For office use only
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For office use only
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2016

19th Annual High School Mathematical Contest in Modeling (HiMCM) Summary Sheet

Team Control Number: 6618
Problem Chosen: A

Summary

Triathlon, the world-famous and challenging sport, derived in California, America in 1974. It is a multiple-stage competition involving the completion of three continuous and sequential types of sports. It involves swimming, cycling, and running in immediate succession over various distances. Triathlete who completes the competition within the shortest time without any external help is rewarded as the winner. The sport became more and more popular since many benefits are involved in joining the competition. However, when holding such a significant and influential event, a reasonable arrangement is urgently needed to prevent potential risks.

Potential risks arise when the triathlon competition is unreasonably scheduled. Firstly, the congestions happen during the competitions cause great casualties. According to regulations from World Triathlon Company, congestion occurs when two participants have a distance of less than 0.75m. Large number of athletes entering the competition field at the same time will easily lead to collisions. Thereby, it is difficult to notice participants who are in trouble. Besides, hindrance during the competition could strongly affect triathletes' mode status. Fast competitors are not able to reach their fullest potential with slower competitors in front of them. Moreover, triathlon usually requires long hours of blocking the main roads in the city. As a consequence, traffic jam is one of the main problems to be solved. According to the previous research, traffic jam causes massive economic losses and complains from citizens.

In order to assist the organizer to appropriately arrange the upcoming competition, we built a simulation platform to simulate the triathlon process of each participant. Based on the output of our simulation model, we obtained the optimal solution: each participant should depart by a sequence (the professionals and premiers one by one and the other categories start by waves); the time interval of the professionals and premiers was 3 seconds while the interval of others was 2 seconds. This schedule could effectively prevent congestion and potential collisions, and leave enough space for faster participant to overtake.

On the other hand, the longer the roads closure time, the more possible potential problems we would face. If an upper limit of road closure time was set, the inappropriate schedule could lead to a lot of participants' failing to finish the competition. Adjusting the distance of the sections was a possible way to deal with the problem. We used our simulation model to investigate the effect of adjusting distances of swimming, biking, and running. The result showed that reducing distance of the cycling section could effectively reduce the congestion and eliminate the issue of participants who were unable to finish within the constrained time period, therefore reduced road closure time.

In conclusion, by simulating different kinds of schedules and ways of dividing participants, our paper reached an optimal solution as well as the best adjustment plan to reduce the road closure time while minimize the race congestion.

Catalogue

Dear Mayor,

Several days ago, we received your request of scheduling the open triathlon in your town. We understand your high prospective of the event and your desire to involve not only professional triathletes but also the general-publics. In our suggested schedule, we aim to make sure that the competition finish on time and minimize the congestion as much as possible at the same time. We have also considered a lot of factors that might affect the town regular routine and the race process. We sincerely hope our proposals will meet your expectation.

First of all, we have done a thorough research about the recent successful triathlons and build models to determine the optimal way that minimizes both congestion and the closure time of the road. We contribute two great factors that could affect these two indices, the divisions of participants and the order of groups to start the competition.

Referring to the division methods used in most of the world-class triathlon competitions, we decide to categorize the participants into three major groups: Professional, Premier and Open. Each of those categories is then separated into male and female. This method is expected to stimulate public participation and satisfy the requirements of a formal world-class event. According to our analysis, the majority of the participants will be male Open, which will count for 67%, while female Open will make up about 28% of the total population.

In order to make sure the process of competition in order, we suggest the professionals and premier should start the competition first. According to our research, for an international triathlon, the distance between 2 participants during the competition should be more than 0.75m in order to avoid possible collisions which may lead to injuries. To provide the best interval time for professionals and premiers, we find that the interval time for each individual should be 3 seconds. For Opens, we expect slower process time. We find that using 2 seconds as individual interval time will be the best choice. To sum up, we suggest that this competition can follow the order of Male professional and premier, Female professional and premier, Male open, Female open. The interval time of professionals as well as premiers should be 3 seconds. The interval time of opens should be 2 seconds to pursue a minimum congestion index.

Considering about further improvement, we suggest that you can also consider reducing the distance of a section to reduce the congestion and the time for traffic control without violating the race rule of the Olympic Triathlon. On the basis of our analysis, to decrease a certain amount of distance in the cycling section is the optimum and most effective way. It is also a good way to reduce the number of potential unfinished participants, which can increase the participants' satisfactory.

We believe that the application of our recommendations will surely contribute to a successful high quality triathlon competition and bring an enjoyable and meaningful experience to our citizens.

Sincerely,
Team # 6618

Schedule (22nd November – 23rd November)

22rd November 2016

Before the competition (staffs)

1. Regulation meeting (14:00-16:00)
2. First aid training (18:30-20:30)

Before the competition (Participants)

1. Participants arrive in the hotels of the town and check in (22nd 10:00-14:00)
2. Professional triathletes meeting (14:30-16:30)
3. Welcoming dinner party (18:30-22:30)

23rd November 2016

06:00-07:00	Participants collect equipment
07:00-7:30	Participants place their bicycles
07:45-08:00	Professional and Premier triathletes check in
08:00-09:00	Open, Clydesdale and Athena check in
09:00-09:05	Departure of professionals and premiers
9:05-10:10	Departure of the rest
14:30	Estimated time of the last participant finish the competition
14:30-17:00	Sponsors’ exhibition
17:00-17:30	Award Ceremony

Restatement

The triathlon will be sponsored by the Super Tread Race Company. My town will corporate with the company and try the best to support the competition. It is an international sports competition including participants from all over the world with a wide age range. We aim to attract professional and premier triathletes and to encourage general-public to participate as well. In order to ensure the town's discipline, the local roads cannot be closed for more than 5.5 hours. We are asked to come up with a plan to make sure the process of competition to succeed with a minimum congestion which means excessive crowding on the course. We have been given a dataset contains a recent triathlon include participants' gender, age, status, race event times, transition times, and total times.

Assumptions

1. The number of participants is exactly 2,000.

Justification: There was not enough information to determine the exact number of participants; therefore we assumed that there were 2,000 participants.

2. The weather condition has no effects on the performance of participants.

Justification: Different weather conditions might have different influences on the performance of the participants. As we did not know the weather condition of the given data or the weather condition in the upcoming race, we assumed weather condition had no effects on the time taken in each section and we could use the given data set to estimate the performance of those 2000 participants.

3. Less than 5 participants who cannot finish the competition with 5.5 hours can be tolerable.

Justification: It is possible that few of the participants cannot finish the race within the 5.5 hours. We assumed that the situation which no more than 5 participants failed to finish the competition due to the time limit still satisfied the requirements.

4. The difficulty coefficient of the triathlon in My town is the same as which of the previous triathlon.

Justification: The difficulty coefficient determines the result. In order to make accurate use of the data given, we assumed that the difficulty coefficient of the triathlon in My town was the same as the previous triathlon.

5. The speed of each participant is constant in each section (swimming, biking and running).

Justification: If the distance of the race of each section changes, the time taken needs to be adjusted. This assumption allows us to adjust the time taken more conveniently and reasonably.

6. No participants give up the competition voluntarily.
Justification: The number of participants needs to be at a certain degree to ensure the accuracy of the data. Therefore, we assume that no participants give up the competition voluntarily.

7. Congestion takes place when the distance of two participants is less than 0.75m.
Justification: The congestion happens when the distance between two participants is too close. In this paper, we assumed that the distance should not be less than 0.75m, otherwise it would affect the result and the performance of the participants.

Notations

SWIM: time for swimming

TI: time for transition area from swimming to cycling

BIKE: time for cycling

T2: time for transition area from cycling to running

RUN: time for running

FINALTM: total time for the competition

$\cent$: The congestion index

Data analysis

Percentage of categories

The pie chart (Figure 1) illustrates the percentage of the participant's categories. Among all the participants, more than 90% belonged to the open race group, and there were only less than 5% belonging to the professional and premier groups. The similar structure of the categories would be assigned to the 2000 participants who would join the triathlon competition.

