Analysing Velodrome Cycle Racing Using Witness Simulation

Alex Burns, Muhammad Latif, Rameez Khalid

***Abstract*— This paper reports on a project that was centred on using simulation as a way to test to what extent speed affected the aerodynamic drag exerted on a cyclist. This was done by building a simulation model in which the user could adjust data to drive the Witness model and analyse what happens over the length of a race.**

Real data was gathered from four sessions at the National Cycling Centre, UK, in order to create an accurate model that could be run on Witness Simulation software. Using cadence values that were measured from an advanced cyclist, factors such as speed, lap times, section times and drag were measured. These were all affected by the energy of the rider as it decreased throughout the race.

After varying the values for the cadence and the values for the drag force measured, it was observed that as the speed of the pedals increased, the drag on the rider increased substantially. After the cadence exceeds 130 rpm, it becomes inefficient to attempt to overcome the forces. This was similar to the range of cadences measured on the cyclist, which lead to the second conclusion that the model was an accurate simulation of the race track event.

***Keywords* — Traffic Simulation; Discrete Event Simulation; Witness Modelling**

I. INTRODUCTION

This project concentrates on modelling and simulating racing strategies used by track cyclists to give them an edge over their competitors. In highly competitive sports, it is becoming increasingly more important for individuals and teams to simulate what their racing conditions, outputs and final position could be [1,2]. Due to the increasing costs and smaller margins acceptable between riders, many individuals and coaches are turning to race simulation to give them that extra edge over their competitors [3,4]. The riders and coaches are looking to aid their training, and find the effects of what changing certain variables has on the rider [5,6]. With limited time and expensive resources to test strategies and other varying factors it is important to find some way of testing these before the race begins and it is too late.

Computer simulation software has been developing alongside the major advancements in technology we now see today which is generally a well-understood field [7]. This approach allows a real world scenario to be modelled safely and answers domain-specific set of questions [8]. Simulation first started with a user-defined input in a non-graphic's environment, the process happening away from sight within the computer, and then an output of various values within which were the results. As simulation has developed, so has the user interface. Some of the 'behind the scenes features' are still hidden however, in recent years the visual simulation on many forms of software has greatly increased. This is useful for the user to be able to see visual representation of what is happening throughout the process. Changes can also be made instantly with the added benefit of speeding up and slowing down time - something that is not possible to do otherwise [8].

The proposed approach is to use a discrete-event queue-based model as it has some advantages over other methods [9].

WITNESS is an industry-standard software program that was selected as it has the ability to model a wide range of process and operational tasks [9]. By utilising it, a racetrack simulation model can be built and tested eliminating the need to physically carry out tests on the track. The model can then be modified and adapted in a number of ways in order to reach a favourable outcome.

Once the final model is built, the project focus will look into the correlation between cadence [10,11], speed and frontal wind drag of the track cyclists. Using the values from this output data, the user will then be able to adjust certain parameters and see what sort of effect this has on the frontal wind resistance. Once this has been reduced, it will allow the rider to perform better as the resistance will reduce and they will be able to travel at a faster pace.

The validity and reliability of the model is directly linked to the quality of the data gathered and which the model is built upon. If the data received lacks substance reliability then the model that is built will not be up to a high and accurate standard. Therefore, the data that is gathered will need to be from a quality and accurate source.

1.1 Specific Problem and its Issues

The purpose of this project was to design, develop, and test a model that could be used to determine what effect changing certain variables on a rider competing in the velodrome has on the wind drag experienced by the rider. This will aid the riders and coaches and help facilitate how the rider will perform at their current level of ability, and will allow the team to adjust necessary factors to give the rider that slight advantage over their opponents. The project will also look into what relationship the speed of a rider has on the aerodynamic drag experienced.

1.2 The Aim

The aim of this project was to design, build and test the optimal racing strategy for track cyclists. To do this, various sectors of the sport will have to be researched and observed to

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see what kind of effect they have on the riders lap times and final times. This study will be looking into building and developing a model that can be used to vary certain parameters that the rider or coach may want to alter. To create an accurate model that will give the most detailed output, values for cadence, wind resistance, weight, power, torque, and speed will have to be found. To complete the project, an analysis will take place to determine the effect a rider's speed has on the drag force.

