Creating a world
fit for the future

Simulating Passenger Comfort and Motion Sickness in Autonomous Vehicles

Michael Wheeldon

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Connected Autonomous Vehicles

- **Connected Autonomous Vehicles** (CAV) are focus of significant automotive development
  - Varying levels of autonomous driving, SAE Scale 0-5
- Why CAV?
  - Increased driver assistance
  - Fits with transition to shared vehicle architecture (mobility as a service)
  - Reduced environmental impact
- Challenges of CAV (including but not limited to):
  - Vehicle control
  - Path planning
  - Route planning
  - Safety (inc other road users)
  - Cyber Security
- Safety and cyber security will be assumed of any commercial offering, therefore cannot be brand differentiators


To sleep, perchance to dream on the commute

Runners and riders in the race for autonomy

Source: Times 6 Sept 2018

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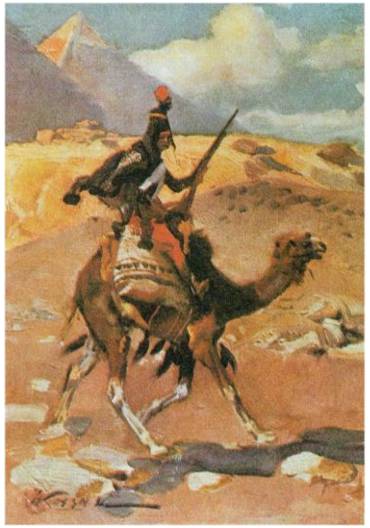
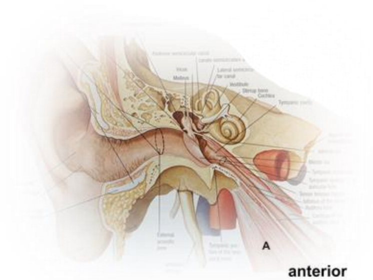
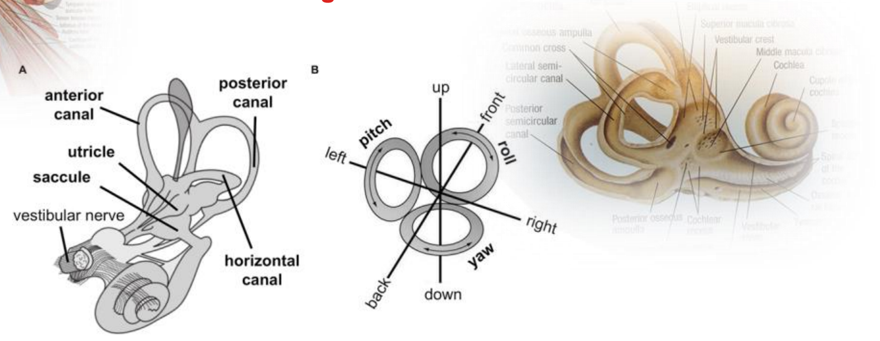