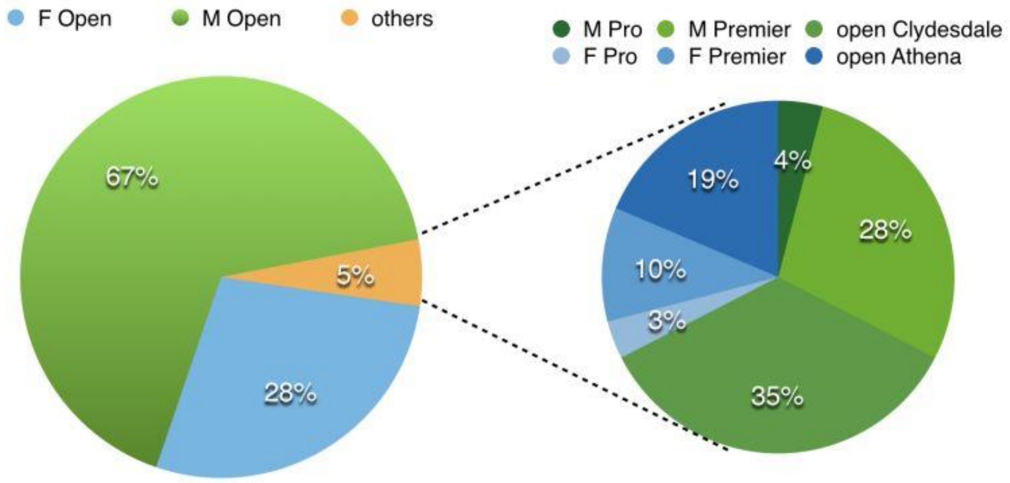


Figure 1 Percentage of participants' categories

Relationship between age and time

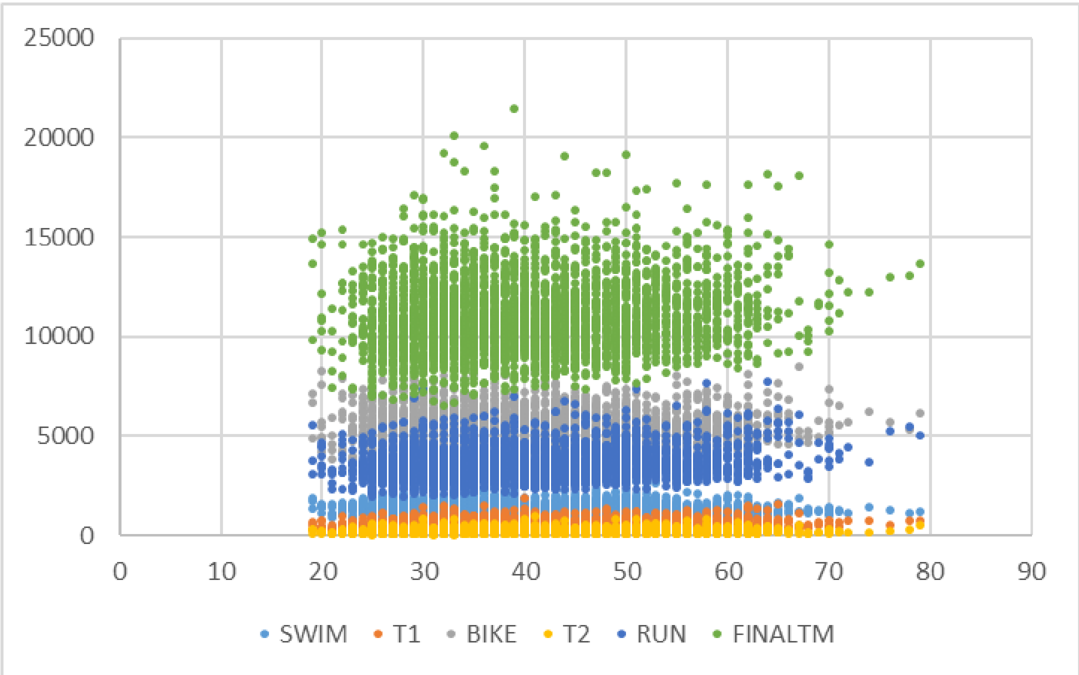


Figure 2 Relationship between age and time

Figure 2 shows that there is no clear relationship between age of the participants and the time in each section (SWIM, T1, BIKE, T2, RUN, and FINALTM). The correlation coefficients between age and time are shown in Table 1. All the correlation coefficients are quite small, which supports our findings from Figure 2. Therefore, we could conclude that there is no significant relationship between age and time, and we could not use age to estimate the time taken for the upcoming 2000 participants.

Table 1. Correlation coefficients of age and time

	AGE
SWIM	-0.05661
T1	0.148792
BIKE	0.01825
T2	0.139995
RUN	0.193456
FINALTM	0.103857

Category and time

We also calculated the average total time taken for participants of each category. The results showed that the Professionals were faster than the Premiers; the premiers are faster than the Open, Clydesdale and Athena; Open was slightly faster than Clydesdale and Athena; male was faster than female within each category. Therefore, in order to reduce the congestion, it was better to divide the divisions by category rather than by age. In this paper, we discussed both situations: the faster divisions started earlier and the slower divisions started earlier.

Part 1

We built a simulation model to simulate different scenarios of divisions and schedules of start time. The flowchart of the model is shown in Figure 3. The whole process was repeated 10 times for each scenario to reduce the randomness brought by the random number generator.

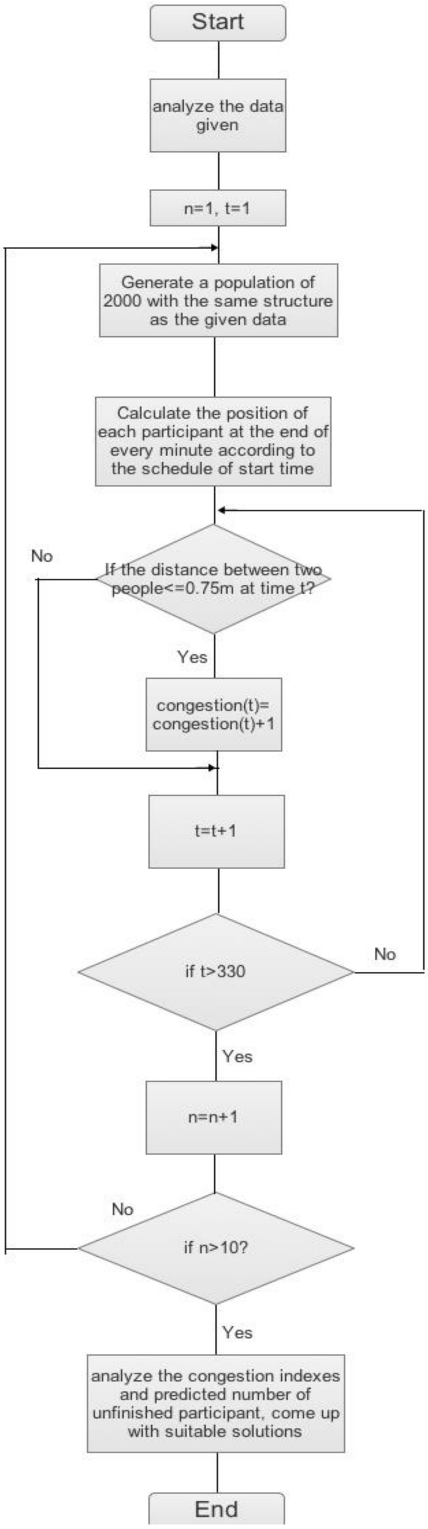
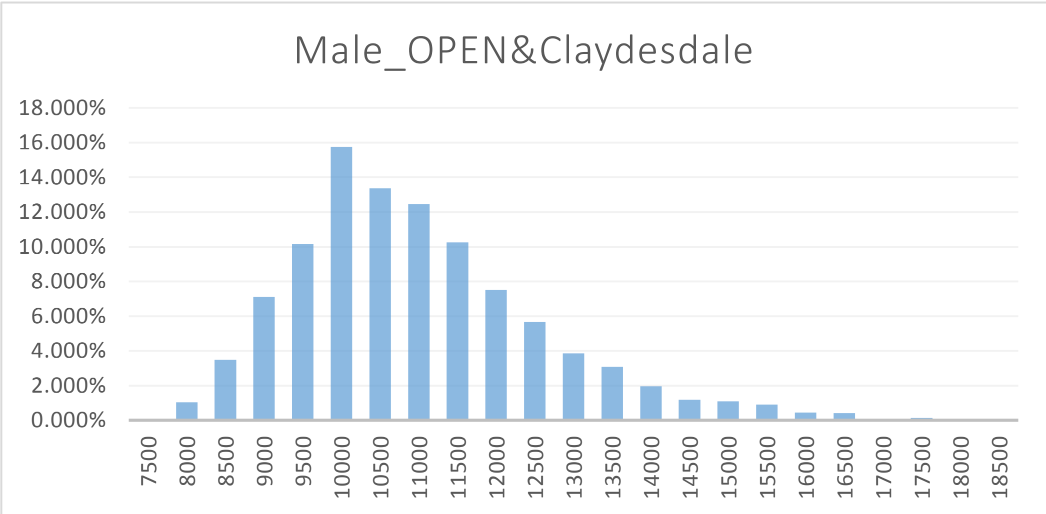


