Cycling | Digital Doping with LS-OPT

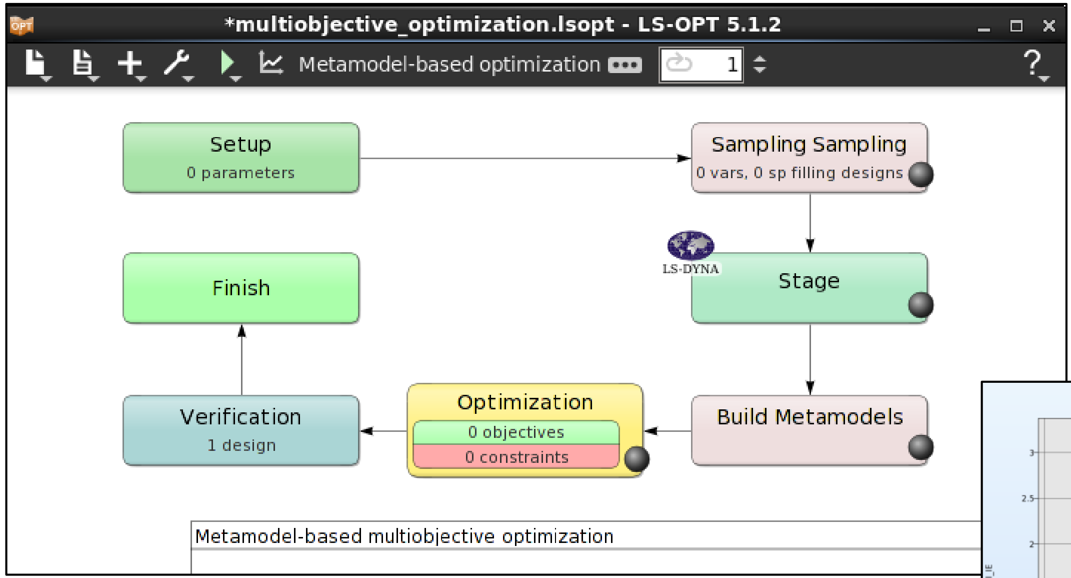
24th January 2018

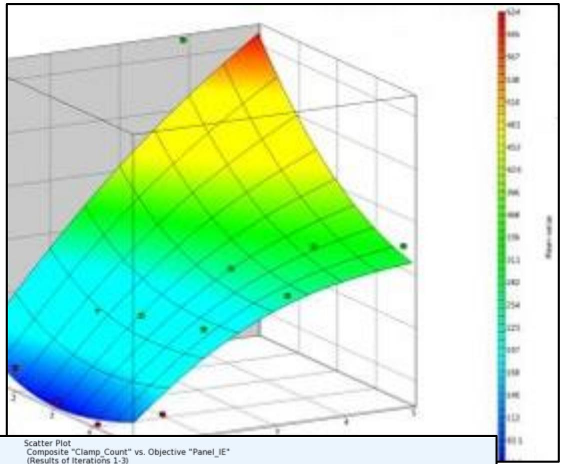
Ben Crone

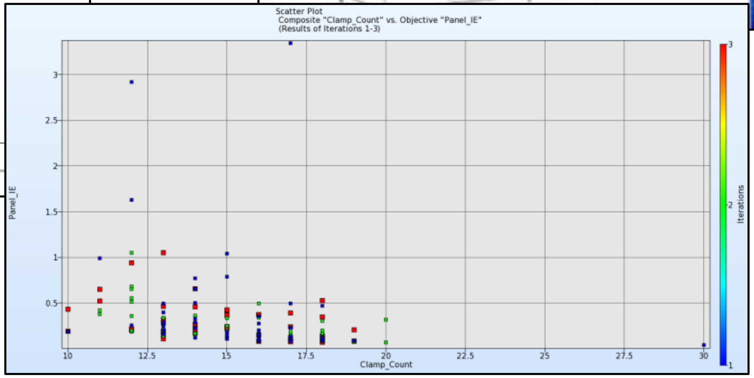
ARUP

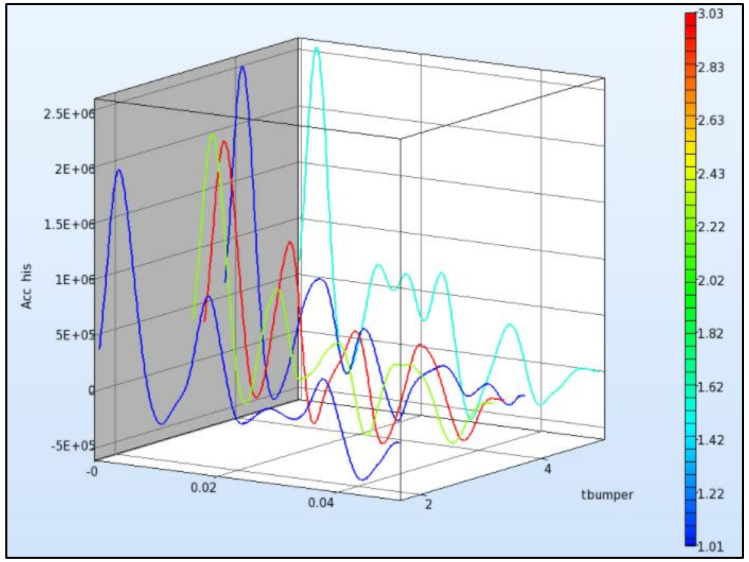
LS-OPT

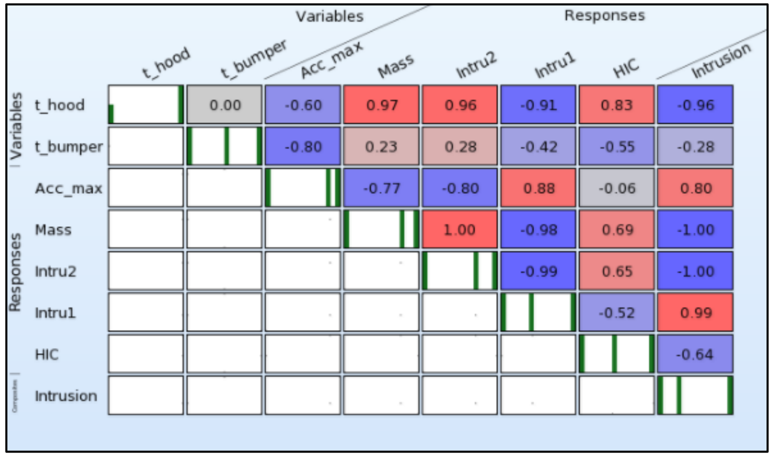
- Optimisation.
- System identification.
- DOE.
- Curve matching.
- Robustness.
- Sensitivity studies.











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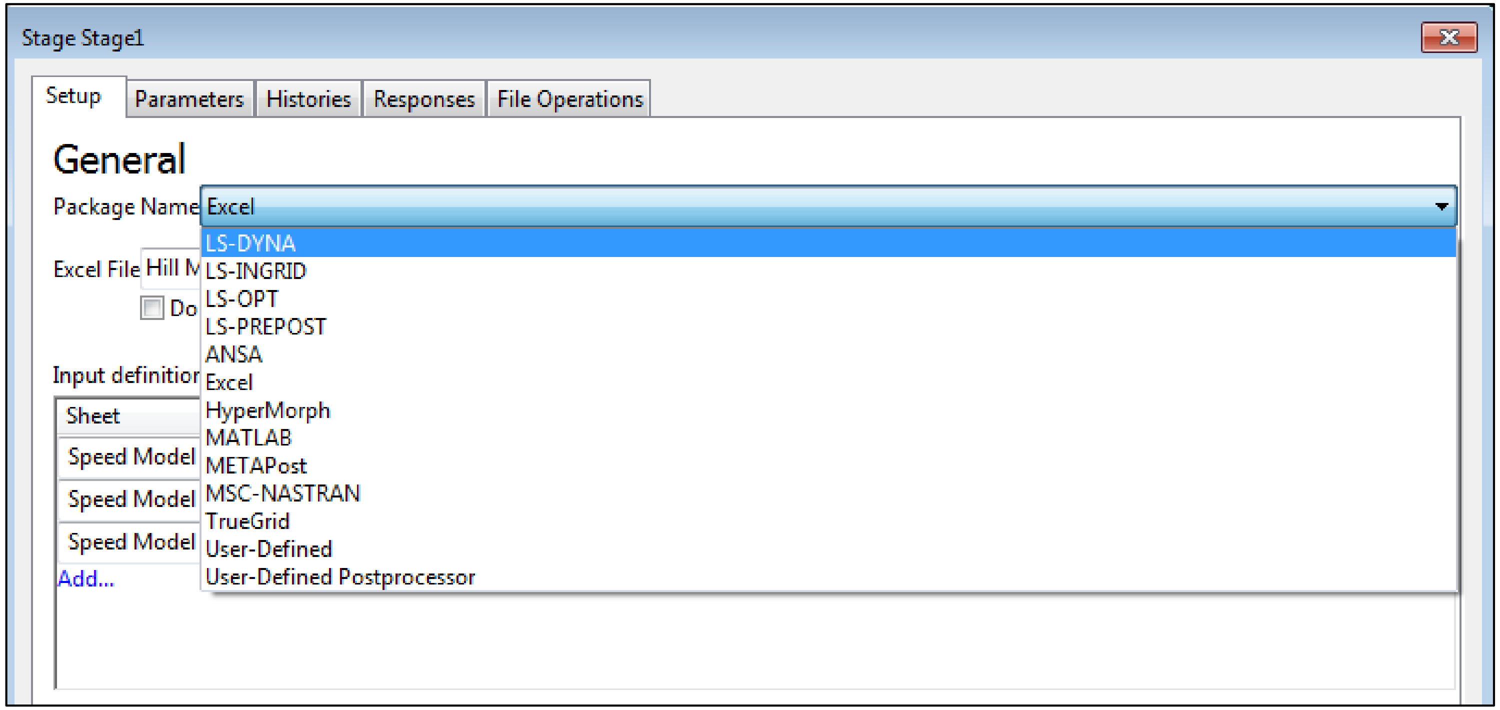
LS-OPT - Solvers

- 11 built in solver options, including:
  - LS-DYNA
  - MS Excel
  - MATLAB
  - NASTRAN



- User defined routines also possible.

