IE-2086 Decision models
Final Project Presentation

Vehicle Performance Optimization

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Introduction

- A bicycle that has 7 different gears.
- Four riders to substitute.
- Each rider has different forces and power values.
- Rider covers less distance on gear n than on gear n+1.
- Rider depletes less energy per unit time while on gear n than on gear n+1.

Determine how much time a rider must spend on a gear to achieve overall maximum distance.

Stage

- Each gear change corresponds to a stage.
- 7 stages occur during the tenure of every rider. 28 in total.
- For simplicity, we model this sequential problem for individual riders (7 stages).

Constant and deterministic values

- Force capacity: Maximum impact force by a normal human = 2000 N
  Only a fraction of it is used during pedaling.
  F = 488 N and fraction force **ff = (488/2000) = 0.244**
- Mass of the rider **m = 73 kgs**
- Rider power decreases after each stage by a known power depletion factor **pdf = 0.05**.
  Power during stage 1 $\mathbf{P_1 = 400\ watt}$
  Power of rider on gear j = $\mathbf{P_1}$ – ($\mathbf{P_1}$ * **pdf** * (j-1)) for j = 2 to 7
- $\mathbf{cog\_radius_j}$ = { j=1:0.068, j=2:0.046, j=3:0.042, j=4:0.038, j=5:0.034, j=6:0.03, j=7:0.026 }

Constant and deterministic values

- On every gear j the rider initially spends a specific amount of time ${}^{*}t_j$ under constant acceleration ${}^{*}a_j$ before he reaches to a final constant speed and travels a distance ${}^{*}d_j$ during this time.

- Though the rider can practically skip this time and change to next gear, these values are assumed to be non-zero for the sake of avoiding complications in the modeling of this project.

$${}^{*}t_j = f\,(\,F\,,\,cog\_radius_j\,,\,m\,,\,P_j\,)$$
$${}^{*}d_j = f\,(\,F\,,\,cog\_radius_j\,,\,m\,,\,P_j\,)$$
$${}^{*}a_j = f\,(\,F\,,\,cog\_radius_j\,,\,m\,,\,P_j\,)$$

Stage or gear - j	accelerating time (s) – (*tj)	distance travelled during accelerating time (m) – (*dj)
1	6.738888	16.10185
2	5.954503	36.95961
3	0.932611	7.311164
4	1.379133	11.47019
5	2.12807	19.08346
6	3.462291	34.22947
7	6.027885	67.78453

State variables

- The speed/velocity of the vehicle associated with a specific gear can be calculated using basic engineering mechanics knowledge given the **deterministic values** and **speed during previous gear**.

- Apart from $^{*}t_j$ rider spends t_j amount of time riding on stage j and covers $\mathbf{d}_j$ amount of distance in addition to $^{*}d_j$.

  V_j = Vehicle velocity achieved by rider on gear j (stage j)
  t_j = The amount of time that rider spends on gear j (stage j)

Decision variables

- Each shift in gear is considered as a stage. The decision variable would be whether to shift a gear at a given point in time.

  x = 0 no gear change happens
  x = 1 gear change happens

Exogenous variables

- The amount of time the rider can last on any gear is limited by an equation.
- As the rider moves to higher gears this time will reduce by a certain amount (**TDF = Time Depletion Factor**) which is random.
- $\mathbf{TDF_{j+1}}$ is not known during stage j.

Transition function

- Initial velocity during stage n+1 is the final velocity of stage n

$V_{j+1} = f(F, cog\_radius_{j+x}, m, P_{j+x}, V_j) = V_j + {}^{*}a_{j+1} * {}^{*}t_{j+1}$

$t_{j+1} = f(ff, t_j, TDF_{j+1})$

Transition function

- However, t_j for every j is limited by an equation.