Figure 3 flowchart of the simulation model

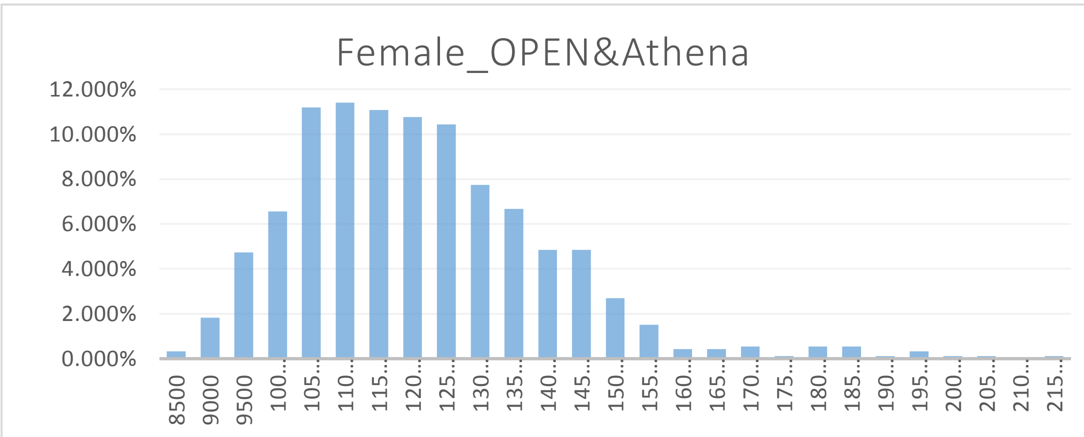
Population generator

We used the following steps to generate 2000 participants with their age, category and time taken in each section:

1. We divided the overall data into 4 groups: (1) Male Pro and Premier; (2) Female Pro and Premier; (3) Male open and Clydesdale; (4) Female open and Athena. The Clydesdale and Athena groups were slightly slower than their corresponding open groups of their gender, but due to its small amount comparing to open groups, these participants could be generally considered as a part of the open group.
2. As there were only a few participants belonged to Group (1) and Group (2), we just assumed that the participants in these two groups would have the same performance as in the previous competition. We randomly picked up a certain amount of participants from the data set according to the percentage of each group, and assumed that they would attend the upcoming competition and take the same length of time to finish each section.



(a)



(b)

Figure 4 The probability distribution of a. Group (3) Male_OPEN&CLY and b. Group (4) Female_OPEN&ATH

3. We analyzed the probability distribution of time taken in the race of the last two groups mentioned above. The histogram (Figure 4) shows the probability distribution of total time taken of two groups.
4. We generated a random number uniformly distributed between 0 and 1 for each participant, and determined the corresponding cumulative probability interval it belonged to. Then we assigned the corresponding time interval to the participant. After that, we used a random number generator to determine the actual time within the assigned time interval.

Algorithms

We assumed that the congestion took place when the distance of two participants was less than 0.75m. We also defined $\cent$, the congestion index, as the total number of congestions happened at the end of each minute.

In order to minimize the course congestion and road closure time, we attempted to find the proper time interval which could result in a small congestion index $\cent$ and a number of unfinished participants no more than 5 (mentioned in the assumption part).

According to the aforementioned assumptions, we assumed that each participant kept constant speed in each section in the competition. We divided the overall time period of 5.5 hours into 330 one-minute intervals. By using the time taken of participants generated before, we used the time elapsed to calculate the exact position of each participant at the end of each minute in each scenario. We then calculated $\cent$ at the end of each of those 330 time intervals.

$\cent$ of each scenario was compared to find the best schedule of divisions and start time.

Results

Scenario 1

Divisions and stat time:

1. Professional and premier participants: participant starts the competition one by one every 3 seconds (the amount of these two categories was small, and we could follow the rule of Olympics and provide them a good competition environment).
2. Open participants: enter the competition by groups of 50 participants with the same interval time between groups.
3. The order: Male professional and premier, Female professional and premier, Male open, Female open.

We calculated the congestion indexes of 4 different time intervals and the number of unfinished participants. As we repeated the model 10 time in order to reduce the unexpected randomness, we obtained 10 groups of congestion indexes for each time interval and the number of unfinished participants. We plotted the mean as well as their 95% confidence interval of congestion indexes (Figure 5 to 8). The shapes were similar but the curves in Figure 7 and Figure 8 have lower peaks when comparing to Figure 5 and Figure 6. However, when considering the number of unfinished participants (Table2), numbers with interval time of 100 seconds were constantly higher than numbers with interval time of 90 seconds. For the scenario of 100 second, there was even one simulation where the number exceeds 5 unfinished participants. Therefore, the best interval time in Scenario I was 90 seconds.