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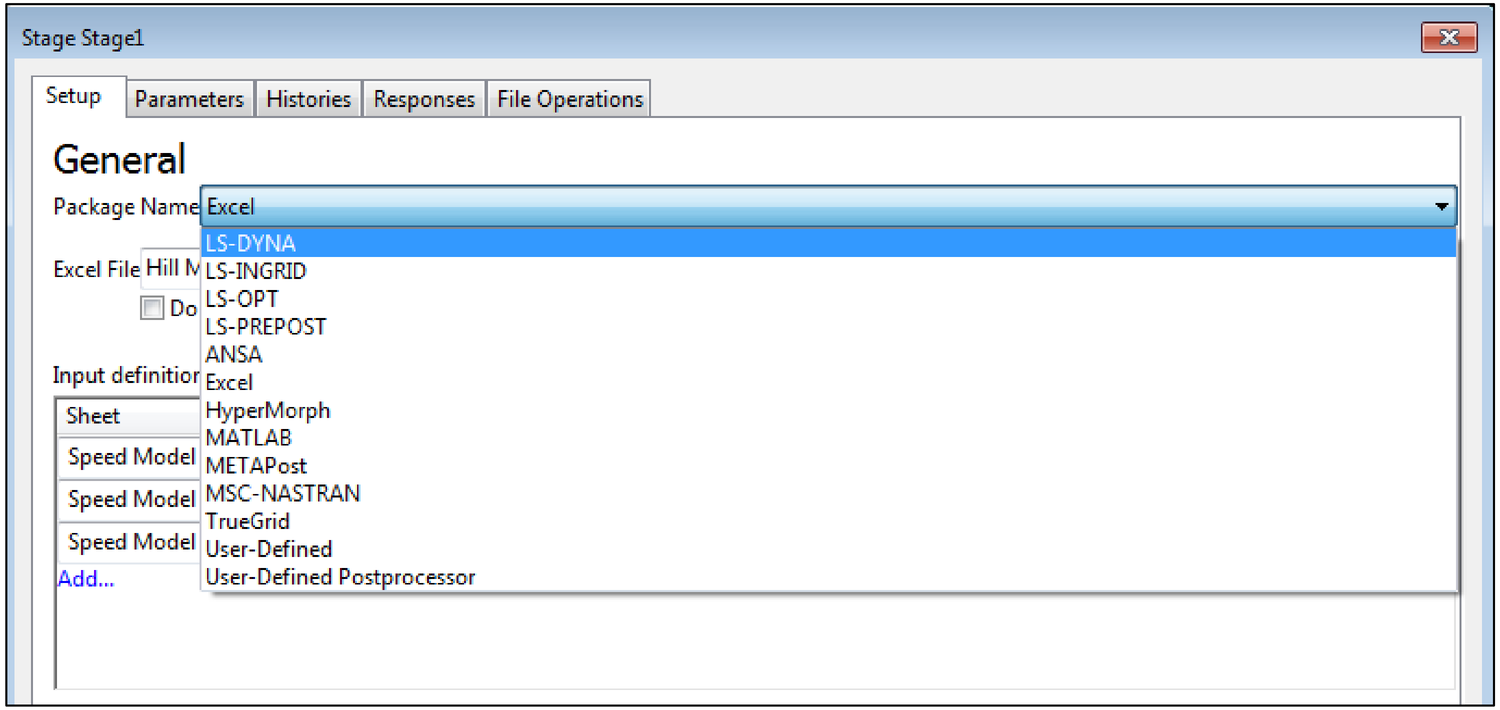
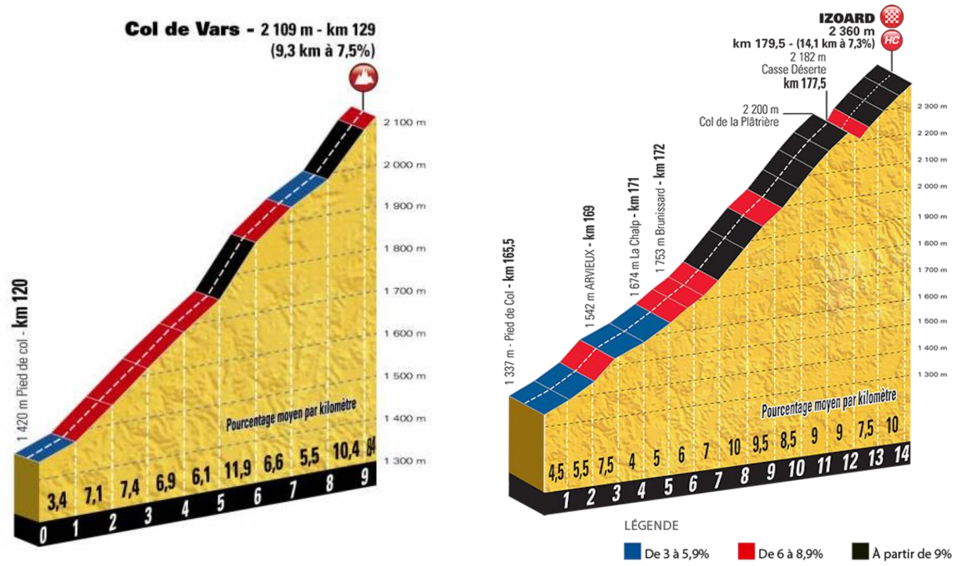
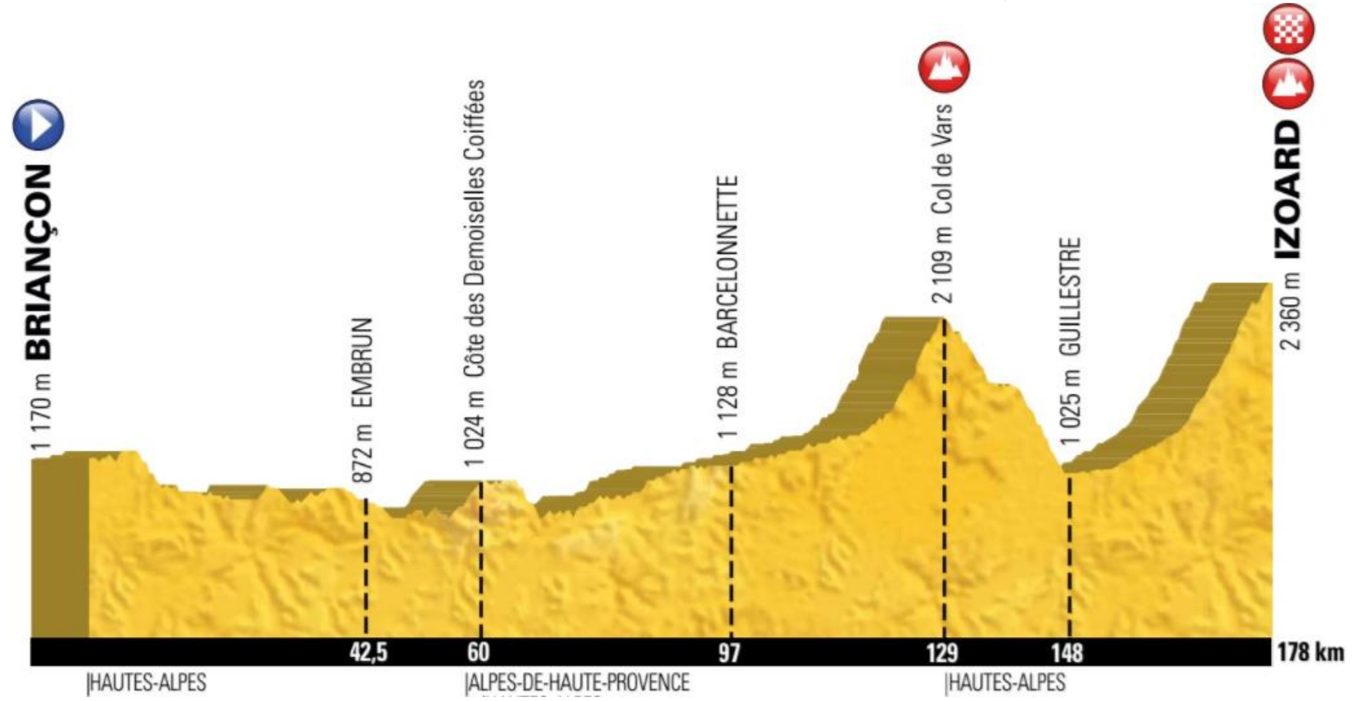


- User defined routines also possible.