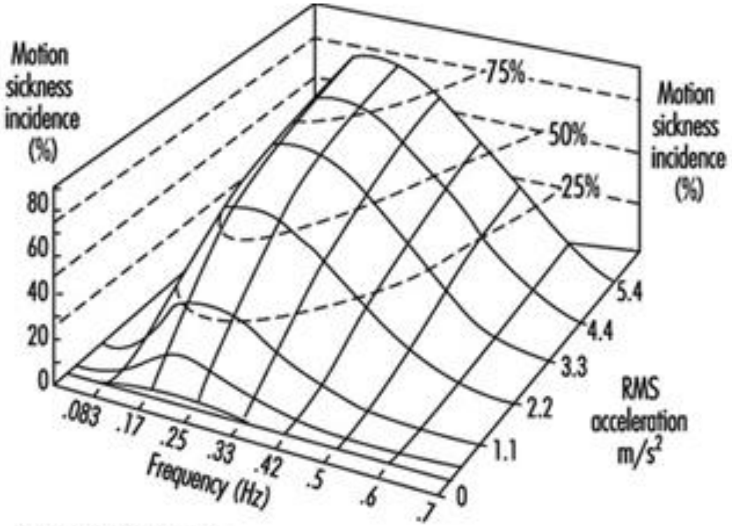
Motion Sickness/Kinetosis

- Motion Sickness, a misnomer:
  - Motion not required and it's not a sickness!
  - Natural human response to conflicting sensory inputs
  - Evolutionary benefit to Motion Sickness: Poison Theory hypothesis – kinetosis mimics nervous system malfunction through food poisoning– so eject toxins ! (Treisman)
- How model Motion Sickness?
  - Stott (1986) identified 3 core rules, which if violated, could result in motion sickness
  - Bos and Bles (1998) proposed a model just considering vertical motion and the sensed vertical
- Deaf people are immune to motion sickness (Irwin 1881). Blind people are not (Reason 1975)



Fluid in canals is diluted by alcohol causing dizziness….



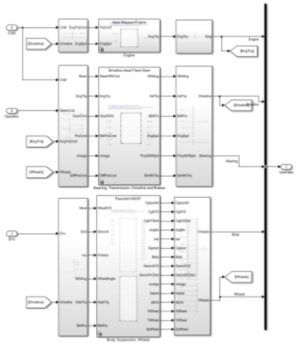


Source: McCauley et al. 1976.

Modelling motion sickness in vehicles

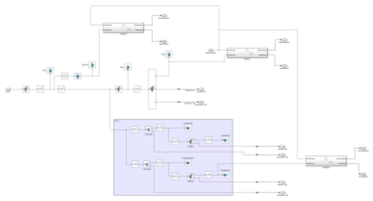
Driver Inputs
Environmental conditions

Vehicle Dynamics
How does the vehicle respond to driver inputs and road conditions?



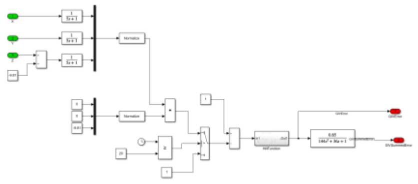
Vehicle/Seat motion

Human Dynamics
How does the occupant respond to vehicle motion?



Occupant body motion (head and stomach)

Neural Processing
How does the motion make the occupant feel?



Motion Sickness Index (MSI) / Misery Index

Modelling motion sickness in vehicles

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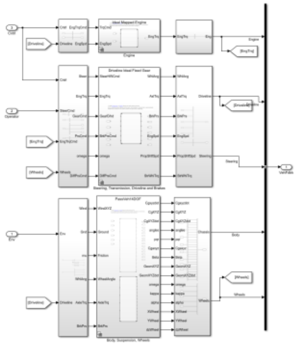

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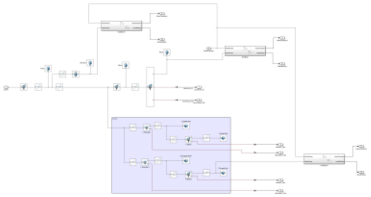