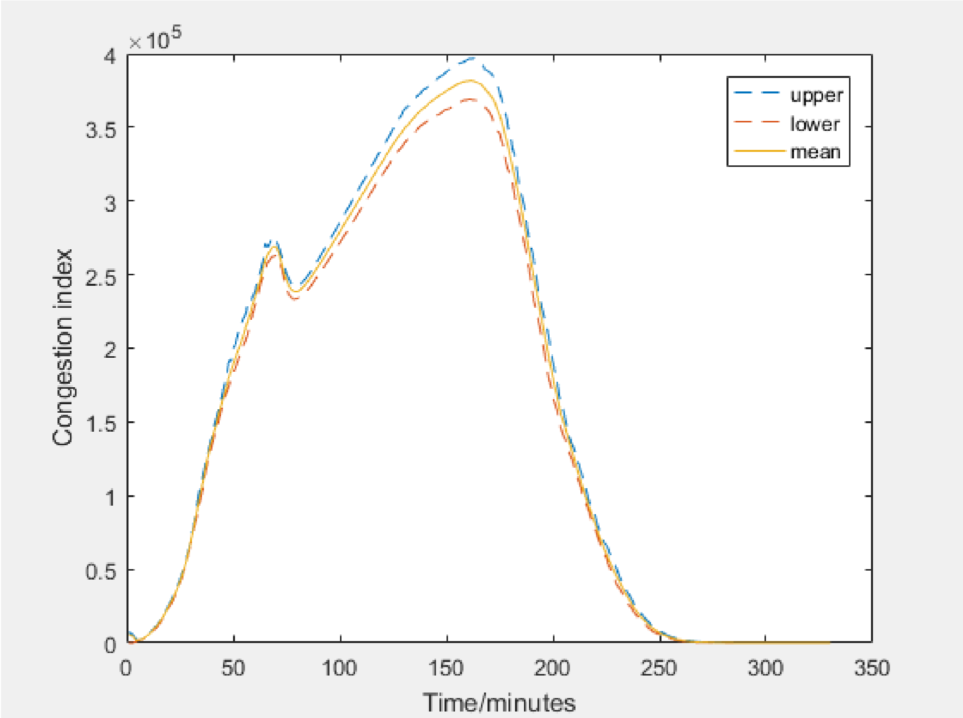


Figure 5 Interval time 70s

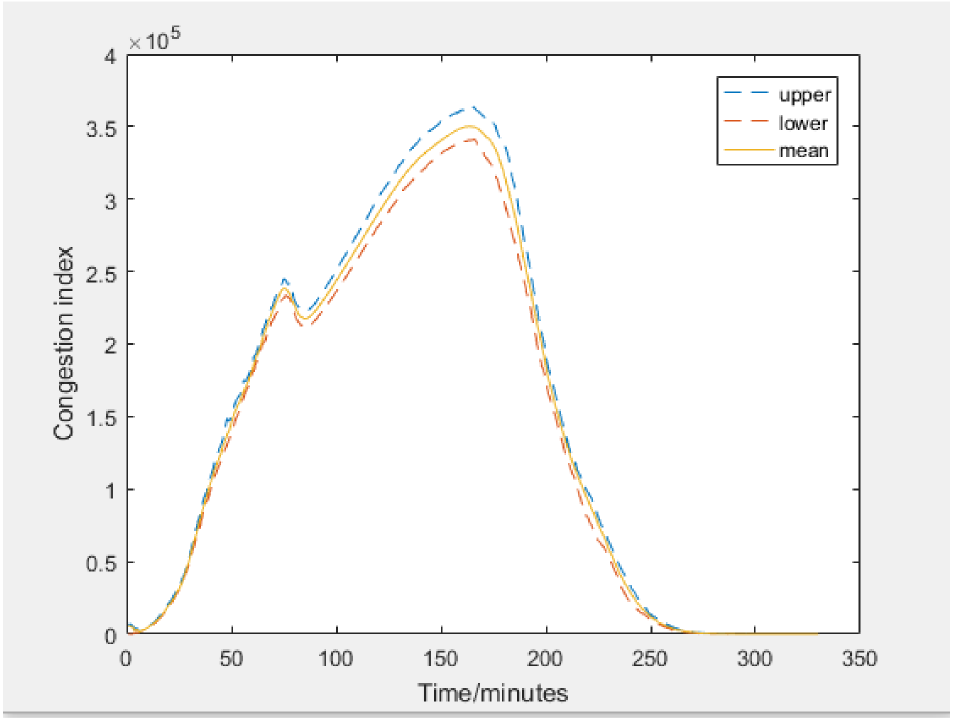


Figure 6 interval time 80s

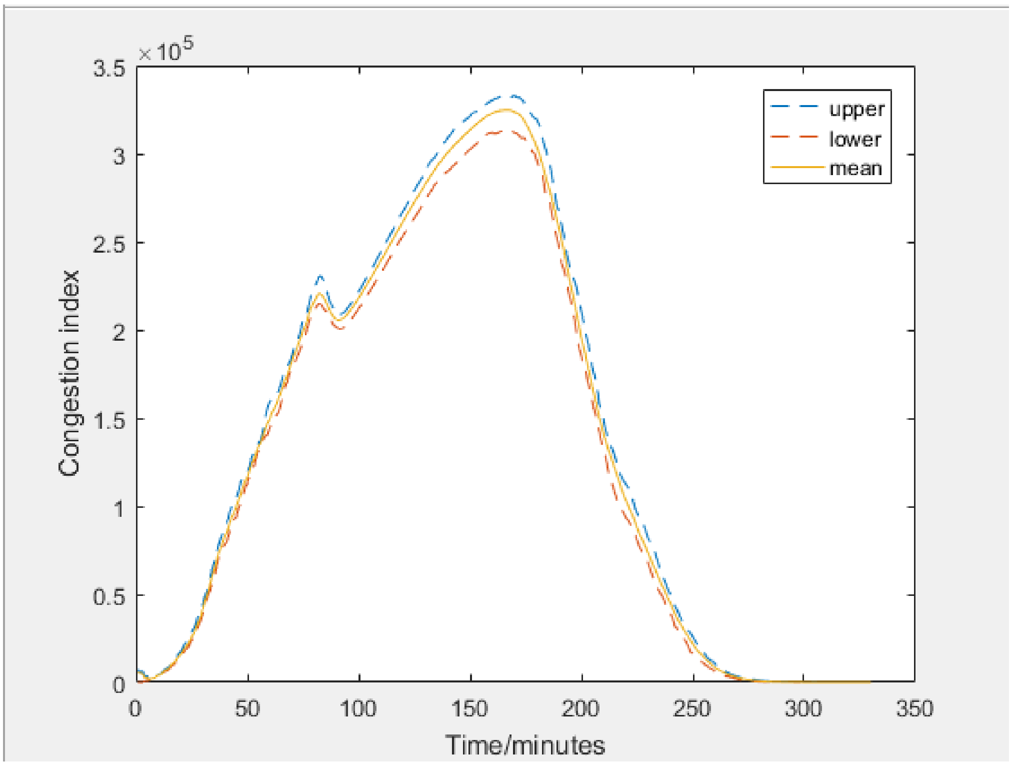


Figure 7 interval time 90s

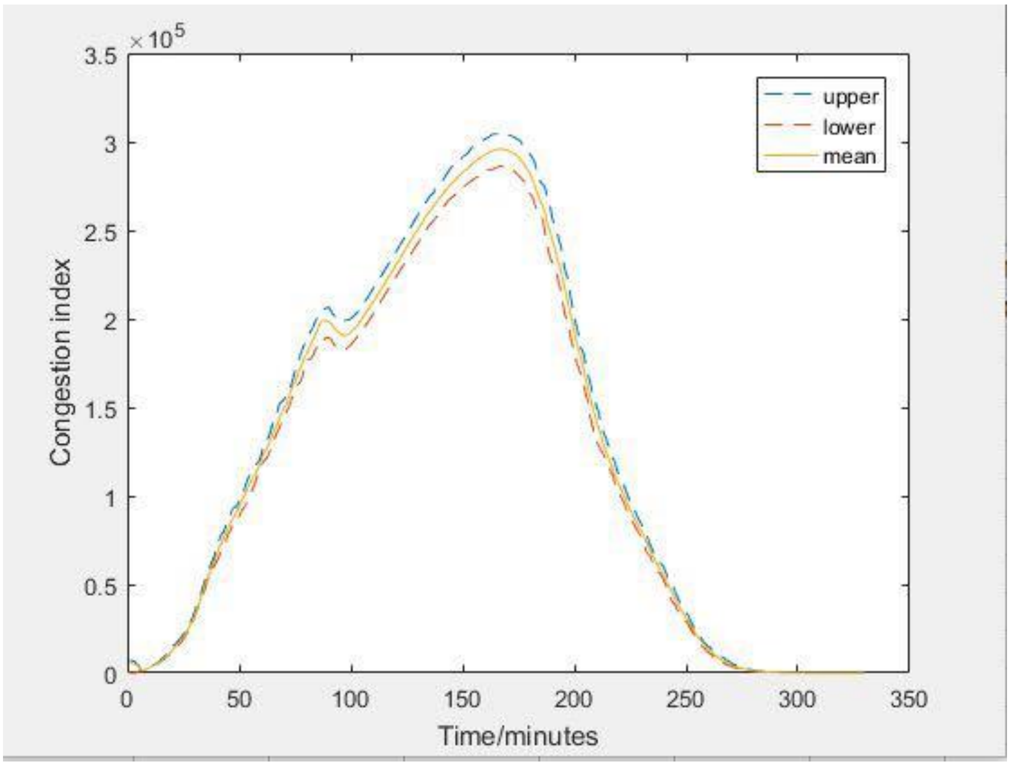


Figure 8 interval time 100s

Table 2: number of unfinished participants

Time interval	1	2	3	4	5	6	7	8	9	10
70s	1	0	1	1	0	1	0	2	0	2
80s	1	0	2	1	0	0	0	1	1	1
90s	4	4	0	3	4	4	1	0	3	0
100s	5	4	5	2	4	7	3	4	4	3