II. TRACK CYCLING

Track cycling is a form of bike racing that is governed by the UCI (Union Cycliste Internationale). Varying race styles have been included in every modern Olympic Games, with the exception of 1912. The race begins with the riders starting either side by side or on opposite sides of the track to each other. The match sprint race is the only one that requires the riders to start side by side, but this is not being looked at in this study. The cyclists race around a 250m long track, which is built up of two steeply banked 180° corners that are connected together with two shallowly banked straights through a moderate easement curve. To allow the tracks to give out the fastest times, today they are built from various pinewoods and varnished to reduce the rolling resistance that the rider experiences.

Like every sport, strategy plays a major role in the competition that is why teams, especially in sports with little margin for error, such as track cycling and formula one, spend hundreds of thousands of pounds developing their own strategies to give them the winning edge over their opponents. Dave Brailsford, the British Cycling Head Coach uses the philosophy of the "aggregation of marginal gains". By this, he means that changing many small, but numerous parts of either the rider's daily routine or the teams race technique this can add up to make a considerable impact to the performance of the team or individual rider. This is where the use of simulation within cycling can become useful, to create these marginal gains and to see the effects that they have.

The individual pursuit is one of the racing events that take place in the velodrome. It consists of a 4000m long race for men and 3000m long race for women, 16 laps and 12 laps, respectively of a 250m circuit. The aim of this race is for the two riders, who start opposite each other, to catch the other rider up within the race length. However, this rarely happens, in which case it is the rider who completes the required laps in the shortest possible time.

The team pursuit event (figure 1) is similar to the individual pursuit where the aim of the race is to catch the other team or complete the distance in the quickest time. This race however, includes two teams of four riders competing together. The races still require the teams to cover the 4000m and 3000m that the individual riders cover, but the overall times that are achieved are generally quicker due to the ability to draft behind the other riders and regain energy. That is where the similarities between the races end though. Because there are four riders in total, for the majority of the race, this allows the teams to work together to increase their efficiency. They do this by allowing one rider to stay at the front of the group for one or two laps and then once the leading rider starts to tire, they will pull up onto the banking in the corners and drop back down at the back of the pack. This cycle then continues throughout the race.


Figure 1. Team pursuit

The ability to draft behind other riders has a great effect on the total time, as throughout the race the riders are able to maintain a higher speed compared to the individual pursuit. Figure 1 illustrates just how compact the riders are whilst they are racing. Keeping up this shape for the duration of the race is what allows the riders behind the leader to maintain their energy, by reducing the drag that they experience. This allows them to "rest" slightly as the rider in front takes on the full force of the frontal wind force.

III. DATA COLLECTION

To design and develop the model, various amounts of data, from various sources had to be collected to build the model to an accurate level that could be reliable once completed. Data from live track sessions were obtained from Manchester Velodrome. The data readings on SRM (Schoberer Rad Messtechnik) cranks were used to determine the values for the cadence from four different sessions that were conducted.

The SRM cranks are extremely beneficial for professional and amateur cyclists or coaches. They allow the cyclist to monitor how the force that is being applied to the pedal is being used throughout various sections on the track. With racers accelerating in the second half of the bend, and with the aid of centrifugal motion, the power that the rider applies decreases anywhere up to 200 watts as they are being thrown around the track between the bends and the straights. This will mean that the rider will not be keeping up a steady power output, reducing their efficiency. These cranks allow the coaches to monitor the rider's effort around the bends, and adjust the rider's pattern if necessary. The rider must learn to ease coming into the banking, but apply more force coming out.

3.1 Model Observations

After some initial model building it was found that realistic data was needed to increase the accuracy of the simulation model. Research into what affects the cyclist as they are going around the track had to be undertaken to find what needed to be incorporated into the model. The data that was gathered to build the model was taken from various sources. The cycling data required for the cadence of the rider was taken from four separate sessions at the velodrome in 2011. The data that was extracted from the SRM cranks had to be analysed and manipulated in Golden Cheetah (a freeware product that is able to analyse the crank data) to find the correct distribution shapes.