Etape du Tour

- Organised by Tour de France.
- Official stage opened to amateurs.
- Mountain stage.
- Circa 10,000-15,000 riders.
- 2017 stage:
  - 110 miles.
  - 2 mountains.
  - 3700 m ascent.

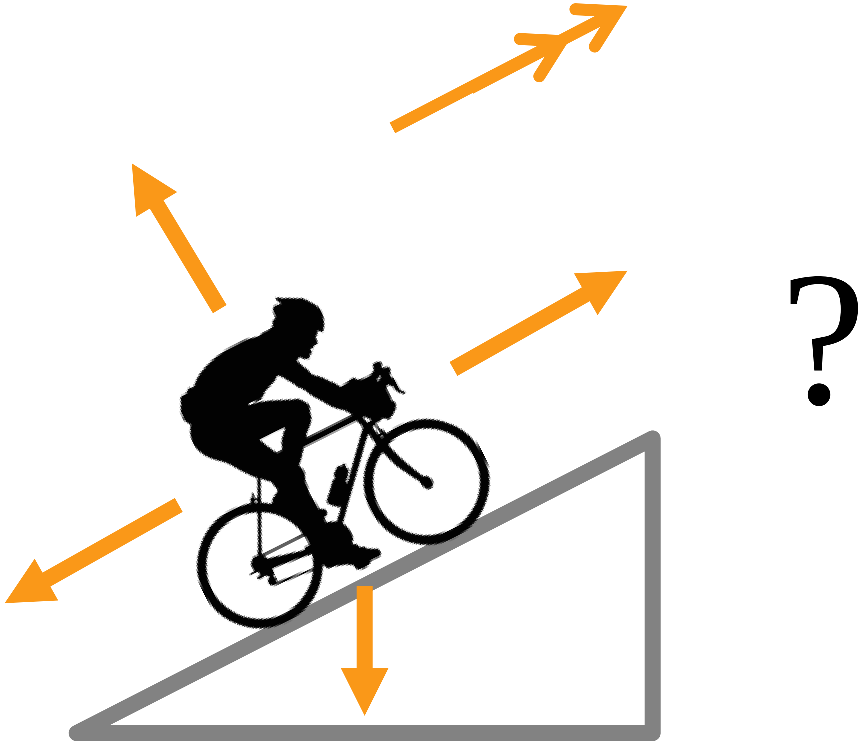




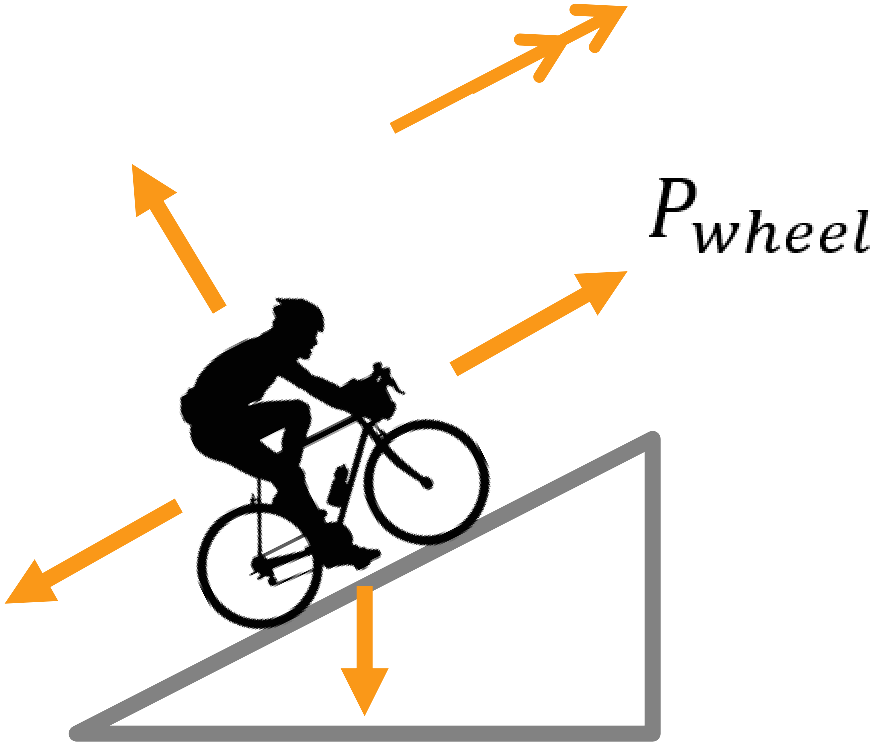
ASO

Mathematical Model

- Energy based calculation using force balance.
- System input less system outputs.



Mathematical Model



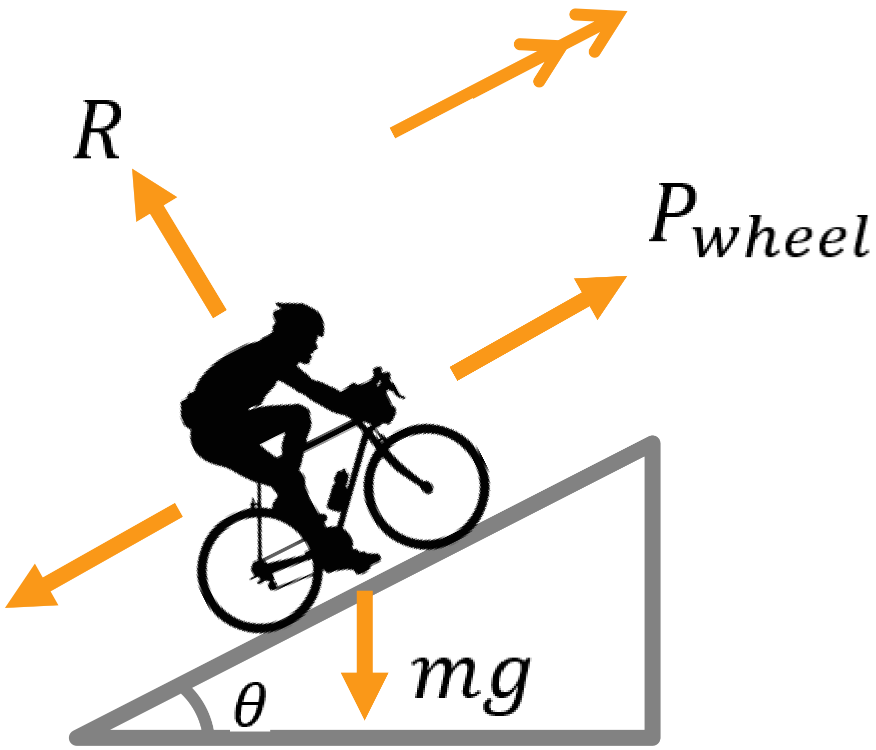
- System input:
  - Driving force.
  - Power at pedal as generated by cyclist.
  - Minus drivetrain losses, ~3%.
  - Power at wheel (drive).

$$P_{wheel} = \eta_{drive} \cdot P_{pedal}$$

Mathematical Model

- System output:
  - Gravity.
  - Work done travelling uphill.

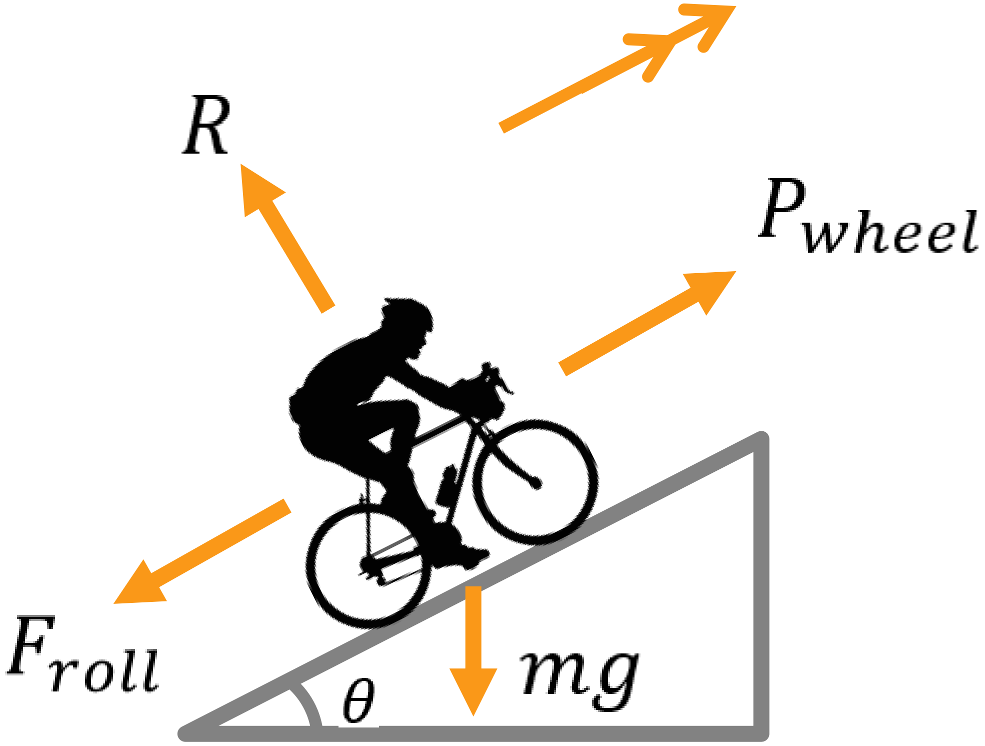
$$F_{grav} = mgsin\theta$$



$(m = m_{cyclist} + m_{bike})$

Mathematical Model

- System output:
  - Rolling resistance of tyres.
  - Function of weight and tyre friction.
  - Tyre rolling resistance coefficient approx. 0.005.