Scenario 2

Divisions and stat time:

1. Professional and premier participants: Participant enter the competition one by one every 3 seconds
2. Open participants: enter the competition one by one for the same interval time
3. The order: Male professional and premier, Female professional and premier, Male open, Female open

Same calculation process was applied in Scenario 2 as in Scenario 1. We tested three time intervals for Open participants: 1 second, 2 seconds, or 3 seconds. When considering the congestion index, Figure 9, 10, and 11 showed that the longer the interval time, the better the performance. However, when the interval time was 3 seconds, all the numbers of unfinished participants exceed 5 in all the 10 tests (Table 3). Therefore, the best interval time among in Scenario 2 was 2 seconds.

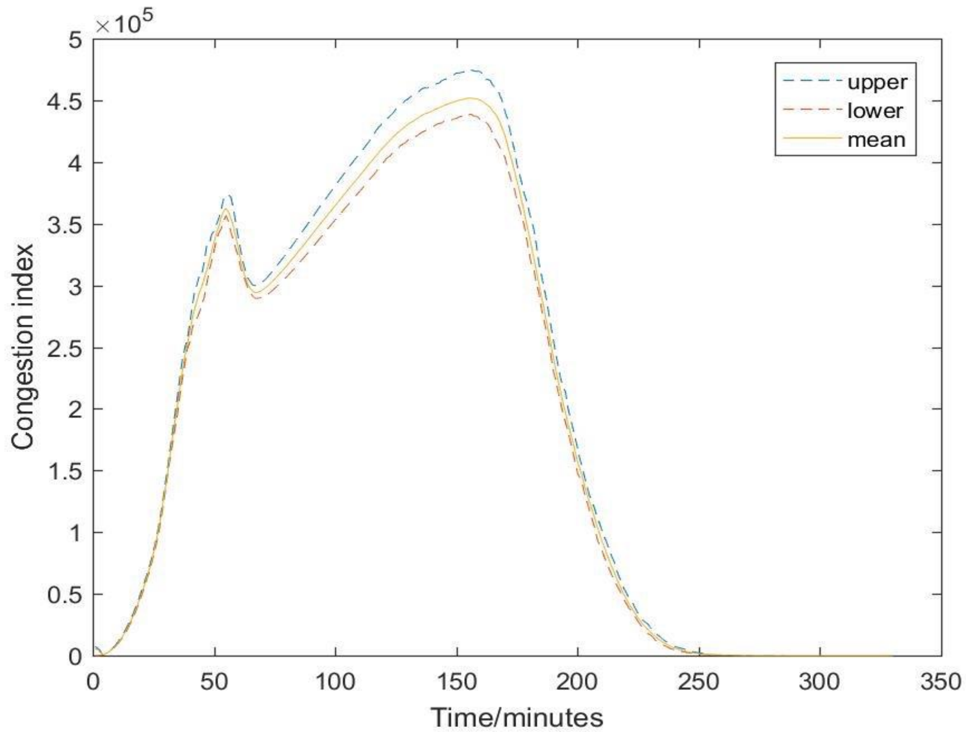


Figure 9 Interval time 1s

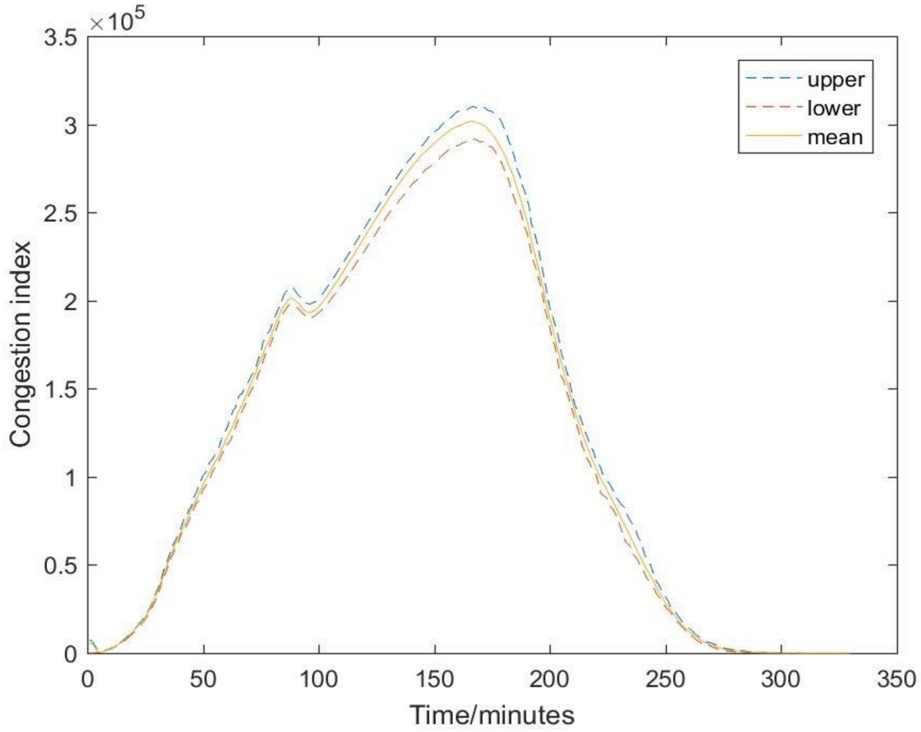


Figure 10 Interval time 2s

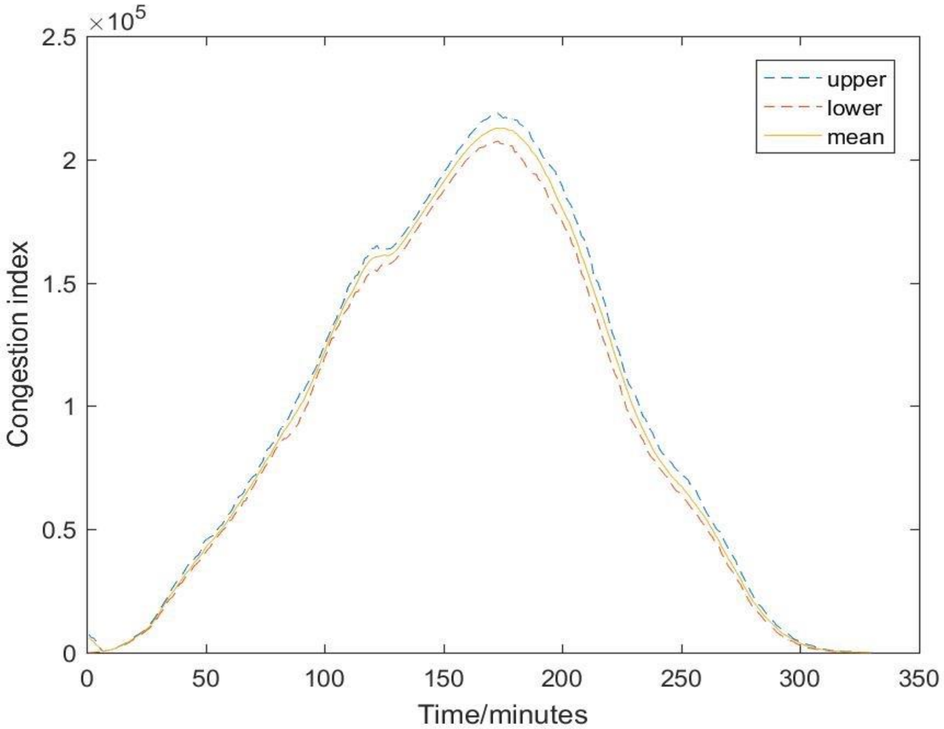


Figure 11 Interval time 3s

Table 3: number of unfinished participants

Time interval	1	2	3	4	5	6	7	8	9	10
1s	1	0	0	0	1	0	0	0	1	0
2s	1	3	2	1	5	3	2	1	4	3
3s	16	16	17	17	22	12	17	21	20	14

Scenario 3

Divisions and stat time:

1. Professional and premier participants: Participants enter the competition one by one every 3 seconds.
2. Open participants: enter the competition one by one every 2 seconds.
3. Two orders were tested: A. Female open, Male open, Female professional, Male professional; B. Male professional, Female professional, Female open, Male open.