3.2 DATA COLLECTION

Using the data from four sessions at the Manchester Velodrome, recorded by a cooperating coach, the cadence of an advanced level cyclist was measured and analysed.

Using Golden Cheetah's ride plot the data that was extracted is plotted. Graphs for the all of the cadence value on that day were plotted, a second for the peak five minute cadence plot and a final histogram of the total cadence. A sample of these are shown in figures 2 and 3. Such samples were collated for riding sessions over four individual days.

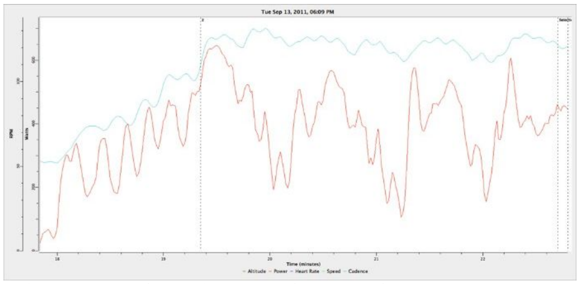


Figure 2. Peak 5 minute Cadence and Power over a 40 min riding session

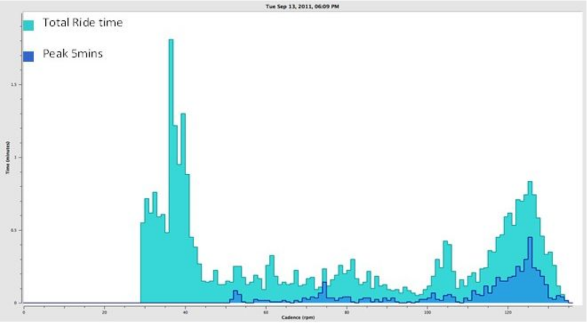


Figure 3. Histogram of total Cadence and peak 5 minute Power over a 40 min riding session

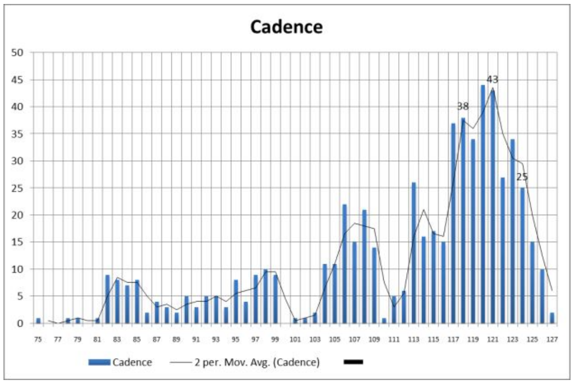


Figure 4. Histogram showing mean Cadence and 2 period moving average

Once the graphs had been plotted, the values of cadence over the peak five minute times were then imported into MS Excel. Using these values, a final histogram was then created showing the mean cadence over the 300s time period. This is shown in Figure 4

Figure 4 shows the average cadence over the peak five minute time. This can be used to find the required distribution size and shape required for the sections of path. By displaying a two period moving average, the shape of the distribution can be matched to the ones available in Witness' distribution wizard. With the knowledge that the cyclists reduce their cadence slightly going into the bends and coming out, the values that will be used for the distributions in the straights, turn entries and turn exits will vary slightly. Using this knowledge, distributions were then created for each of the three different parts of the track where cadence differed.

After choosing a Normal distribution it was then necessary to establish the standard deviation for the distribution. This was done by taking the values for cadence under the normal shaped arc (110-127) and calculating the mean and standard deviation of these values.

When the normal distribution values were entered into Witness it was found that the data varied drastically and was not consistent with what the rider should have been doing. It would have been expected that at the corner entries the rider will decrease in speed, at the corner exits the rider will increase in speed and on the straights the rider should be in between the two. It was therefore decided to split the entire data into three sections, the three sections of track where the speed varies. When the data was split, and the distributions were recalculated, and found to be of type TNormal. The new distributions that have been created give a much better result visually. It is known that when the cyclist enters the corner his cadence will decrease, the results obtained had a mean cadence of 115rpm with a standard deviation of 1.98. For the steady state cadence of the cyclist a value of 119 rpm was used. When the cyclists accelerate as they come out of the bend, their cadence will increase to a value of 123 rpm with a corresponding standard deviation of 1.51.