  $t_1 \leq ((1.2/(ff - 0.15)^{0.618}) - 1.21)*2*60$
  $t_j \leq t_1 - t_1 * \mathbf{TDF}_j$ for j = 2 to 7

" The harder the muscle fibers contract, the more the interlaced arterioles and capillaries are compressed and the more the blood flow and oxygen supplies are restricted, the faster the muscle fatigues. "

Niebel's Methods, Standards, and Work Design - Thirteenth Edition
Andris Freivalds and Benjamin W. Niebel

Transition function

- There is another constraint that comes into picture if we solve this problem using a heuristic approach that assumes some values for exogenous variables. This constraint restricts the total time spent by a rider by a forecasted value.

- $\mathbf{T = \sum_{j=1}^{7} (*t_j + t_j) \leq 757}$

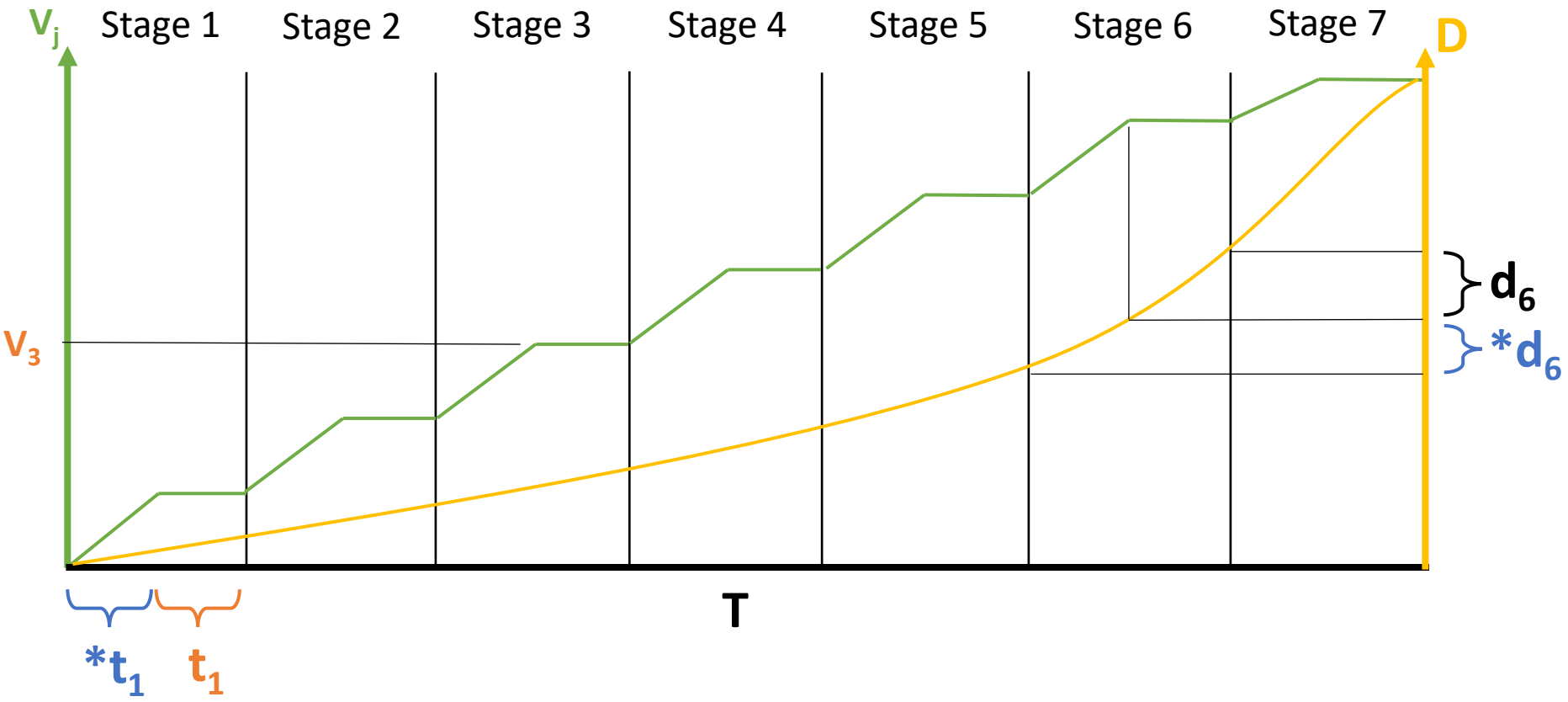
Objective function

- $^{*}d_j$ is the initial distance travelled in time $^{*}t_j$ and let $\mathbf{d_j}$ be the distance travelled in time t_j during stage j.
- $^{*}d_j$ has already been found using simulator
- $\mathbf{d_j} = V_j * t_j$

Objective function to be maximized

$\mathbf{D} = \sum_{j=1}^{7} ({}^{*}d_j + \mathbf{d_j})$

- The following graph shows the values of times and distances during every stage.