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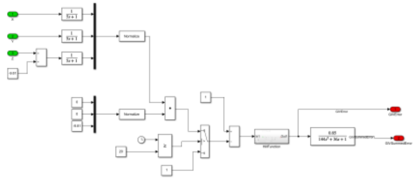
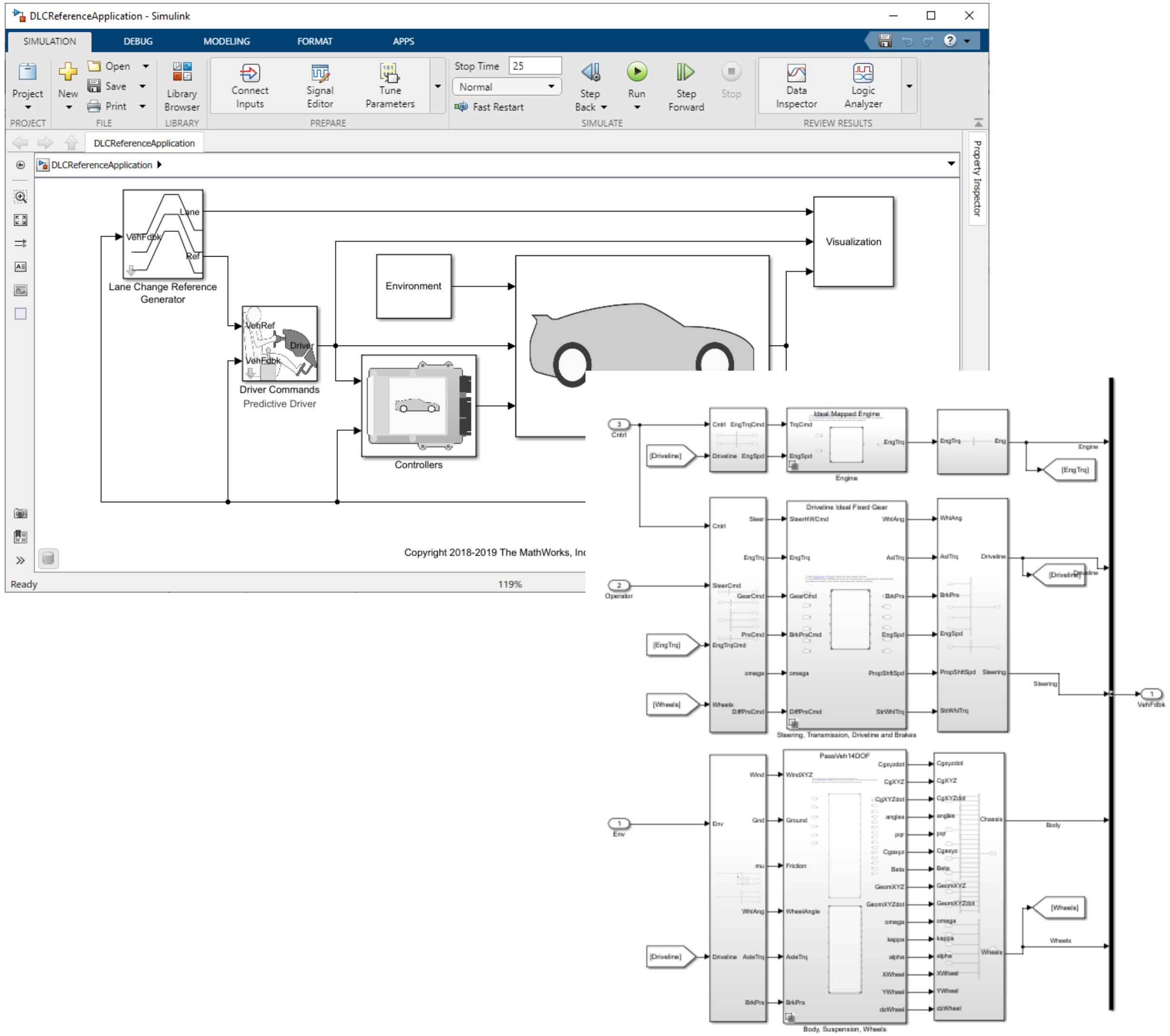


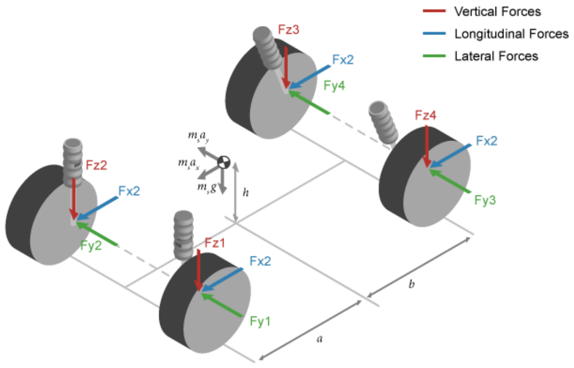
Motion Sickness Index (MSI) / Misery Index

Increasing:
Modelling complexity,
Modelling uncertainty,
Correlation difficulty

Vehicle Dynamics

- Models the response of a vehicle to a set of driver inputs
- Switchable between 6 DOF dual track bicycle model and articulated suspension 17 DOF model as supplied by MathWorks in the Vehicle Dynamics Toolbox
- Pacejka Magic Tyre model – suitable limit handling not expected
- Heavily parameterised and customisable. Out of box model sufficient for initial testing
- Includes predictive driver