When the second set of distributions were entered into Witness, the results were greatly improved. The simulation reciprocated what the real life cyclists do, as they enter the bend they slow down very slightly and then when they exit, their momentum and centrifugal force acting upon the rider, flings them out at a faster pace.

3.2.1Data for Cyclists Energy

The energy that the cyclist would require for the race was taken as an educated estimation based on discussions with cyclists and their coaches. This was because no reliable data could be found on the energy loss that a track cyclist experiences over the race.

It was estimated that the energy that the cyclists each start off with was between 85% and 90% of their total energy, and throughout the race decrease in a negative linear pattern. This was chosen because when the cyclists warm up, they will lose energy and there will be slight energy loss transferring the power from the rotation of the legs into the wheels. It was then estimated that per lap the rider would lose 0.95% of their total energy.

The value taken from the energy would then be used to affect the varying cadence over the whole race. Meaning, as the race went on the riders energy levels would decrease along with a slight decrease in the cyclist's cadence

3.2.2 Data for Wind Resistance

The data for the wind resistance was gathered from online sources and journals [12-15].

To calculate the wind resistance on a rider, values for the frontal area, velocity and the wind drag coefficient had to be found.

Cycling Power Lab [12] noted that a number of sports scientists particularly focused on cycling have attempted to create a formula to measure the frontal area of a cyclist using the riders height and weight. This, in parallel with the drag coefficient was used to calculate the aerodynamic drag.

Burke [16] stated, “you can decrease aerodynamic forces by choosing shapes that move through the air efficiently.” The coefficient of drag is determined by how streamlined an object can flow through a substance, in this case, air. Figure 5 shows a two-to-one ellipse. This is the typical shape of a cyclist taken from an aerial view. It is clear to see that the air flows around the object in a smooth manner; however there is still some residual drag at the end of the object due to the way the air flows around the body.

The elliptical shape in Figure 5 has a typical drag coefficient, C_d of 0.6. It was then assumed that a trained track cyclist would be more streamlined and have a smaller aerial shape. This meant that the C_d of the cyclist was then taken as 0.5.

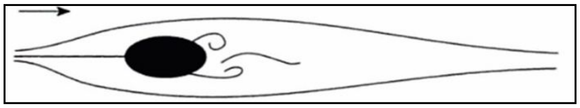


Figure 5. Air flow around a 2:1 ellipse [11]

3.2.3 Track Data

The data required to build the tracks was gathered from numerous different sources. Various pieces of information were needed such as, the track length, length of straights, radius of turns, rolling resistance and air density. The data was gathered from various online sources [15-21].

The track that the model is based on is The National Cycling Centre in Manchester. This was chosen because the data from the riders was taken at this track and it was consistent using the same track. The National Cycling Centre contains a 250 metre long Siberian pine track and has been the home of British Cycling ever since. From the opening of the track in 1994, it has maintained a reputation for being a very fast track. Using the data from [21], the separate section lengths for the straights and bends were found and illustrated in figure 6

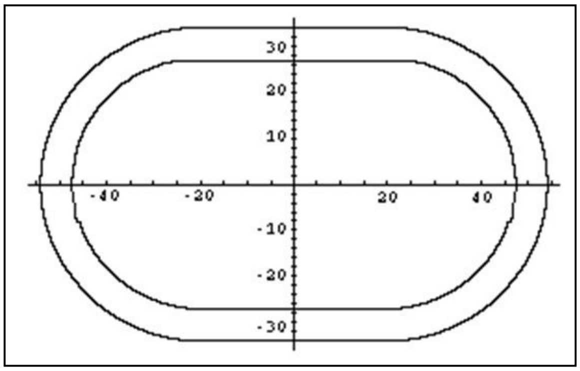


Figure 6. Illustration of a 250m Velodrome track [21]

IV. MODELLING THE SYSTEM

Witness models are built around some basic elements. The elements used include:

Activities - An activity is an element that the active entity flows through and gets processed. During this process the activity will usually perform actions upon the entity.