In this scenario, we tested the performance of the schedule that slower divisions start earlier than faster divisions. The results (Figure 12, 13) showed that congestion indexes were much higher than those in Scenario 1 and 2 although the number of unfinished participants (Table 4) was quite low. As to control congestion was the key objective, this scenario would not be considered.

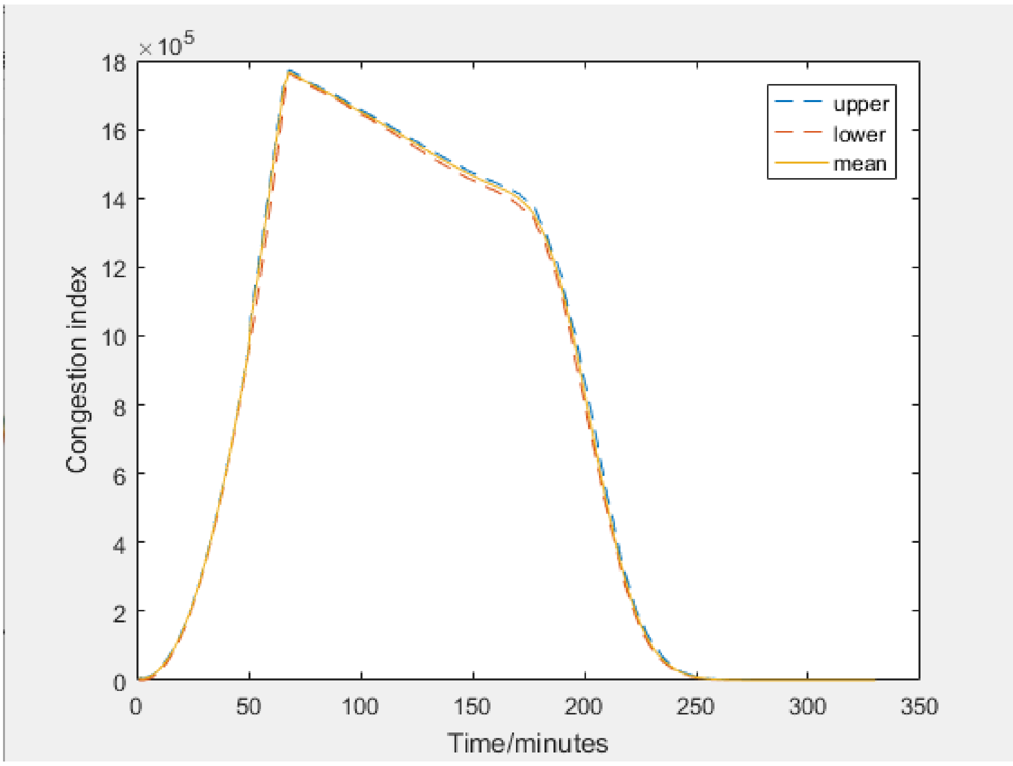


Figure 12 Order A: Female open, Male open, Female professional, Male professional

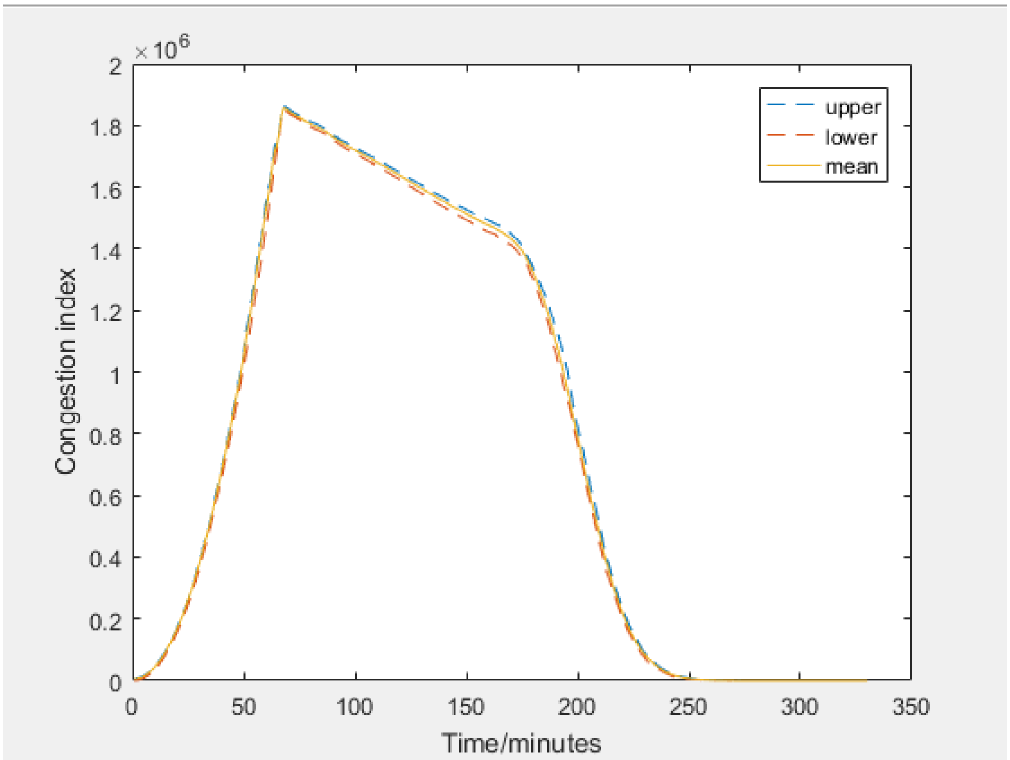


Figure 13 Order B: Male professional, Female professional, Female open, Male open

Table 4: number of unfinished participants

Order	1	2	3	4	5	6	7	8	9	10
Order 1	0	0	0	0	0	0	0	1	0	0
Order 2	0	1	0	0	0	1	0	0	0	0

Conclusion

After comparing the three major methods, it turns out that Scenario 3 was the worst because of the high congestion indexes under both of the conditions. So the best choices obtained from Scenario 1 and Scenario 2 were the two alternatives to choose, while both choices had the same condition that 'Professional and premier participants enter the competition one by one every three seconds'. Thus the open participants could either choose to enter the competition by groups of 50 with the same interval time (90 seconds) between groups or to enter the competition one by one with interval time (2 seconds) between each person. Since the numbers of unfinished participants predicted in both scenarios were within the acceptable boundary and the traffic closure time required was lower than 5.5 hours, the only factor that influenced our final decision is the congestion index. When comparing Figure 7 and Figure 10, we could see that Figure 10 has a lower peak. Therefore, the final solution we choose was Scenario 2 with interval time of 2 seconds.

Part 2

Adjusting the distances of each section in the triathlon would affect the congestion indexes, road closure time, and the amount of unfinished participants. In order to test the influences of adjusting the distances of triathlon as well as to make the comparison fair and reasonable, two assumptions were made in Part II model:

- Only one of the three sections (swimming, cycling, and running) could be changed.
- Only 10% or 30% adjustment could be made, either longer or shorter.