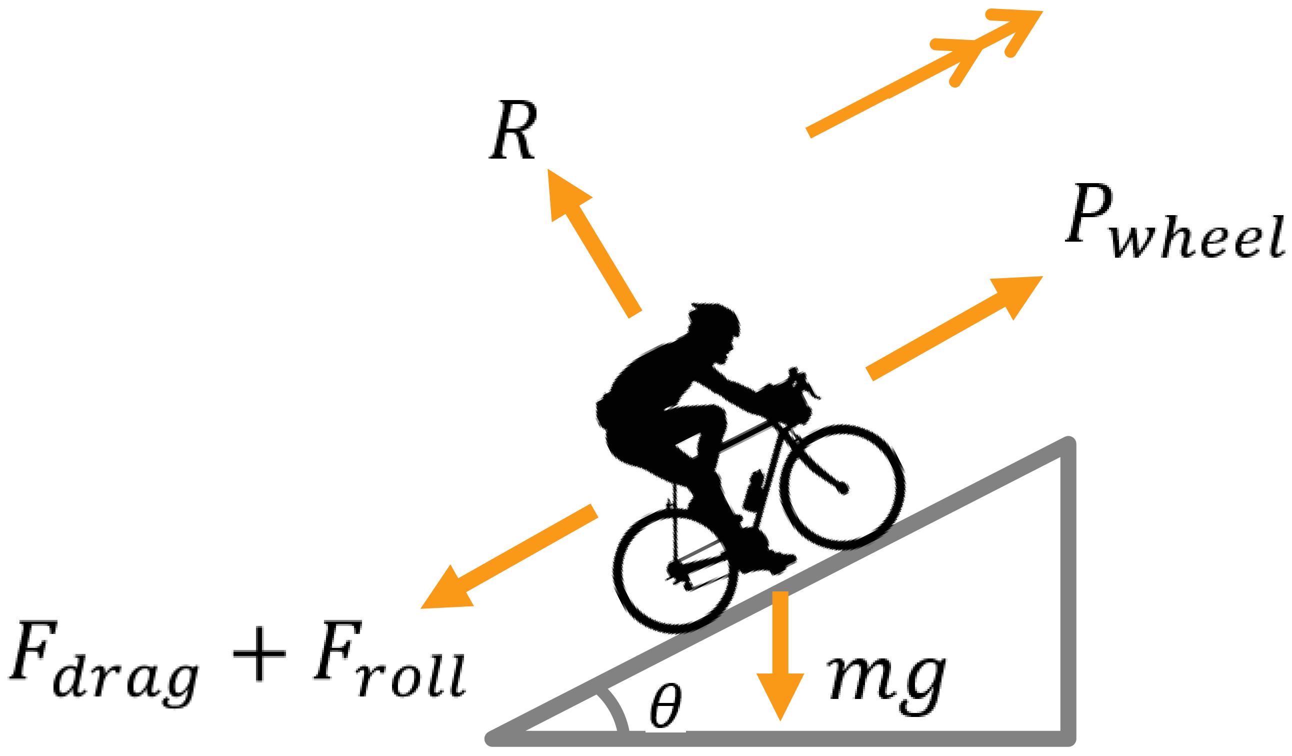
$$F_{roll} = \mu_{tyre} \cdot R = \mu_{tyre} \cdot mgcos\theta$$

$(m = m_{cyclist} + m_{bike})$

Mathematical Model

- System output:
  - Air resistance.
  - Function of frontal area and shape.
  - Increases in proportion to the square of velocity.

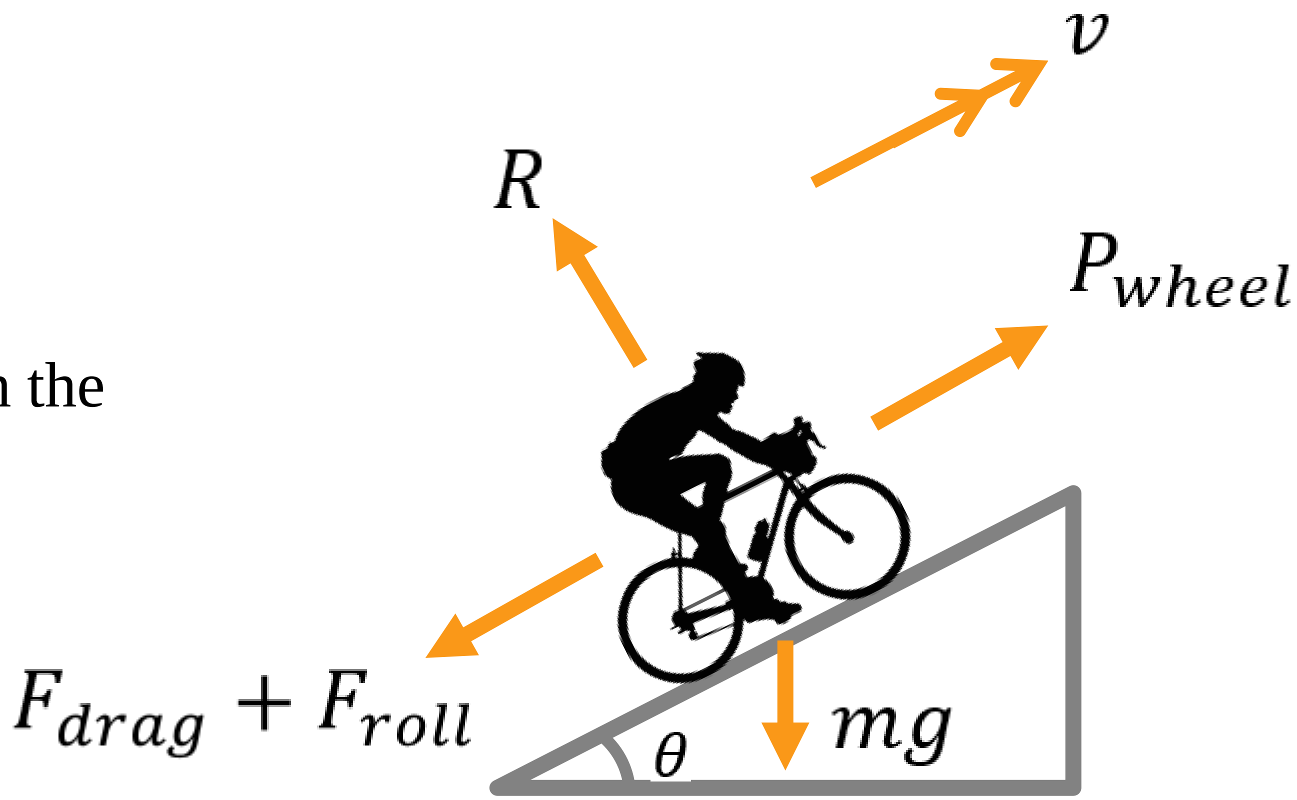
$$F_{drag} = \frac{1}{2}\rho v^2 C_d A$$



ρ	Air Density
v	Velocity
C_d	Drag Coefficient
A	Frontal Area

Mathematical Model

- Balancing the driving force/power with the resisting forces:

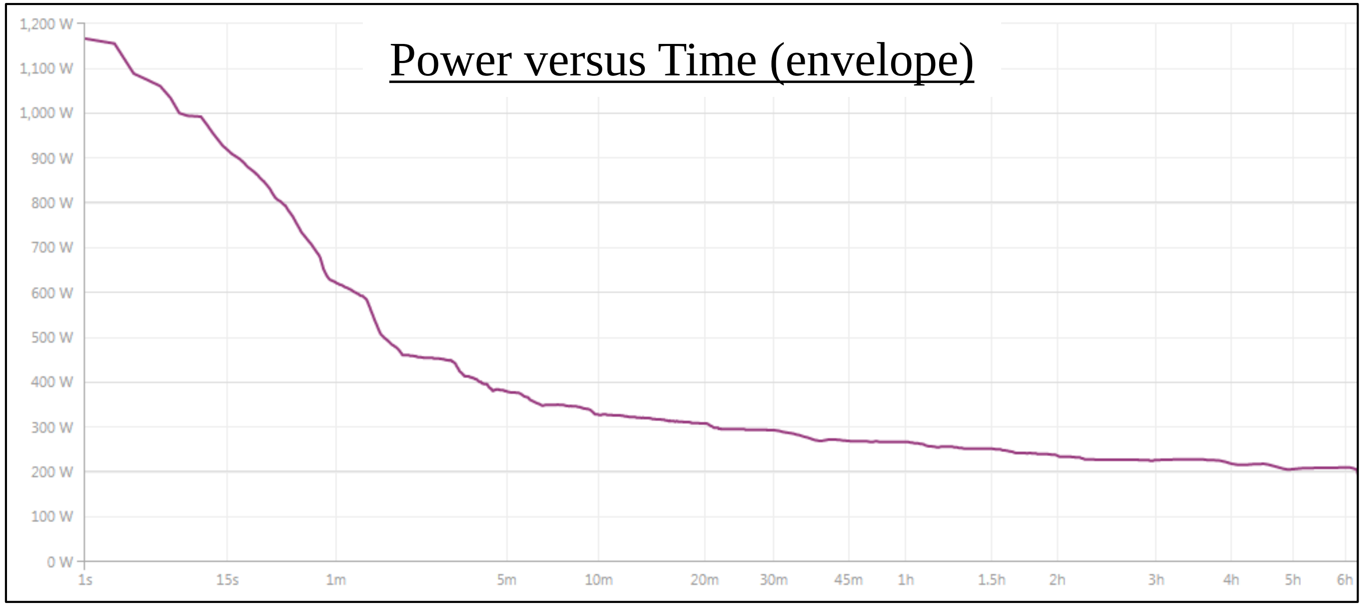


$$P_{wheel} = \left(F_{roll} + F_{drag} + F_{grav}\right) \cdot v$$

Cubic equation that can be solved for velocity.