Entity - In Witness, it is possible to have both an active and passive entity. An active entity is an element that flows through the model on the paths if they have been specified. These generally represent the dynamic physical component of the model. In this case they would represent a cyclist. A passive entity is an element that represents a static physical component. This can be used to represent signals that update data tables

Paths - Paths are used to give the simulation a more realistic effect. By allowing entities to flow along such paths and have time values linked to these to fully incorporate Witness’ visual interactive system (VIS). In this model the paths will be used to represent the track that the cyclists must follow.

Queues - The queue element in Witness is used as a place to store an entity. They can have a duration value set at zero, in which case no time will be lost sending the entity through the queue. In this model, the queues will be used to represent the pre-race sections and will be used as a connection between one path and the next.

Variables - The variables available in Witness are used to display data and values extracted from the model. They can be in the form of real or integer variables. The real variables can be used to represent factors such as speed, cadence and torque whereas the integer variables can be used to represent lap numbers and rider number.

To make full use of the visual interactive system (VIS) that Witness incorporates there are four main elements which will need to be included in the basic model. These are:

The Track
The Cyclist
Section Times
Race Time

The Track

The Track will be modelled using the path element from the *Transport* tab in Witness. The multiple paths will be used to send the cyclists around the model track. The time that each cyclist takes to travel along a certain path will be dependent upon the distribution assigned to the respective path.

The Cyclist

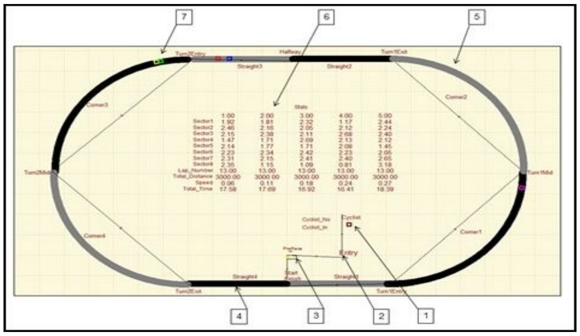
The Cyclist in this model will be represented by an entity. When the entity is created it will be assigned various attributes that can be altered as it passes through various queues whilst making its way around the track.

Section Times

The times for each path section that the entity travels along will be based upon an assigned distribution. The output value of the distribution will change in each lap keeping up the realism of the race. The lap time will be calculated from the sum of the section times and updated every lap. This will then be used to calculate the race time.

Race Time

The race time will be calculated from the sum of the lap times. Every time an entity passes through the finish, the lap times



```
                                   Stats
                  1.00      2.00      3.00      4.00      5.00
       Sector1    1.92      1.81      2.32      1.17      2.44
       Sector2    2.46      2.16      2.05      2.12      2.24
       Sector3    2.15      2.38      2.11      2.68      2.40
       Sector4    1.47      1.71      2.69      2.13      2.12
       Sector5    2.14      1.77      1.71      2.08      1.45
       Sector6    2.23      2.34      2.42      2.23      2.05
       Sector7    2.31      2.15      2.41      2.40      2.65
       Sector8    2.36      1.15      1.09      0.81      3.18
    Lap_Number   13.00     13.00     13.00     13.00     13.00
Total_Distance 3000.00   3000.00   3000.00   3000.00   3000.00
         Speed    0.06      0.11      0.18      0.24      0.27
    Total_Time   17.58     17.69     16.92     16.41     18.39
```

will be added together and a final value shown.

Figure 7. The basic model

Figure 7 shows the basic initial model that was built to display the data which were needed to be shown. Various parts of the model are numbered in figure 7 and these include:

The cyclists are created as an entity at zero time. Upon being created they are assigned numbers, one through five in this example. The numbers that the cyclists have been assigned are then used in the Stats table to distribute the data, which are the output from various activities and queues.

Once the cyclists have been created they are then pushed to the Entry. When they have arrived at the Entry, which is represented by an activity element, the entities then wait to be pulled to the PreRace. This happens so that the entities can be registered and that all of the entities start together, and do not leave individually as they reach the start.

When the entities are pulled to the PreRace queue, the variables that have been defined to them upon being created are applied. The time value for this queue has been set to zero because there is no need for the entity to be waiting at this point; it just needs to be pushed to the start.