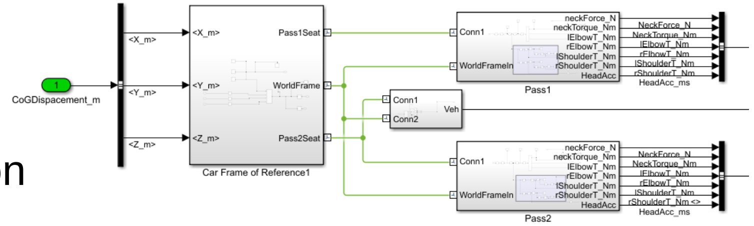


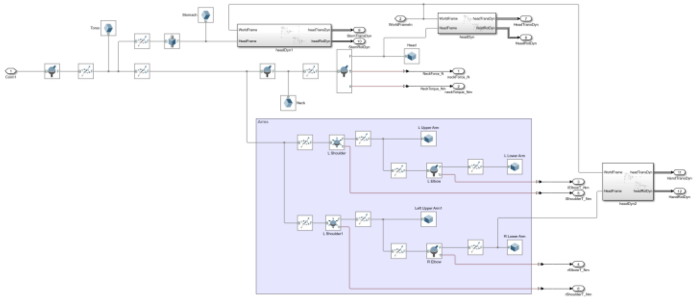


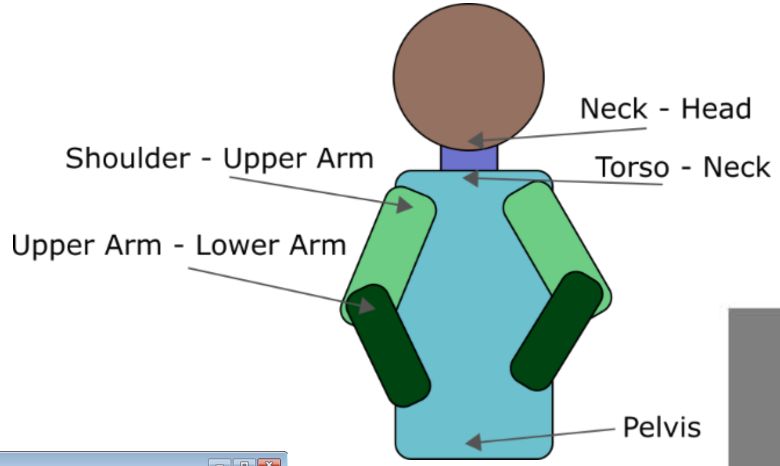
https://uk.mathworks.com/help/vdynblks/ref/vehiclebody6dof.html