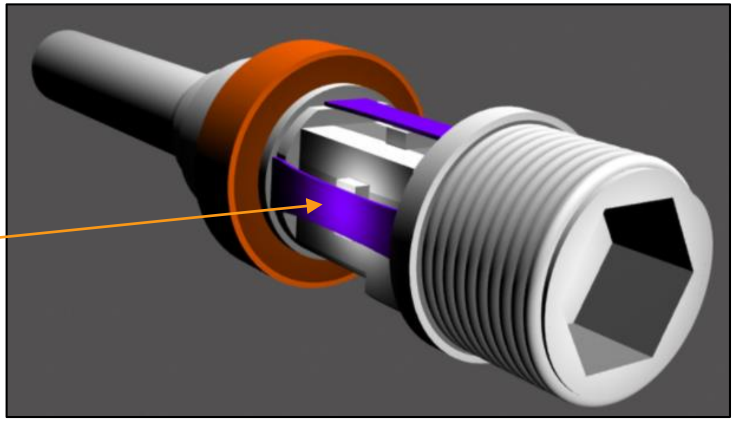
Unknowns… Input Power

- Not commonly known.
- Various methods of measuring exist.
- Pedal based measurements use strain gauges located within pedal spindle.



Garmin

Strain gauge



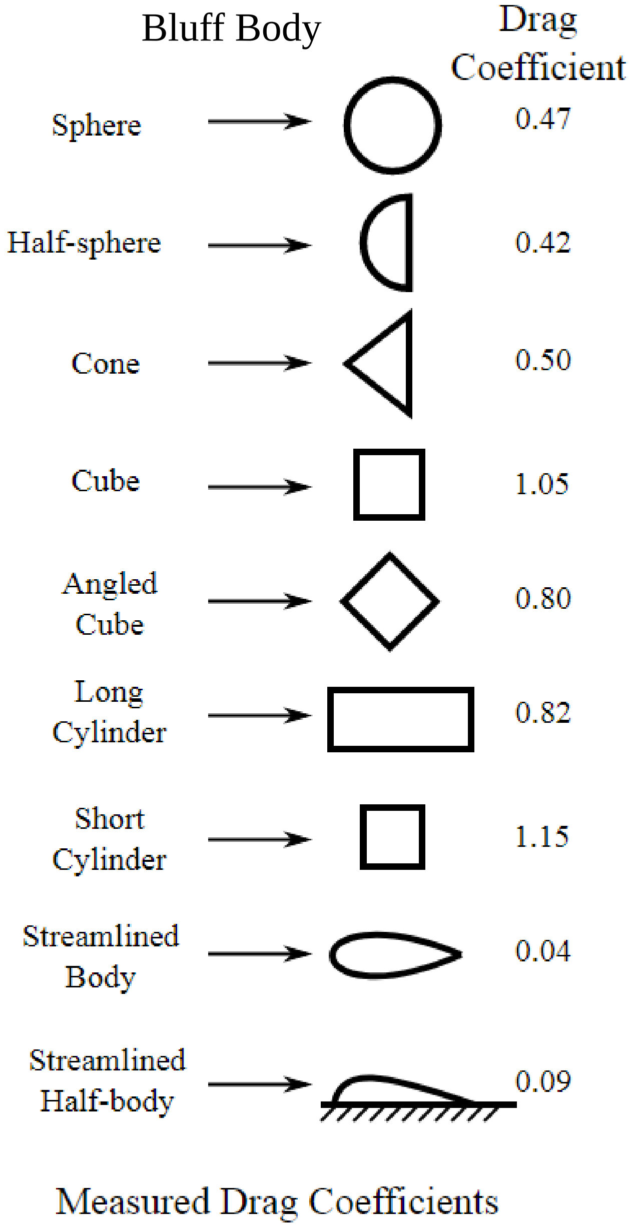
Swedish Adrenaline

Unknowns… CdA

- Typical values not appropriate.
- Requires extensive testing.
- Controlled conditions.

POC

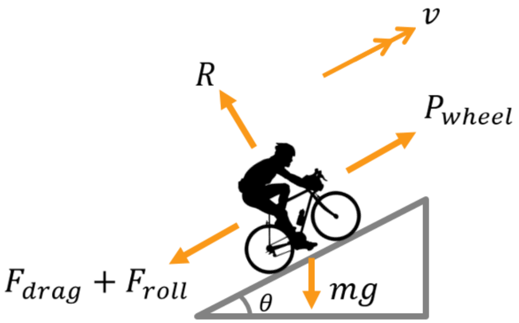
- Values tuned so that model agreed with test data.
- Cd = 0.6.
- CdA = 0.3 m^2