Solution

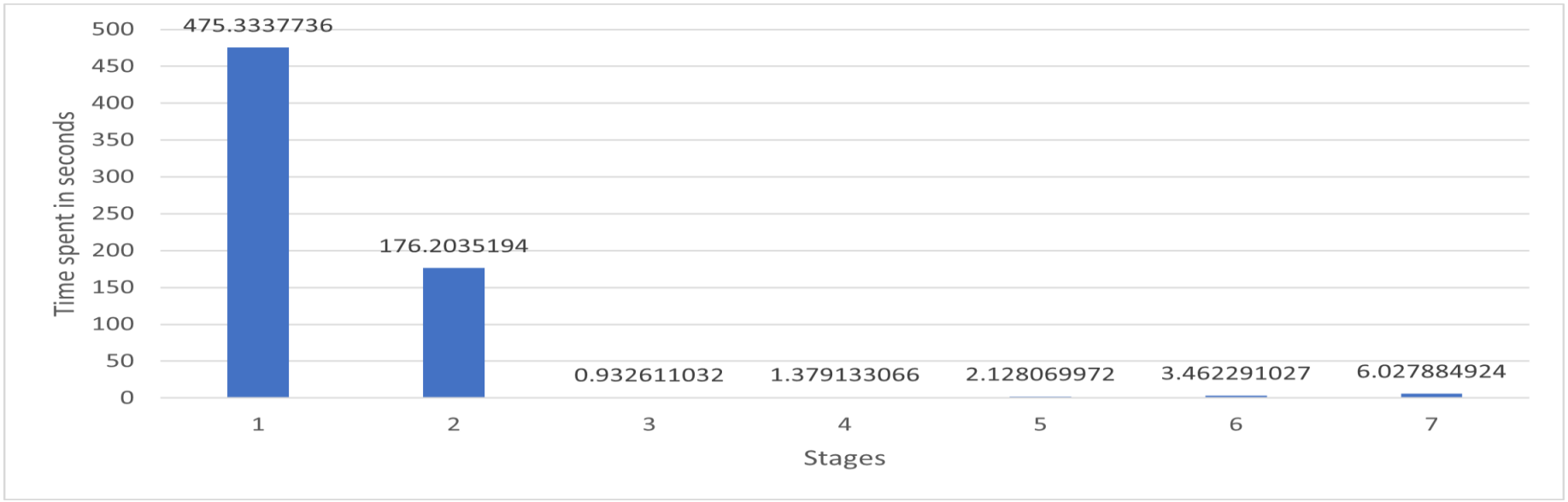
- Three ways of policy approach.

- Risk-averse heuristic
- Greedy heuristic
- Heuristic by fixing the exogenous variables

Risk-averse approach (Solved using Gurobi)

- The rider is not willing to take risk and tries to avoid higher gears in a fear of receiving a higher **TDF_j**
- Shifts from a gear only when the time exceeds the limit on that gear

Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 | Stage 7

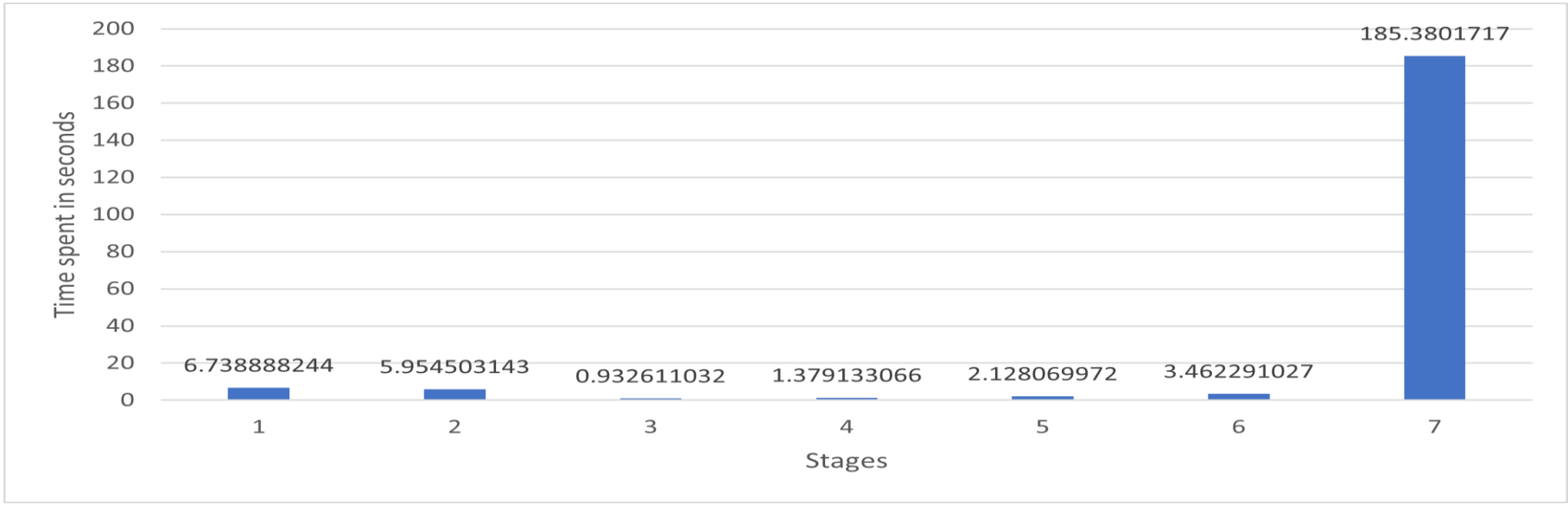


D = 3732 m

Greedy approach (Solved using Gurobi)

- The rider rides on the highest gear possible as he knows that the velocity is maximum.
- The rider takes comfort in high speed and hopes that he will cover more distance though the $\mathbf{TDF_j}$ is higher (i.e. he does not last long).