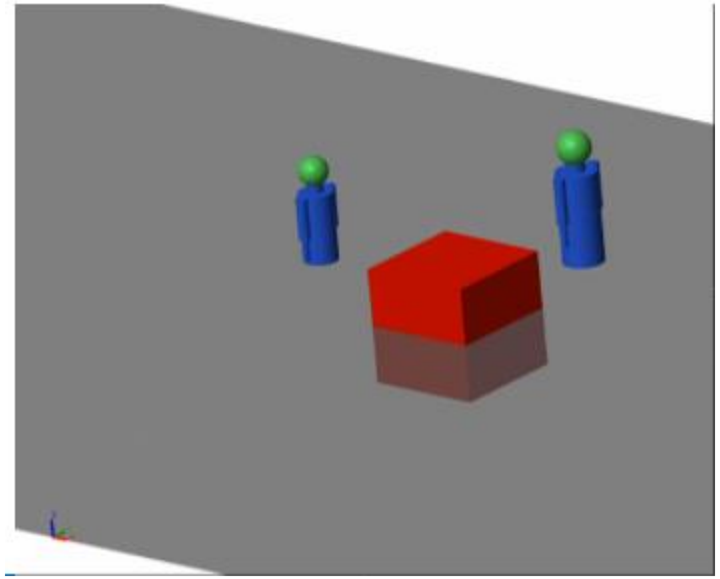
Human Mechanics

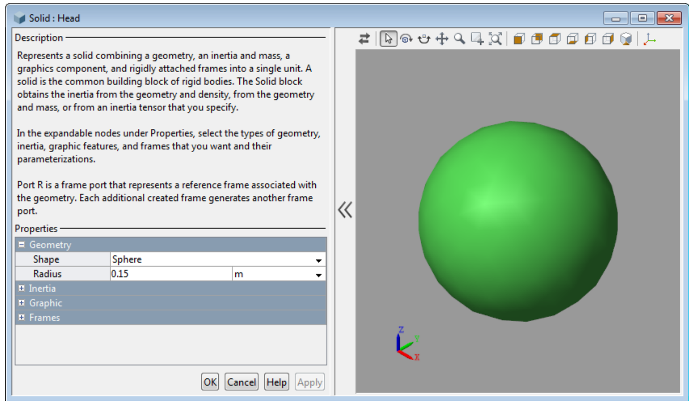
- Passive, simplified crash test dummy style model built in **Simulink Simscape Multibody**
- Solid bodies connected via representative joints
- Assuming no active muscular system/auto correction
  - Suitable for initial developing, but area for future development
- **Manual definition of equations of motion not required**
- Mechanics Explorer used to confirm that model is corrected

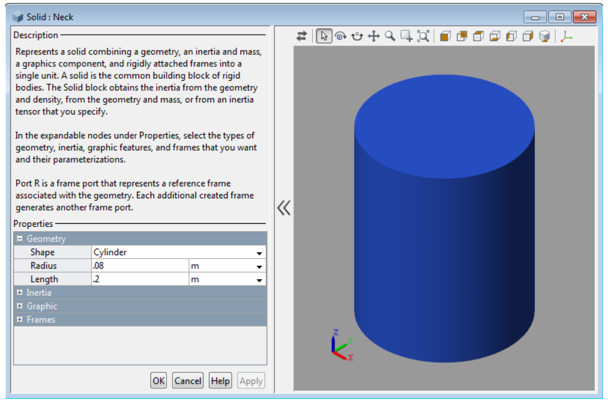










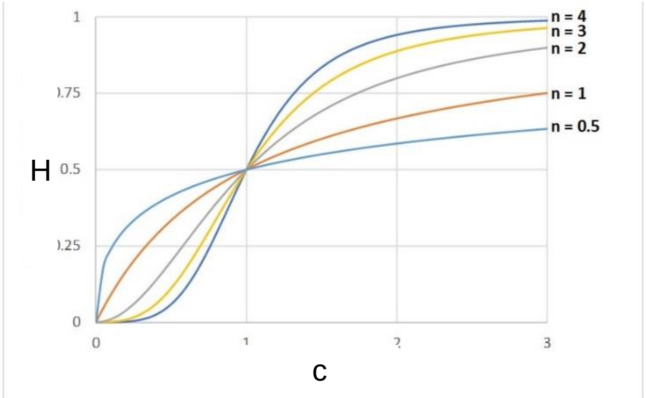


Motion sickness model

- Drawing on Bos and Bled *Modelling motion sickness and subjective vertical mismatch detailed for vertical motions* (1998)
- Human brain has multiple ways of answering the question "which way is down?"
  - Visual input, vestibular otoliths and semi-circular canals, Musculo-skeletal inputs
- Neutral processing then assigns a weighting to all of these based on experience to determine the most likely direction of "down"
- **Biological Sensor Fusion!**

Hill Function

$$H = \frac{\left[\frac{c}{b}\right]^n}{1+\left[\frac{c}{b}\right]^n}$$



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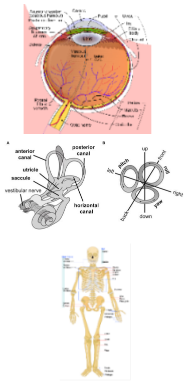


Visual input

Vestibular input

Skeletal input

…

→ Neural processing based on experience → "Which way is down?"