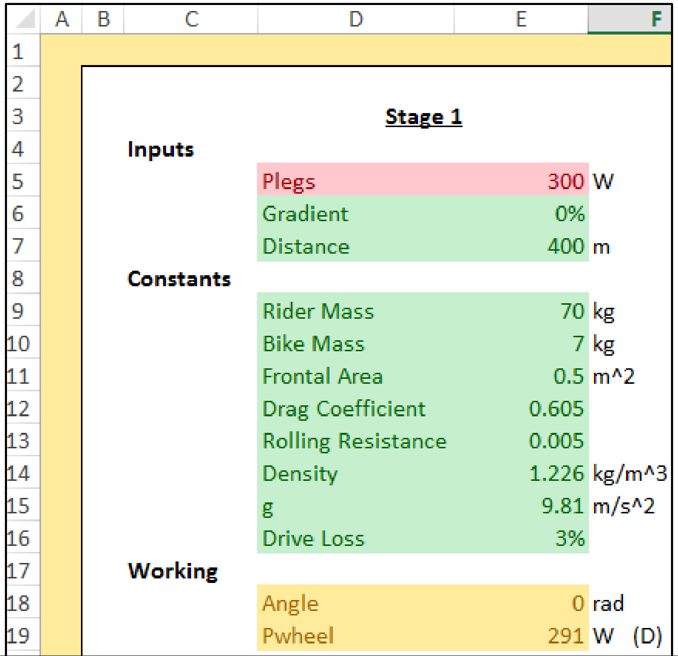


Wikipedia

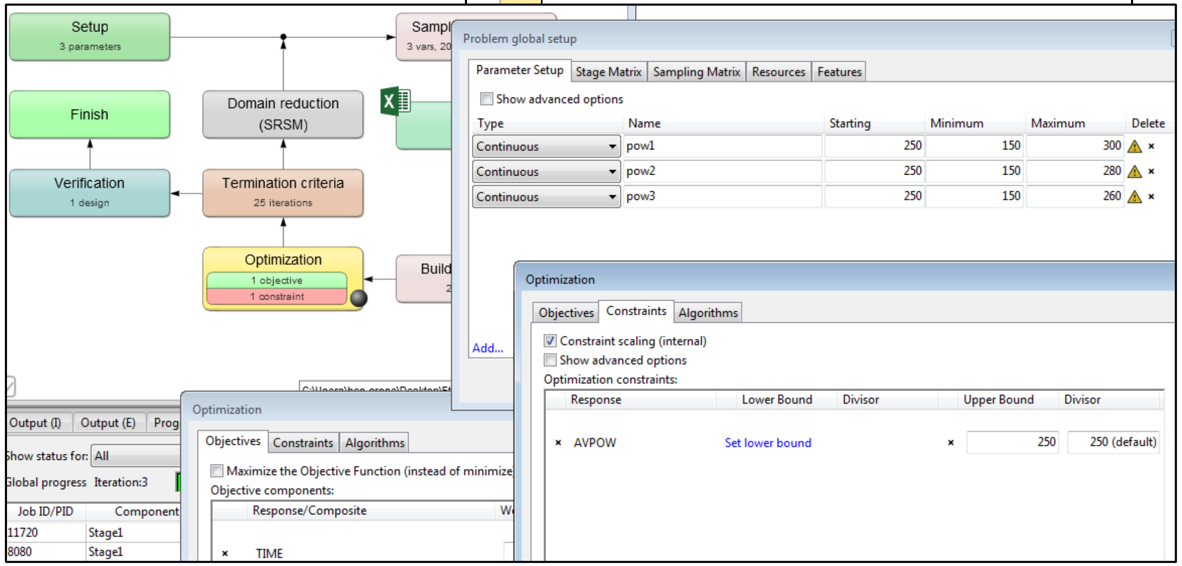
Problem Setup

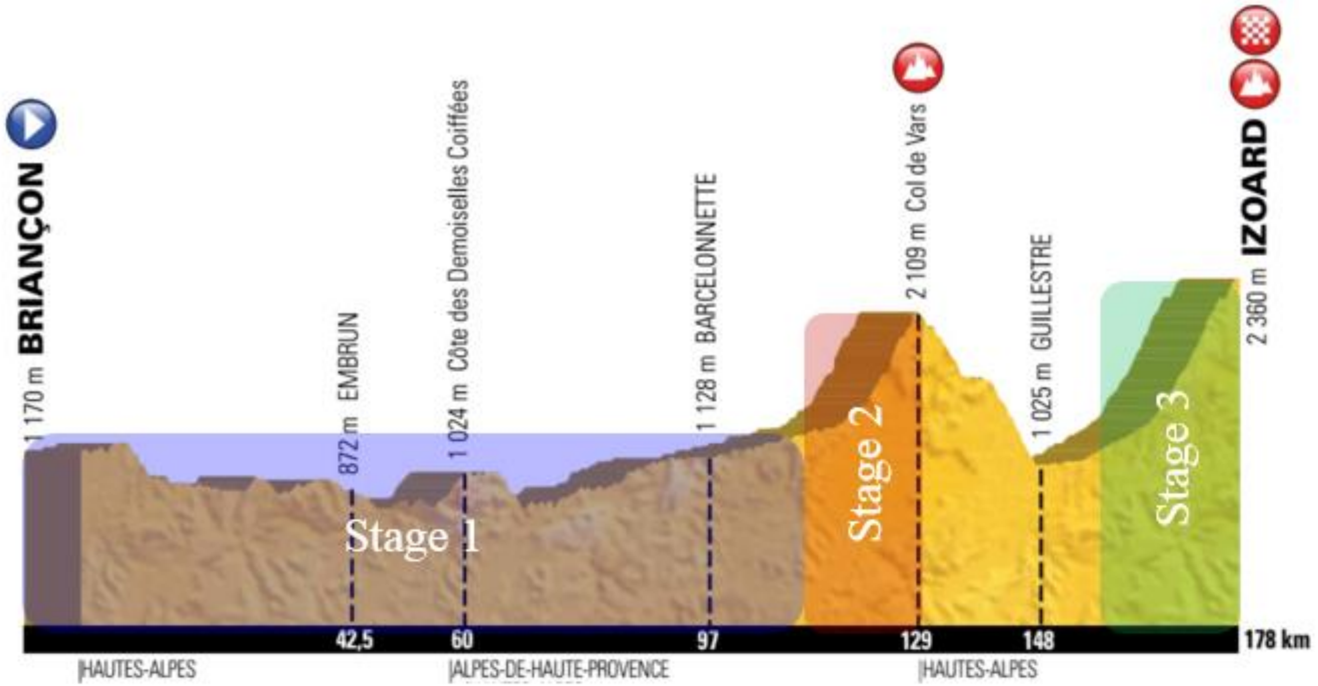
- Minimise total time to complete route.
- Constrained by average power (250W).
- Course broken into three stages.





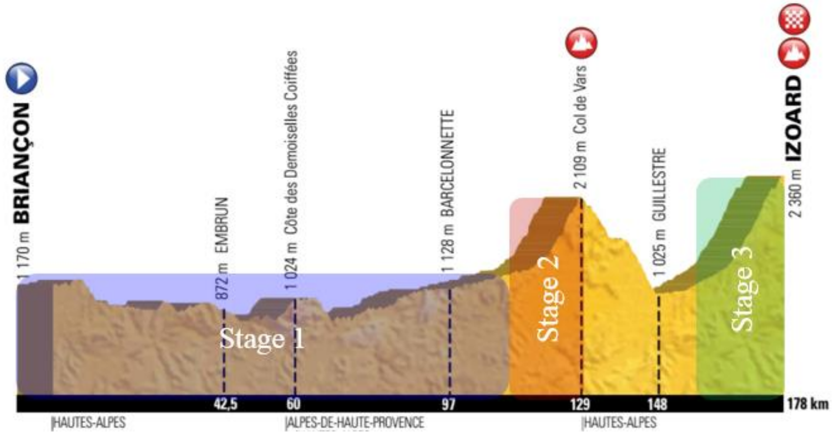
Stage 1		
Inputs		
Plegs	300	W
Gradient	0%	
Distance	400	m
Constants		
Rider Mass	70	kg
Bike Mass	7	kg
Frontal Area	0.5	m^2
Drag Coefficient	0.605	
Rolling Resistance	0.005	
Density	1.226	kg/m^3
g	9.81	m/s^2
Drive Loss	3%	
Working		
Angle	0	rad
Pwheel	291	W (D)





Initial Result

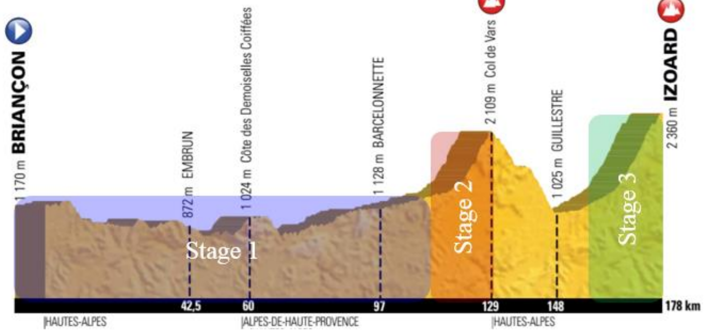
- Not great…
- Model too simplistic.
- Recommended strategy:
  - Gentle on stages 1 & 2.
  - Max effort on final climb.
- **Not practical.**



BikeRadar

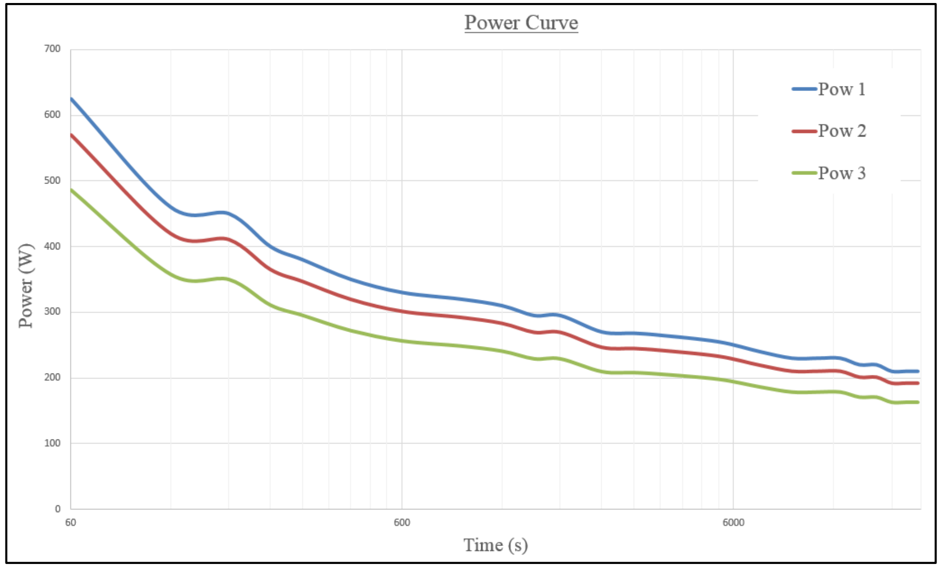
Refined Model

- Utilisation concept introduced.
- Decay factor on latter stages.
- Reduced aero loads for stage 1.