The straight sections of paths in the test model are assigned the normal distribution Normal (2, 0.5). This was assigned as a rough estimate for how long it takes a cyclist to complete this section of track. The lengths of the straights were drawn up roughly so see what data was needed to build the model. For simplicity, the same distribution was used in all of the straight sectors, beginning at the start, Sector1, Sector4, Sector5 and Sector8.

The corner sections of paths in this model were assigned the beta distribution 2+ Beta (1.5, 3).This was chosen again, as a very rough estimate of what the time in the corners for the cyclists were. The Beta distribution was chosen as it gave out the correct values that were being looked for in the total time of the corner. Like the straights, the length of the corners was estimated, just to get an idea of what was needed for modelling.

The Stats table uses a real variable with five columns to display the data required. As the entities travel around the paths counter-clockwise the data is monitored and updated as the cyclists pass through the queues that are around the track.

The Cyclists are displayed as entities with varying colours assigned to them to tell them apart, as well as a race number upon being created, that the length of track being modelled can hold. This will allow the simulation to produce a more accurate result, as it will ensure that the traffic can build up just as it would in real life.

4.1 Issues with the basic model

Using the basic model shown in figure 7 it was further developed in two separate stages. The first stage of development was based on using an average lap time.

Building on the basic model, the speed of the cyclist was put in first using a normal distribution. This was chosen as the values of the cyclists speed were already known from using the average lap times and track lengths.

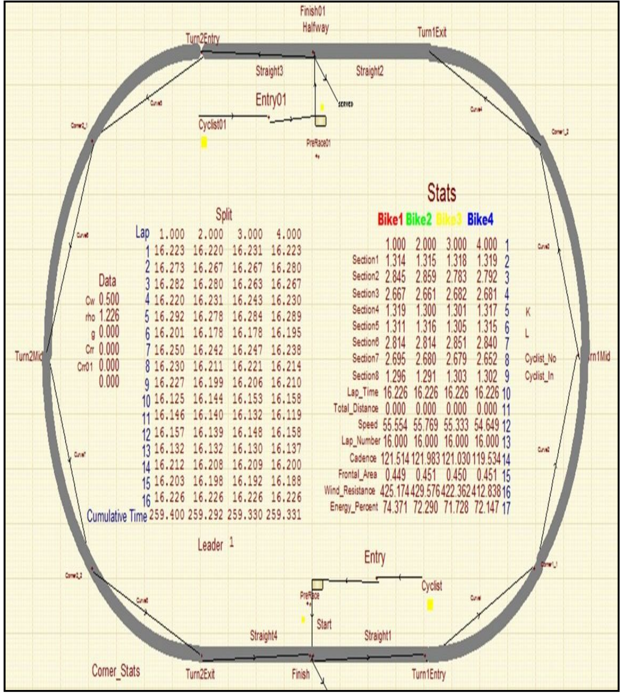
Using the value found for the speed, a Normal distribution of parameters (55.25, 2.5) in minutes was used around the track. This meant that every section had a varying speed, which in turn meant that the time for each lap was roughly the same as the average lap time.

However, after running the model, it was felt that the data given out was not an accurate representation of the actual events taking place on the path. Therefore, it was decided that it was best not to use an average lap time but find another way in which the model could give an accurate representation of track procedures.

Another flaw in this basic model was using only two sections of path to represent the bends. As this is the section where a lot of the race is either won or lost it was decided that, to generate a more accurate model, the number of sections which the circuit was split up into had to be increased.

4.2 Final model

Figure 8 illustrates the final model. When the simulation begins, the entities are created from the Cyclist entity. These are then passed through the Entry to the PreRace and arriving at the Start. Once the entities enter the Start the cadence for Straight1 is determined using the normal distribution TNormal (119, 1.03, 118, 121). The entity is then passed through Turn1Entry, Corner1_1, Turn1Mid, Corner1_2 and Turn1Exit before being pushed through Halfway.