Motion sickness model

- Drawing from Modelling motion sickness and subjective vertical mismatch detailed for vertical motions (Bos and Bles,1998)
- Transfer function easily translated into Simulink

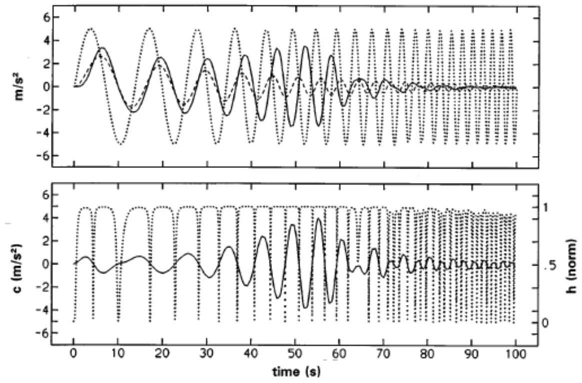


FIG. 6. Intermediate model results. Top: input acceleration (· · ·), sensed (– – –) and subjective vertical (——). Bottom: conflict (——) and Hill-transformed conflict (· · ·).

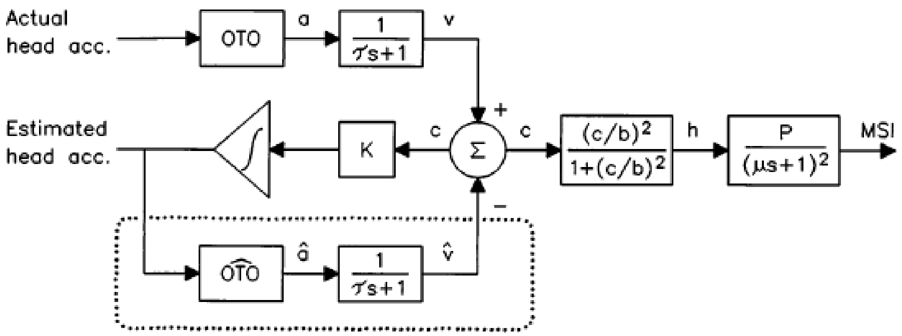
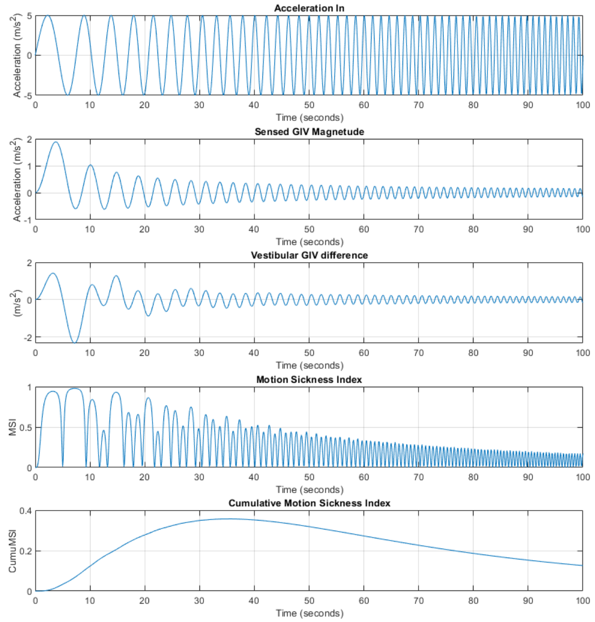
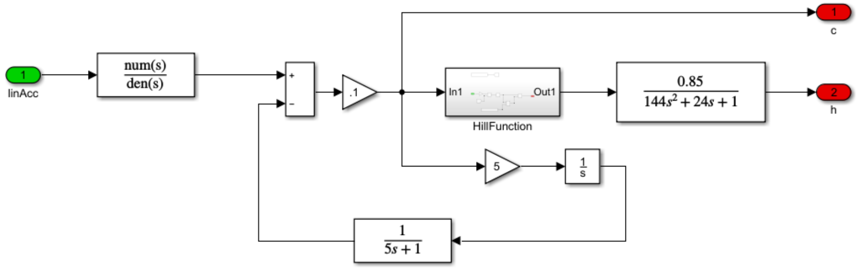


FIG. 5. Subjective vertical conflict model for passive vertical motion.