Besides, the optimal scenario of divisions and start time (3s interval between departure of each Male and Female Pros and Premiers, and 2s interval between each of other Male and Female participants) was used for adjustment. +-10% and +-30% changes of distances of the three sections were made under this scenario and the same simulation model was applied to test the effect of each change. As we have assumed that the participants kept constant speed in each section, the changes of distances caused the same proportion of changes of time.

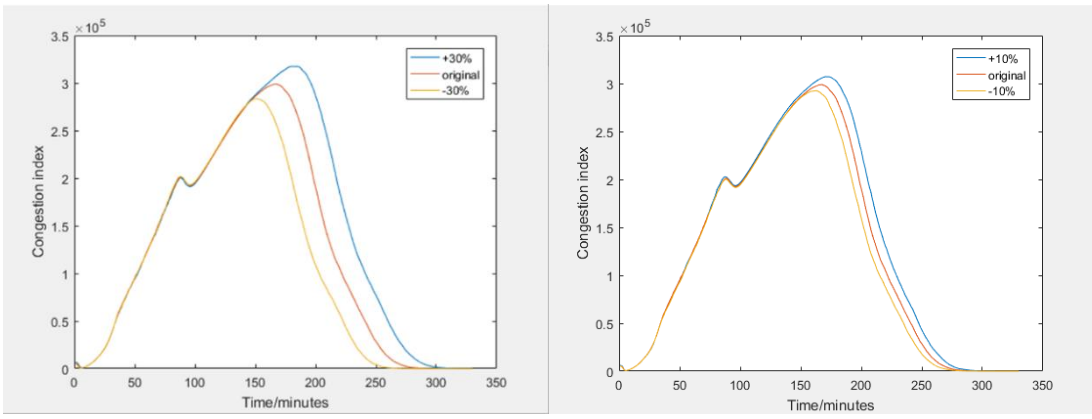


Figure 14 Congestion index varied by changing distance of running section

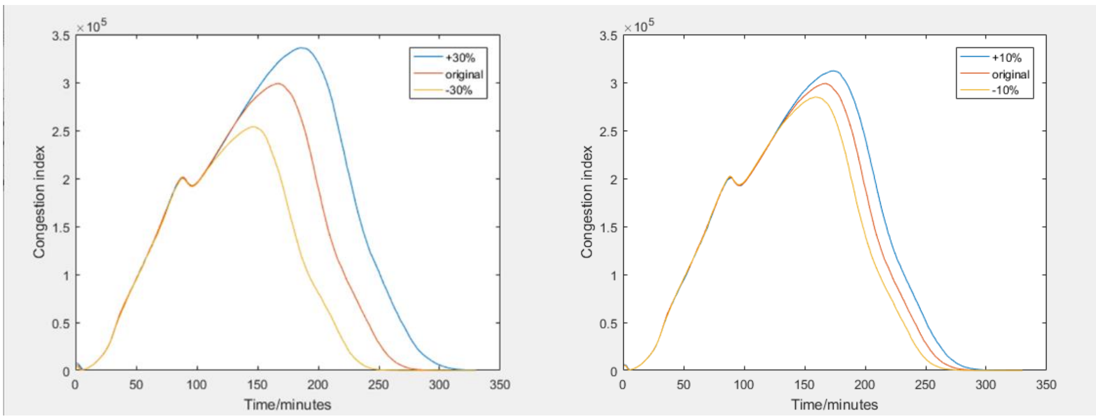


Figure 15 Congestion index varied by changing distance of biking section

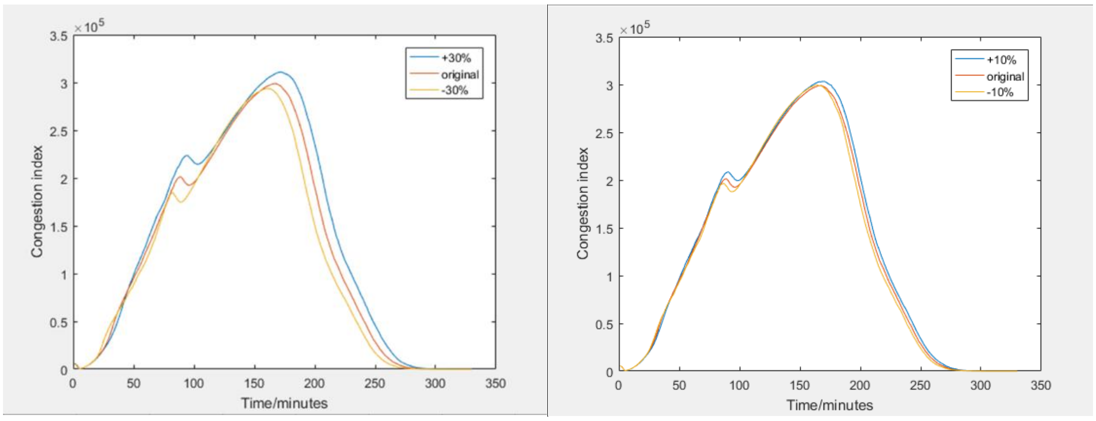


Figure 16 Congestion index varied by changing distance of swimming section

Table 5 Average of 10 numbers of unfinished participants

Change	SWIMMING	BIKING	RUNNING
10%	3.6	7.7	5.5
-10%	2.5	1	2
30%	4.7	28.8	13.2
-30%	1.9	0.1	0.4

Figure 14, Figure 15, and Figure 16 showed the mean congestion indexes of each change. When comparing horizontally, the longer the distance the higher the peaks of the congestion indexes. From the graph it was obvious that changing the distance of cycling section would vary congestion index by the largest extent. Changing the running section would vary congestion index less radical than changing the cycling section, and would only show its effects after about 180 minutes when the race started. Changing the swimming section would result in least effect than changing the other two sections. According to the average number of unfinished participants (Table 5), increasing 30% of a section, especially cycling and running, would result in significant increases of number of unfinished participants, which was unacceptable. Increasing 10% of a section would also increase the number, and the number would probably exceed the designated maximum limit of 5 participants, which was also unacceptable. Decreasing 10% and 30% could control the number of unfinished participants to an acceptable amount.

Therefore, when considering congestion indexes and the number of unfinished participant, decreasing 30% of the cycling section would have the most significant effect. In conclusion, increasing the distances would lead to higher congestion indexes and number of unfinished participants while decreasing the distances would result in the opposite effect. The government and the sponsor could use our model to determine the appropriate change of distance according to their requirements.

Discussion

In this paper, we developed a simulation model to simulate the process of a triathlon competition. This model could help us know the position of each participant as well as the congestion indexes at each time point according to the estimated structure of the participants, which could help policymakers and organizers to make an appropriate schedule of divisions and start time.

There were both strength and weakness in our model. Our strength makes our model reasonable and applicable while we still realized the limitation of some of the methods we used in the modeling process.

Strength:

1. The model could accurately predict the category and race time of each participant
2. The model could calculate the congestion index at any time point as well as position.
3. Our simulation platform could be easily applied to investigate the effectiveness and the efficiency of different scenarios.

Weakness:

1. We assumed that each participant travels in a constant speed which was unlikely to happen in reality.
2. We only investigated some schedules in each scenario which could not be the overall best schedule for the competition. A more generalized algorithm to find the best schedule should be studied.
3. The road closure time was used as a constraint in this model, and it could be better to use the minimum closure time as an alternative objective of the study.