S2 Power	
S1 Util	Factor
0.85	1
1	0.9

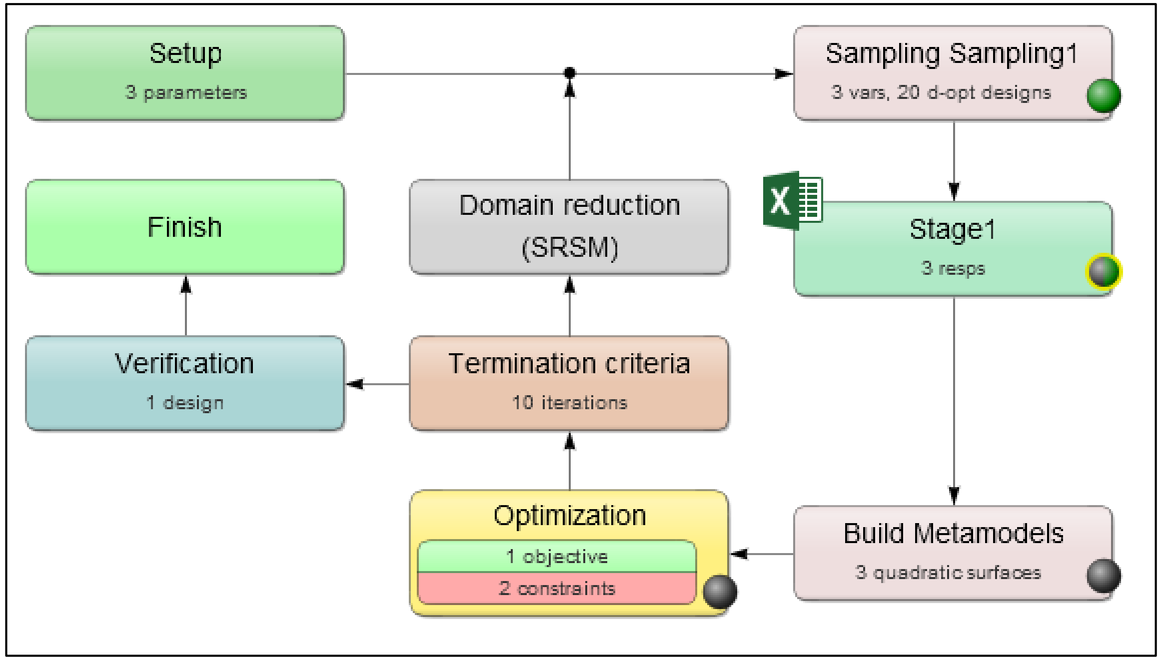
S3 Power	
S2 Util	Factor
0.85	0.9
1	0.8



Dan Pontefract

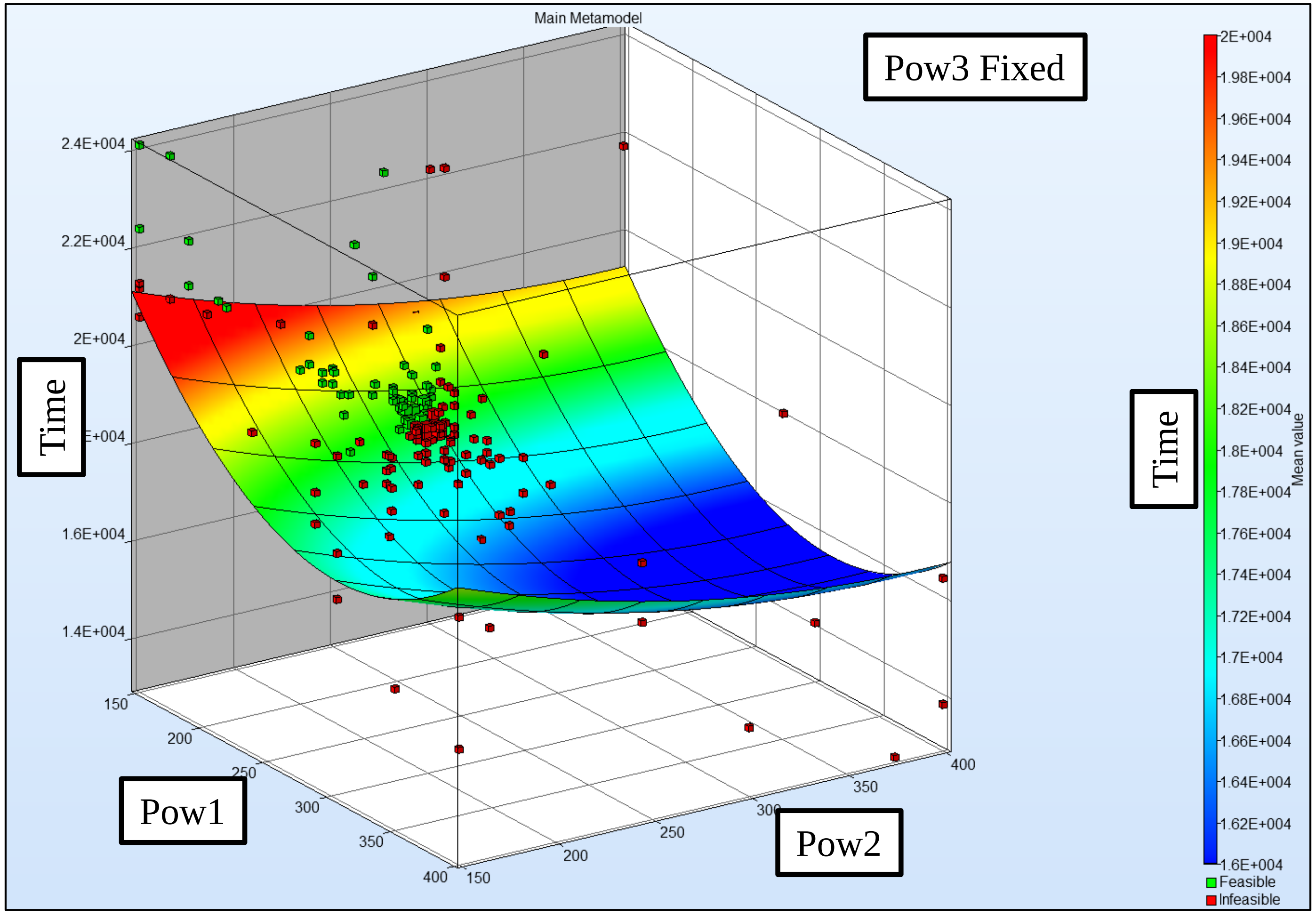
Refined Problem

- Constraints now based on utilisation.
  - Average should not exceed 100%.
  - Max should not exceed 103%.
- Quadratic polynomial meta-model used.
- D-Optimal sampling.
- Domain reduction active.
- 10 iterations.