Split

Lap	1.000	2.000	3.000	4.000
1	16.223	16.220	16.231	16.223
2	16.273	16.267	16.267	16.280
3	16.282	16.280	16.263	16.267
4	16.220	16.231	16.243	16.230
5	16.292	16.278	16.284	16.289
6	16.201	16.178	16.178	16.195
7	16.250	16.242	16.247	16.238
8	16.230	16.211	16.221	16.214
9	16.227	16.199	16.206	16.210
10	16.125	16.144	16.153	16.158
11	16.146	16.140	16.132	16.119
12	16.157	16.139	16.148	16.158
13	16.132	16.132	16.130	16.137
14	16.212	16.208	16.209	16.200
15	16.203	16.198	16.192	16.188
16	16.226	16.226	16.226	16.226
Cumulative Time	259.400	259.292	259.330	259.331

Data

Cw	0.500
rho	1.226
g	0.000
Crr	0.000
Crr01	0.000
	0.000

Stats

	Bike1	Bike2	Bike3	Bike4	
	1.000	2.000	3.000	4.000	1
Section1	1.314	1.315	1.318	1.319	2
Section2	2.845	2.859	2.783	2.792	3
Section3	2.667	2.661	2.682	2.681	4
Section4	1.319	1.300	1.301	1.317	5
Section5	1.311	1.316	1.305	1.315	6
Section6	2.814	2.814	2.851	2.840	7
Section7	2.695	2.680	2.679	2.652	8
Section8	1.296	1.291	1.303	1.302	9
Lap_Time	16.226	16.226	16.226	16.226	10
Total_Distance	0.000	0.000	0.000	0.000	11
Speed	55.554	55.769	55.333	54.649	12
Lap_Number	16.000	16.000	16.000	16.000	13
Cadence	121.514	121.983	121.030	119.534	14
Frontal_Area	0.449	0.451	0.450	0.451	15
Wind_Resistance	425.174	429.576	422.362	412.838	16
Energy_Percent	74.371	72.290	71.728	72.147	17

Figure 8. The final model

Once the entities reach here, they are then carried along the continuous path around to the *Start*, with the same distributions used in the corresponding sections in the first half of the track, although their cadence will vary throughout the second phase. Once the entities reach the *Finish*, the queue will then scan the entity and if the total laps completed are equal to the total laps required for the race then the entity will be pulled off the track, and the race will be over. However, if the lap number is not equal, then the *Finish* queue will push the entity on the *Start* and the process will begin all over again until the laps completed is equal to the total laps required for the race.

V. ANALYSIS OF THE MODEL

After the model had been tested and validated, using the race times from the data gathered at the velodrome, analysis was then undertaken on the model to determine what the effect of the velocity of the rider had on the wind drag which they faced.

This was done by taking the distributions used in the final model and changing the cadence, but keeping the same ratio between them (min, mode max). The results can be seen in table 1.

Cadence Distributions (RPM)	Mean Drag Force Cyclist 1 (N)	Mean Drag Force Cyclist 2 (N)	Mean Drag Force Cyclist 3 (N)	Mean Drag Force Cyclist 4 (N)	Mean Overall Drag Force (N)
65- 69- 73	103.8	103.7	104.4	103.0	103.7
75- 79- 83	140.8	141.1	142.7	140.3	141.2
85- 89- 93	187.5	187.1	189.6	188.8	188.2
95- 99- 103	233.7	233.4	235.4	234.8	234.3
105- 109- 113	288.5	289.1	291.4	289.7	289.7
115- 119- 123	350.1	350.2	352.8	350.7	350.9
125- 129- 133	489.7	490.6	494.1	491.2	491.4
135- 139- 143	569.3	569.7	573.1	570.0	570.6
145- 149- 153	653.5	654.5	658.2	654.9	655.3
155- 159- 163	744.3	745.4	749.3	745.2	746.1
165- 169- 173	840.9	841.6	845.6	841.1	842.3
175- 179- 183	945.9	948.3	948.6	945.0	946.9
185- 189- 193	1051.8	1053.0	1059.6	1051.4	1054.0

Table 1. Mean drag force on cyclists

By plotting the mean overall drag force against the mean cadence it was possible to see what kind of effect the speed had on the drag of the rider. The row highlighted in table 1, are the values that were taken from the model when it was built. These are also the distributions used in the final model.