Recall Challenges of CAV

- Challenges of CAV (including but not limited to):
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  - **Path planning**
  - **Route planning**
  - Safety (inc other road users)
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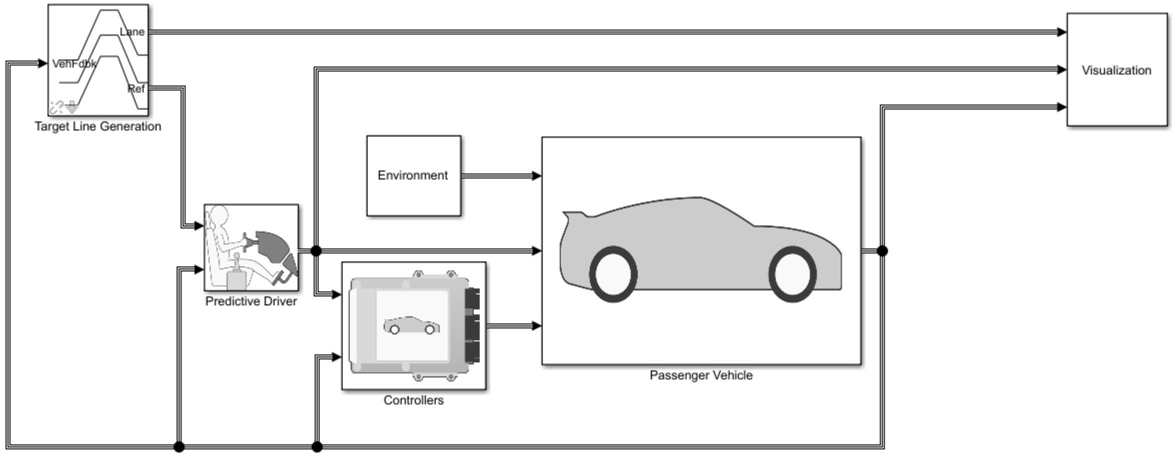
- Motion Sickness model has thus far been demonstrated to address both Vehicle Control and Path Planning for a double lane change/overtake:
  - Vehicle Control: tuning of automated driver parameter
  - Path Planning: route selection for an overtake manoeuvre