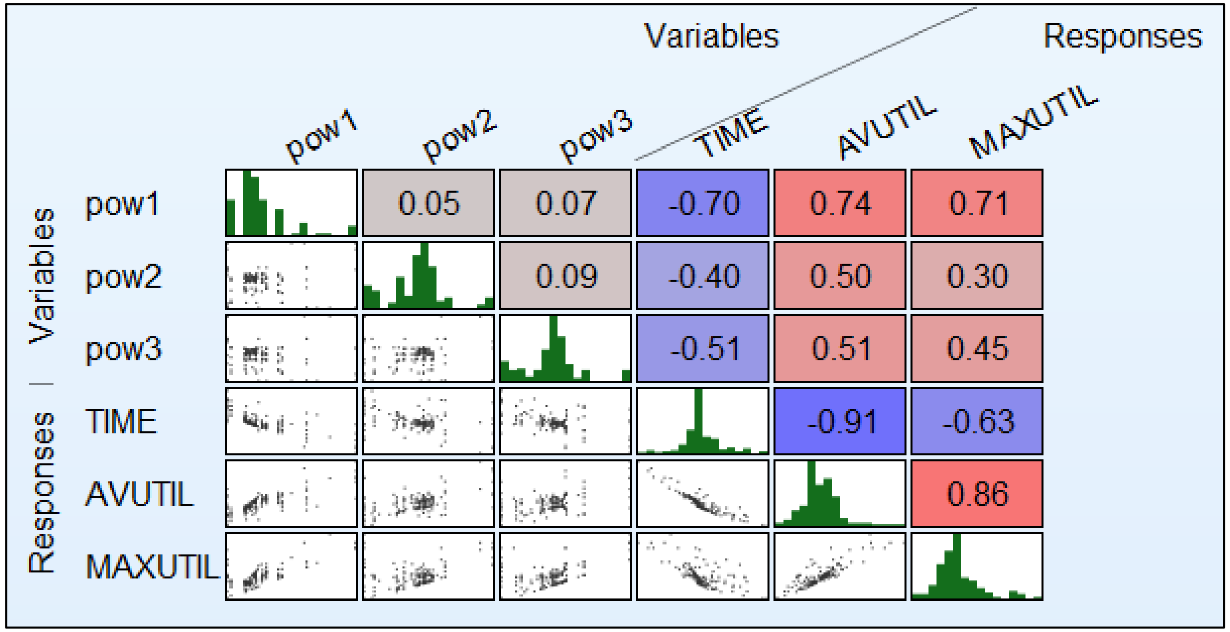
Final Result

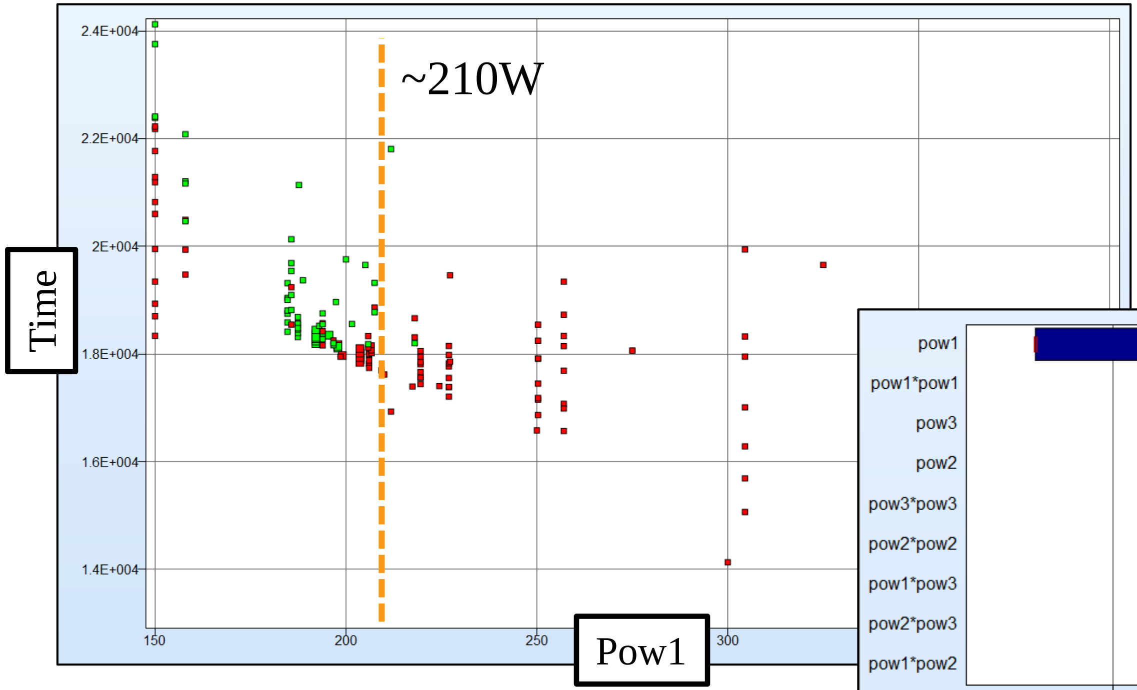
- Much more useful.
- Several possible (and similar) strategies all yielding similar times.
- Preferred result:
  - Stage 1 = 218 W (3 hrs 11 mins).
  - Stage 2 = 214 W (51 mins).
  - Stage 3 = 251 W (61 mins).
  - Total Time = 5 hrs 3 mins.

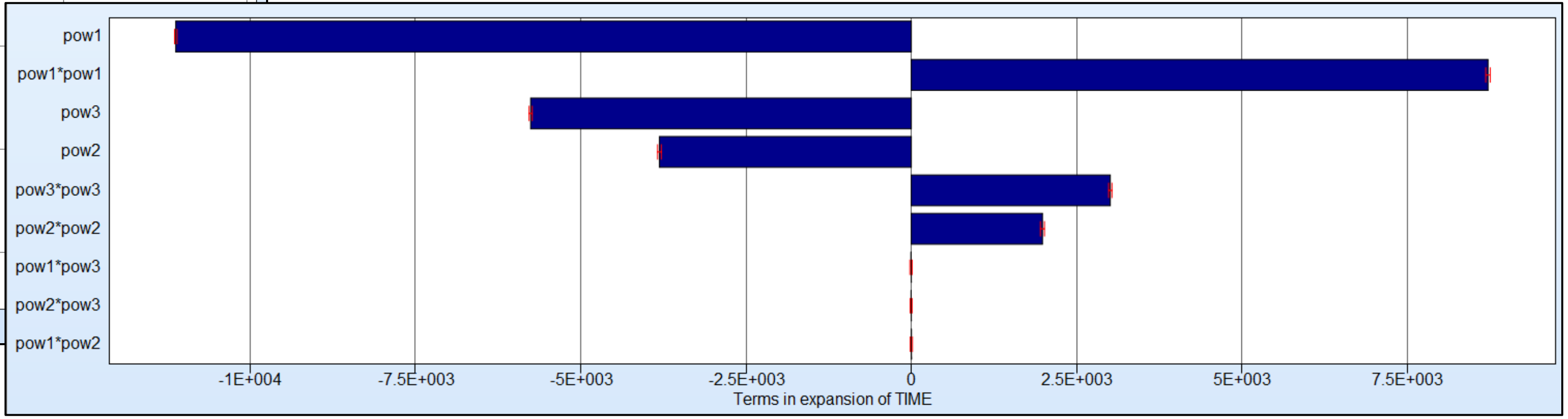


Final Result

- Importance of stage 1 (and 3) reflected in other data.







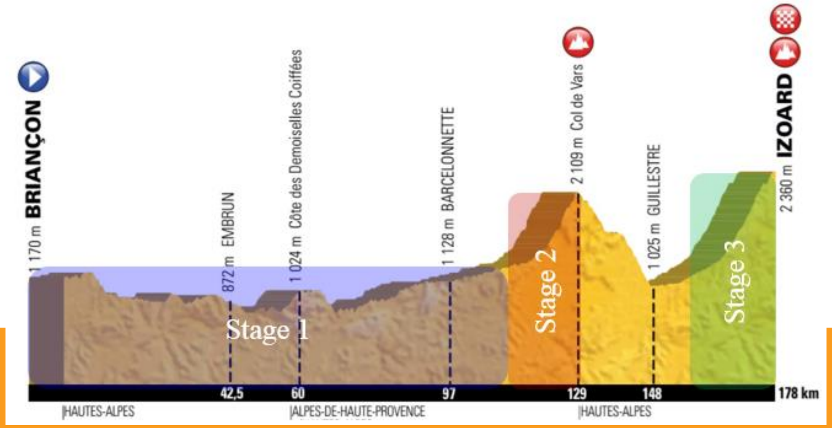
Physical Test

REAL TIME
06:11:18
REAL RANKING
261 / 11234

- Great success!
- During ride focus was stage 1 and stage 3.
- Prediction was 13 mins out.
- Difference is closer to ten mins due to water bottle refills.
- Finished 261st, 56 mins from winner.
- 91 minutes off TdF time…

Timing	Predicted	Actual
Stage 1	3:11	3:19
Stage 2	0:51	0:51
Stage 3	1:01	1:06
Total*	5:03	5:16

*Doesn't include downhill between stage 2 and 3.



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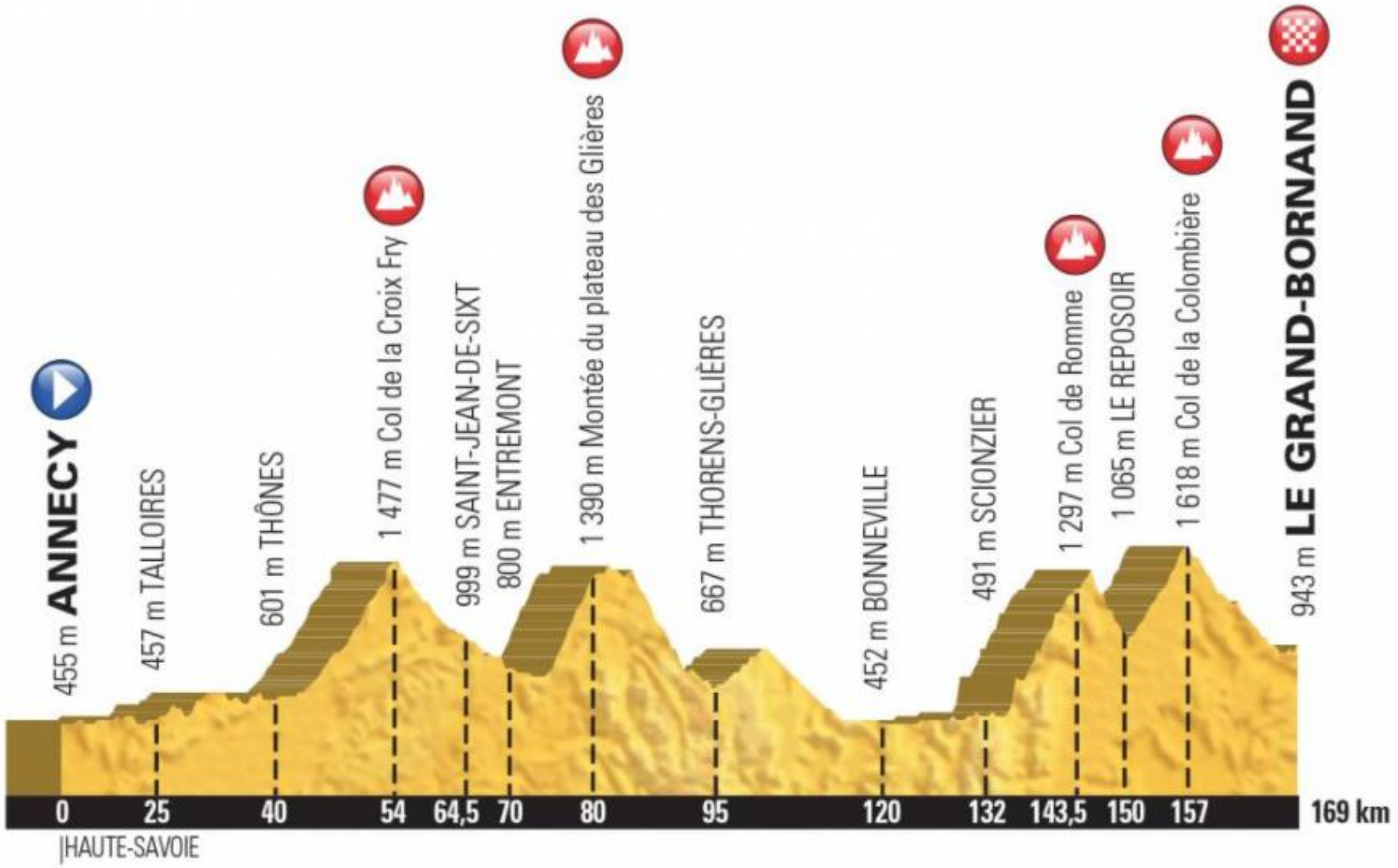
Next Steps…

- Apply it again this year!
- 105 miles.
- 4 mountains.
- +4000 m ascent.



ASO

Thank You

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