References

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4. http://www.ironman-china.com/
5. http://baike.baidu.com/view/18166.htm
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7. www.olympic.org
8. http://www.fitness.com/articles/115/the_physical_benefits_of_triathlon.php

Appendix

Matlab Code:

```
F=zeros(578,6);
M=zeros(1372,6);
MPre=zeros(30,6);
FPre=zeros(12,6);
pos=zeros(330,2000);
mean_cong=zeros(1,330);
StartTime=[0:3:147];
upper_cong=zeros(1,330);
unfinish=zeros(1,10);
lastfinish=zeros(1,10);
for j=1:330
    lower_cong(j)=1000000;
end
for d=1:65
    for e=1:30
        StartTime(20+30*d+e)=147+30*d;
    end
end
for o=1:10

for i = 1:578
    X=rand;
    if X<F_1C(1)
        F_1temp=1050+X/F_1C(1)*150;
    end
    for a=2:10
        if X<F_1C(a)&X>F_1C(a-1)
            F_1temp=F_1(a-1)+((X-F_1C(a-1))/F_1P(a))*150;
        end
    end
    X=rand;
      if X<F_2C(1)
        F_2temp=250+X/F_2C(1)*100;
      end
    for b=2:15
        if X<F_2C(b)&&X>F_2C(b-1)
            F_2temp=F_2(b-1)+((X-F_2C(b-1))/F_2P(b))*100;
        end
    end
    X=rand;
```

```
     if X<F_3C(1)
        F_3temp=4500+X/F_3C(1)*500;
     end
    for c=2:16
        if X<F_3C(c)&X>F_3C(c-1)
            F_3temp=F_3(c-1)+((X-F_3C(c-1))/F_3P(c))*500;
        end
    end
    X=rand;
      if X<F_4C(1)
        F_4temp=100+X/F_4C(1)*50;
      end
    for d=2:19
        if X<F_4C(d)&&X>F_4C(d-1)
            F_4temp=F_4(d-1)+((X-F_4C(d-1))/F_4P(d))*50;
        end
    end
    X=rand;
     if X<F_5C(1)
        F_5temp=2500+X/F_5C(1)*250;
     end
    for e=2:22
        if X<F_5C(e)&X>F_5C(e-1)
            F_5temp=F_5(e-1)+((X-F_5C(e-1))/F_5P(e))*250;
        end
    end
     X=rand;
     if X<F_6C(1)
        F_6temp=20+X/F_6C(1)*5;
     end
    for f=2:13
        if X<F_6C(f)&X>F_6C(f-1)
            F_6temp=F_6(f-1)+((X-F_6C(f-1))/F_6P(f))*5;
        end
    end
    F(i,:)=[F_1temp,F_2temp,F_3temp,F_4temp,F_5temp,F_6temp];
end
for i = 1:1372
    X=rand;
    if X<M_1C(1)
        M_1temp=900+X/M_1C(1)*150;
    end
    for a=2:14
        if X<M_1C(a)&X>M_1C(a-1)
```

```
        M_1temp=M_1(a-1)+((X-M_1C(a-1))/M_1P(a))*150;
    end
end
X=rand;
  if X<M_2C(1)
    M_2temp=300+X/M_2C(1)*100;
  end
for b=2:10
    if X<M_2C(b)&X>M_2C(b-1)
        M_2temp=M_2(b-1)+((X-M_2C(b-1))/M_2P(b))*100;
    end
end
X=rand;
 if X<M_3C(1)
    M_3temp=4000+X/M_3C(1)*500;
 end
for c=2:13
    if X<M_3C(c)&X>M_3C(c-1)
        M_3temp=M_3(c-1)+((X-M_3C(c-1))/M_3P(c))*500;
    end
end
X=rand;
  if X<M_4C(1)
    M_4temp=50+X/M_4C(1)*50;
  end
for d=2:16
    if X<M_4C(d)&X>M_4C(d-1)
        M_4temp=M_4(d-1)+((X-M_4C(d-1))/M_4P(d))*50;
    end
end
X=rand;
 if X<M_5C(1)
    M_5temp=2500+X/M_5C(1)*250;
 end
for e=2:21
    if X<M_5C(e)&X>M_5C(e-1)
        M_5temp=M_5(e-1)+((X-M_5C(e-1))/M_5P(e))*250;
    end
end
 X=rand;
 if X<M_6C(1)
    M_6temp=20+X/M_6C(1)*5;
 end
for f=2:13
```

```
        if X<M_6C(f)&X>M_6C(f-1)
            M_6temp=M_6(f-1)+((X-M_6C(f-1))/M_6P(f))*5;
        end
    end
    M(i,:)=[M_1temp,M_2temp,M_3temp,M_4temp,M_5temp,M_6temp];
end
w=randperm(7);
MPro=[M_Pro(w(1),:);M_Pro(w(2),:);M_Pro(w(3),:);M_Pro(w(4),:)];
x=randperm(6);
FPro=[F_Pro(x(1),:);F_Pro(x(2),:);F_Pro(x(3),:);F_Pro(x(4),:)];
y=randperm(49,30);
for a=1:30
    MPre(a,:)=M_Premier(y(a),:);
end
z=randperm(19,12);
for b=1:12
    FPre(b,:)=F_Premier(z(b),:);
end
for c=1:2000
    ID(c)=c;
end

ALL=[MPro;FPro;MPre;FPre;M;F];
for t=1:330
    for p=1:2000
        if t*60-StartTime(p)>=(ALL(p,1)+ALL(p,2)+ALL(p,3)+ALL(p,4)+ALL(p,5))
            pos(t,p)=51500;
        end
        if          t*60-StartTime(p)>=(ALL(p,1)+ALL(p,2)+ALL(p,3)+ALL(p,4))&&
t*60-StartTime(p)<(ALL(p,1)+ALL(p,2)+ALL(p,3)+ALL(p,4)+ALL(p,5))

pos(t,p)=41500+10000*((t*60-StartTime(p))-ALL(p,1)-ALL(p,2)-ALL(p,3)-ALL(p,4))/
ALL(p,5);
        end
        if
t*60-StartTime(p)>=(ALL(p,1)+ALL(p,2)+ALL(p,3))&&t*60-StartTime(p)<(ALL(p,1)+AL
L(p,2)+ALL(p,3)+ALL(p,4))
                pos(t,p)=41500;
        end
        if
t*60-StartTime(p)>=(ALL(p,1)+ALL(p,2))&&t*60-StartTime(p)<(ALL(p,1)+ALL(p,2)+AL
L(p,3))

pos(t,p)=1500+40000*((t*60-StartTime(p))-ALL(p,1)-ALL(p,2))/ALL(p,3);
```

```
        end
        if t*60-StartTime(p)>=(ALL(p,1))&&t*60-StartTime(p)<(ALL(p,1)+ALL(p,2))
                pos(t,p)=1500;
        end
        if t*60-StartTime(p)<(ALL(p,1))&&t*60-StartTime(p)>0
                pos(t,p)=1500*(t*60-StartTime(p))/ALL(p,1);
        end
    end
end
for p=1:2000
    if (ALL(p,1)+ALL(p,2)+ALL(p,3)+ALL(p,4)+ALL(p,5)+StartTime(p))>19800
        unfinish(1,o)=unfinish(1,o)+1;
        end
    if
(ALL(p,1)+ALL(p,2)+ALL(p,3)+ALL(p,4)+ALL(p,5)+StartTime(p))>lastfinish(1,o)

lastfinish(1,o)=(ALL(p,1)+ALL(p,2)+ALL(p,3)+ALL(p,4)+ALL(p,5)+StartTime(p));
        end


end
pos=pos';
cong=zeros(330,1);

for i=1:330
    for j=1:1999
        for k=j+1:2000
            if
pos(j,i)-pos(k,i)<=0.75&&pos(j,i)~=0&&pos(k,i)~=0&&pos(j,i)~=51500&&pos(k,i)~=5
1500
                cong(i)=cong(i)+1;
            end
        end
    end
    if cong(i)>upper_cong(i)
        upper_cong(i)=cong(i);
    end
    if cong(i)<lower_cong(i)
        lower_cong(i)=cong(i);
    end
    mean_cong(i)=mean_cong(i)+cong(i);
end
cong_data(:,o)=cong;
end
mean_cong=mean_cong.*0.1
```

```
plot(1:330,upper_cong,'--',1:330,lower_cong,'--',1:330,mean_cong)
legend('upper','lower','mean')
ylabel('Congestion index')
xlabel('Time/minutes')
```