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7

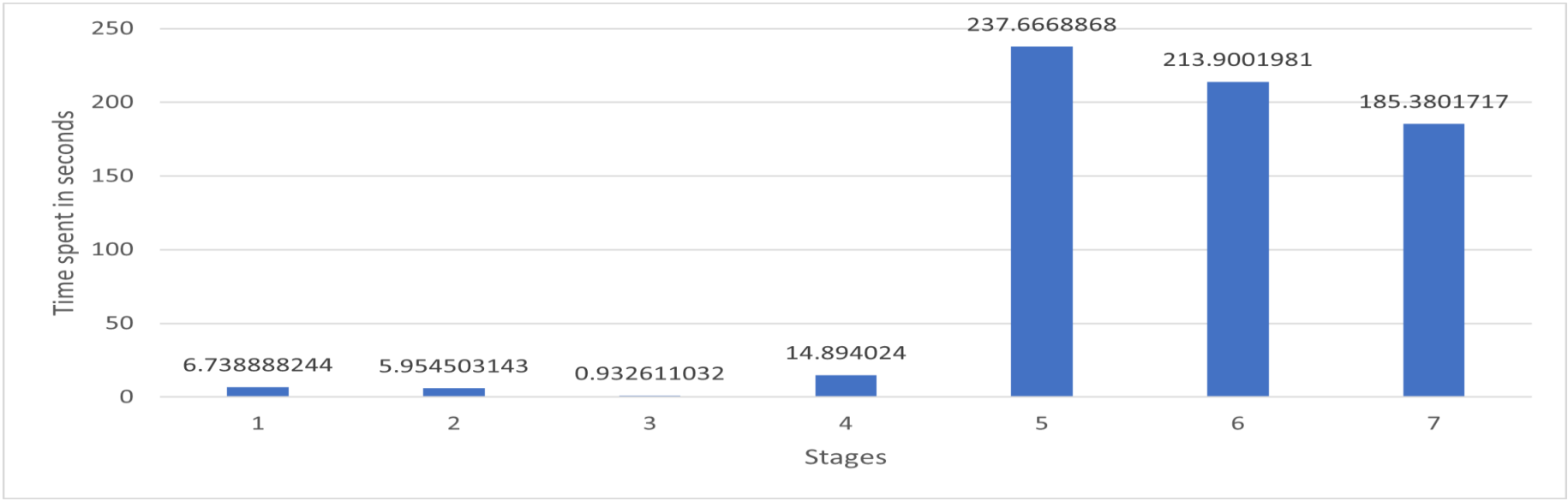


D = 2356 m

Fixing random variables

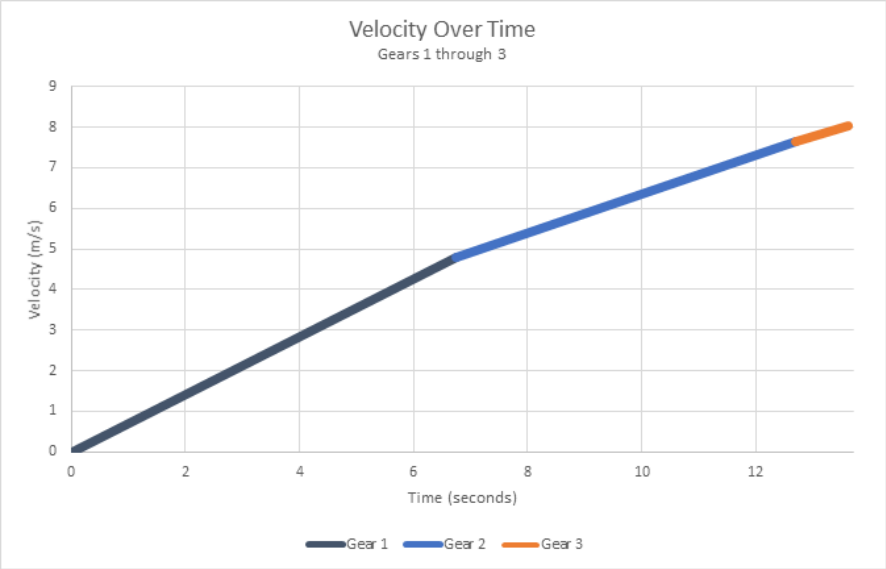
- The rider now has the full knowledge of **TDF_j**.
- Chooses gears wisely.

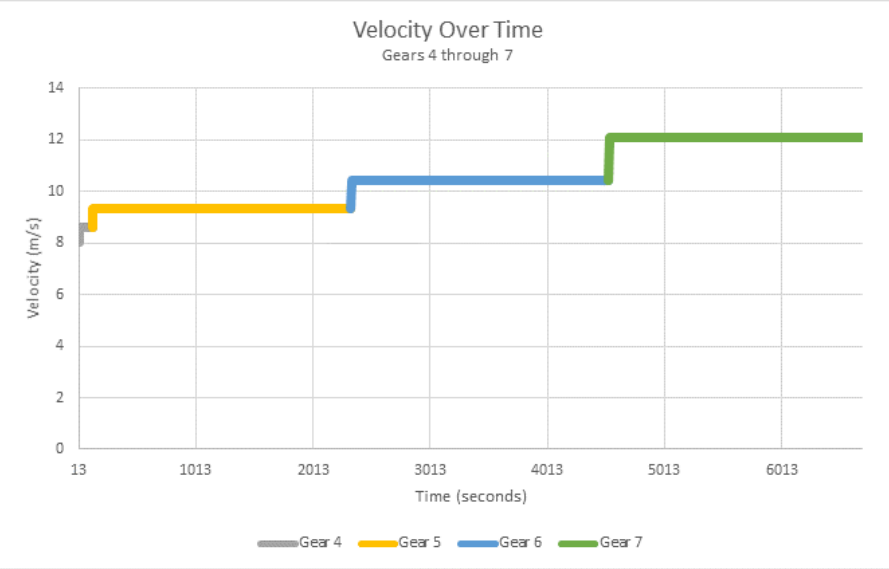
Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 | Stage 7