RESULTS

Figure 9 shows the result of plotting the mean wind drag against the mean rider cadence. From analysing this chart, it is clear that the speed of the rider does have a great effect on the aerodynamic drag experienced by the rider and the drag force increases in a polynomial fashion by factor 2. This would be down to the fact that when calculating the drag the value for the velocity is squared. The effect that this has on the rider means that unless necessary it is inefficient for a rider to increase their cadence above 135 rpm. If a team of pursuits had to ride above their maximum threshold cadence then they would initiate a death pull. That is when the lead rider at the time, typically the strongest, rides at a faster pace for more laps than they normally would. Then after, because they have had to overcome greater drag forces, their energy levels have depleted therefore they pull off to the side and wait for the race to finish.

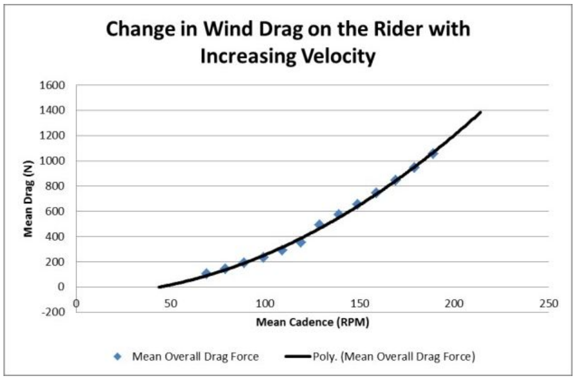


Figure 9. Drag vs. Cadence

VI. DISCUSSION

The basic model shown in figure 7, gave a satisfactory insight into the workings of Witness and how using a visual interactive simulation system, it was possible to simulate the real life events that took place within the Velodrome. Using a basic model initially was a good way to understand what type of data was needed to build the final model. Once the data had been collected and the statistical distributions had been finalised the basic track, which at times only relied on one variable, then developed into a much more in depth track with multiple variables affecting the timing on each section. With multiple variables, the track also had a greater degree of accuracy allowing for results that were more realistic.

Between the basic model and the final model, two major changes were implemented. These were, changing the distribution to generate the section times from the speed of the rider to the cadence and increasing the number of sections used in the bends.

After these changes had been implemented, the model was then tested and variables changed. The model was altered to see what effect an increase or decrease in speed would have on the drag force acting upon the rider.

Looking at table 1, it is clear that the speed of the rider effects the drag force greatly. The drag force of the rider increases in a polynomial fashion as the speed increases, which is why once the rider reaches a certain speed it requires even more effort and power to overcome these drag forces. This leads to the conclusion that once the riders cadence reaches approximately 120-130 rpm it becomes inefficient for them to carry on using the excess force required to overcome the drag. This is why riders initiate death pulls to increase the cadence, with the side effect of greater wind resistance on the lead rider, wearing them out quicker, this results in the race being completed by the remaining riders.

When the model was run initially using the calculated cadence and initial wind resistance was given the model displayed the same lap times, race times and cadence that were analysed from the SRM cranks. This proves that the model is accurate and can possibly be altered to test other factors that affect the riders time in the future.

CONCLUSION

On completion, it was found that the project has successfully met the majority of the objectives originally set out to be accomplished. The first being the requirement to build and develop an accurate model that can be useful to riders and coaches to show what small changes can make to the riders overall time. From looking at the times displayed in figure 8 it is visible that the average lap time affects the position of the rider on the wind resistance along with the speed.

The second objective, which had been met, was to analyse to what extent the speed of a rider has on the overall drag force exerted on the rider. As shown in figure 9, it is clear that once the rider reaches a certain speed, the drag that the rider experiences increase in a polynomial manner. As this increases, so will the lactic build up making it harder for the rider to fully exert the necessary power. This led to the conclusion that after reaching 130 rpm the drag that is exerted on the rider is too great to sustain the corresponding velocity for no more than one or two laps.

An implied objective was to explore into what strategies are currently being used by various cycling teams. Brief research was carried out; however, the end conclusion was that the information that had to be obtained was too sensitive for teams to give out. This could be due to upcoming races, like the world championships, or the team management carefully guard their recent and future race and training strategies. This was one of the reasons why the data that was used was from 2011, even though it is recent. There have been significant decreases in the race times, therefore teams no longer have the need to keep this data hidden.

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