obtain more compelling data, when setting the wind direction, we divided the track into five sections, and each section has a wind with a random angle relative to the direction of the player; when setting the wind force, we divide the track into 100 sections, and each section is allocated a random wind speed of 1.6 ~ 3.3m/s. Under the influence of wind force and wind speed, we can know from the force analysis of riders that the resistance changes, which affects their energy distribution. The stress analysis is shown in Fig.5. The wind speed has a certain angle with the speed and wind direction of the cyclist, so that the direction of air resistance is no longer the same as the speed and wind direction of the cyclist. The cyclist needs to provide an additional force perpendicular to the forward direction to offset its impact on the movement. The algorithm concluded that under the influence of wind and wind direction, the competition result is even 3.32% faster than the original.

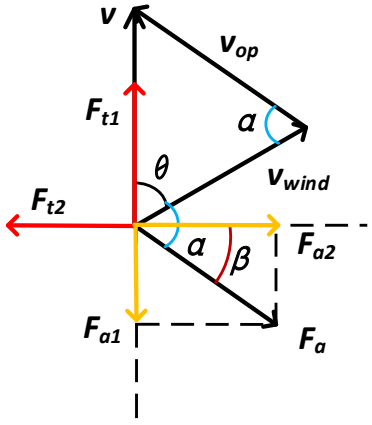


Figure 5. The stress analysis under the effect of wind

4.2. Analysis of the Influence of Rain

According to [5], we know that the friction coefficient of normal dry road surface is 0.6, while after raining, the road is wet and slippery, and the friction coefficient reduces to 0.4. The change of friction coefficient will change the resistance of riders, and then affect the optimal energy distribution. After adjusting the friction coefficient, the competition result is 5.14% faster than the original, within the acceptable range. According to the data, the change of friction coefficient caused by rain will not greatly impact the model.

4.3. Analysis on the Influence of High Temperature

Cycling competition is generally conducted in an environment with appropriate temperatures to ensure that athletes perform well [6]. After having high-intensity exercise in an proper temperature for 15 ~ 20 minutes, the core temperature can rise by 1 ~ 2 degrees. Therefore, profuse sweating, electrolyte, and water loss during exercise are the biggest challenges for cyclists. Under a high humidity environment or windless uphill, if accompanied by dehydration or electrolyte imbalance, athletes will quickly produce fatigue. Therefore, we reduce the CP threshold by 50W, and then use the algorithm to get the optimal result. The result shows that the competition result is reduced by 4.19%. and the temperature does have a worse impact on cyclists, but it is also within the acceptable range of the model.

We test the influence of weather and other environmental factors on model stability by setting reasonable wind direction and force, modifying friction coefficient and maximum output power. It is concluded that environmental factors such as temperature have little influence on the optimal energy distribution of drivers.

5. Greedy Algorithm

The tactical planning from the Drecteur Sportif and the rider's behavior preference may make cyclists change the schedule planning in the race. We assume that the driver is lazy, focuses on the short-term benefits, and ignores the overall results. We use the Greedy Algorithm to solve the problem and divide the track into three pieces, and each part represents a temporary goal. From Table 2, compared with the original scheme, the time it takes him to reach the finish line will increase 5.3%, which has a considerable adverse impact on the race.

In the construction of the model, dividing the race schedule into more units will make the function closer to continuity and improve the accuracy of the algorithm. We choose to be friendly to drivers and maintain the fine division that can make the model give good answers to avoid the situation that it is difficult for drivers to complete the plan and ensure the model's reliability.

Table 2. The result of the Greedy Algorithm

	Phase I	Phase II	Phase III	Sum
Time	23min 23s	39min 28s	21min 27s	84min 18s

6. Team time trial

In the team time trial, the winning team usually spends the least time for the fourth finisher to reach the finish line [7]. This means that each team will at least try to get their top four riders to cross the finish line in a tight group. For any rider, completing the race before the fourth rider is actually a disadvantage. To help the fourth rider get a faster time, he has to make roads for the fourth cyclist, which means going ahead at high speed against great air resistance [8].

In the process of competition, the goal is to keep the team's speed consistently at speed higher than that of any single rider riding alone. We choose six cyclists from various types in the problem-solving process. Considering the influence of aerodynamics, we design a function to satisfy the factor that

the order of players crossing the finish is the order of players whose ability decreases in turn, so as to minimize the time for the fourth to break through the finish line.

7. Conclusion

In this paper, we have obtained a power profile from some data that can be applied to all drivers and distinguish different types of drivers. Analyzing the four common standard data of drivers can better reflect the relationship between the driver's energy consumption and recovery. We have conducted detailed and realistic studies and simulations of driver fatigue and energy changes based on force analysis. The advantage of this model is that the experimental results are more reliable and accurate by fitting the power curve with the data of various athletes. In addition, establishing a corresponding physical model for stress analysis and analyzing a variety of environmental factors and the psychological changes of athletes highlights the strong practicability and stability of the model. The genetic algorithm is used to design a sufficient population size and population number to solve the problem, and the result has good convergence. The disadvantage of this model is that many factors are considered, so the model is more complicated, takes a long time to calculate and has low efficiency.

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