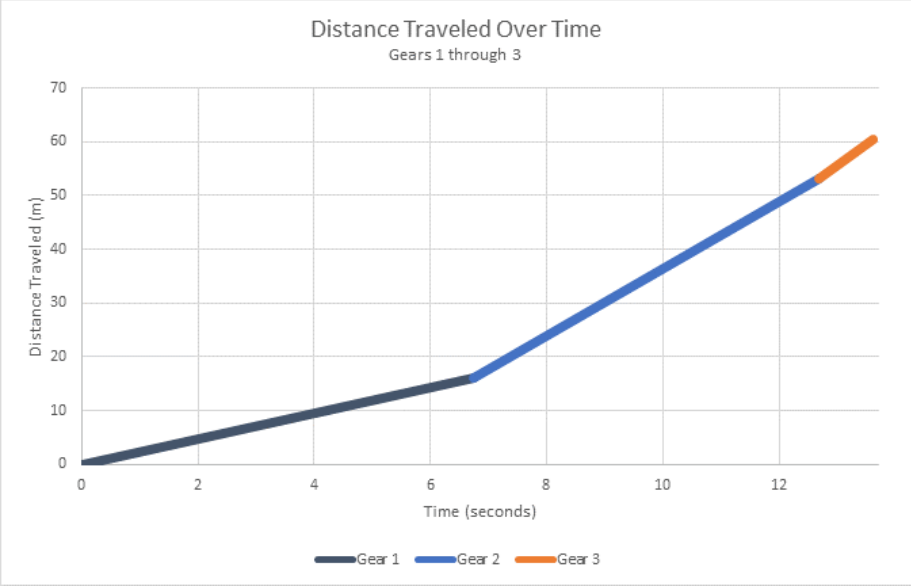
D = 6867 m

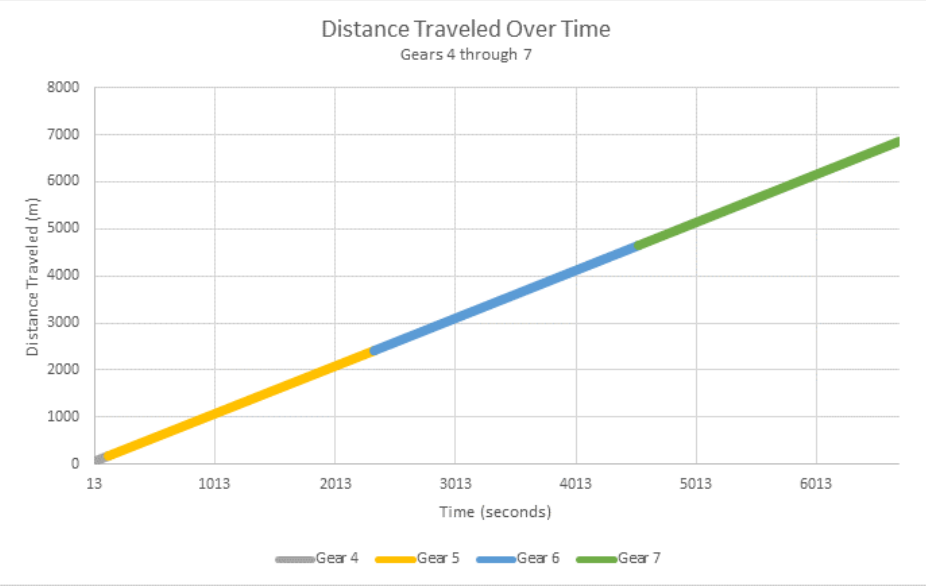
Plots for rider 1





Plots for rider 1





Thank you