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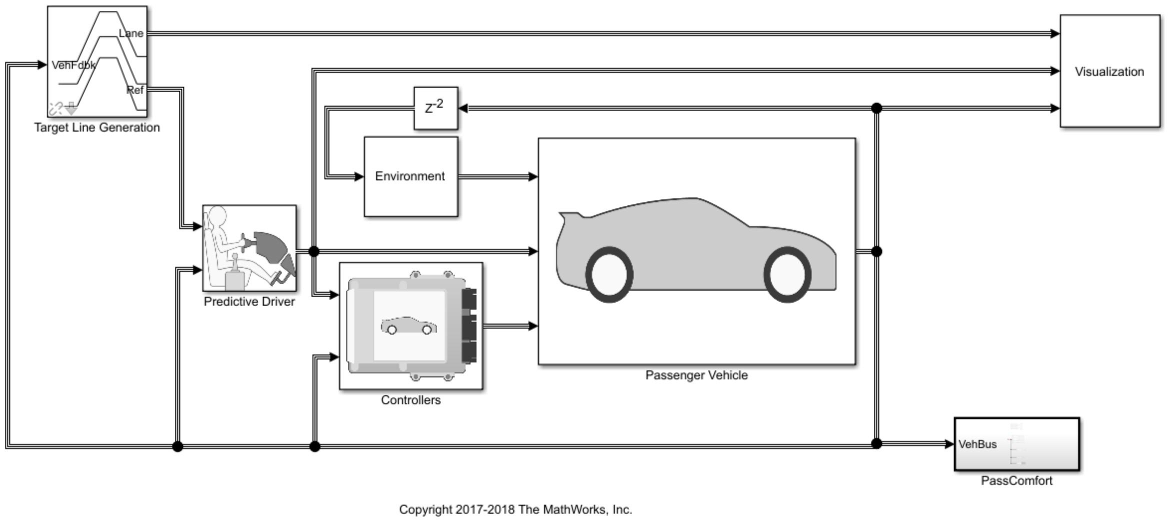
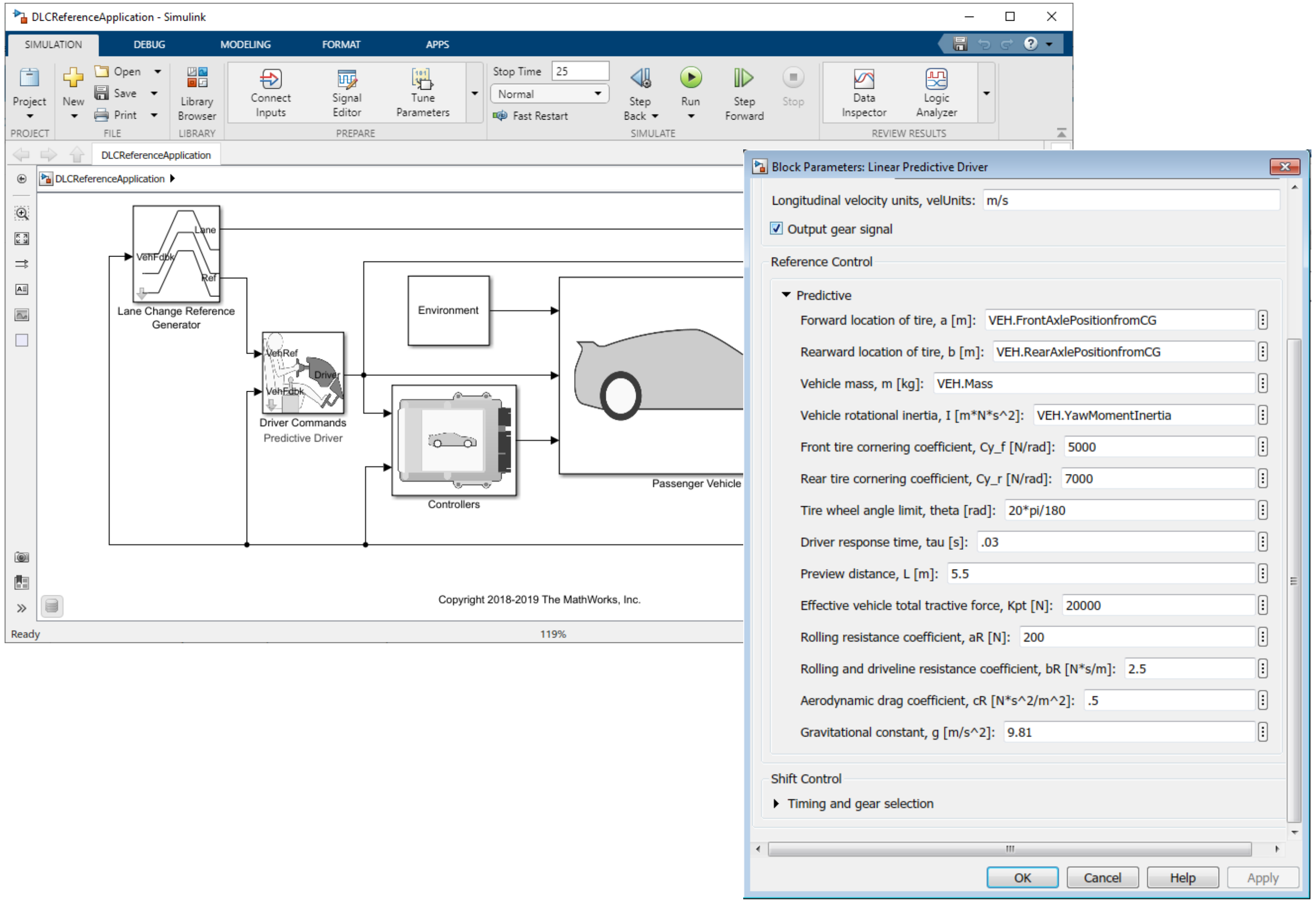
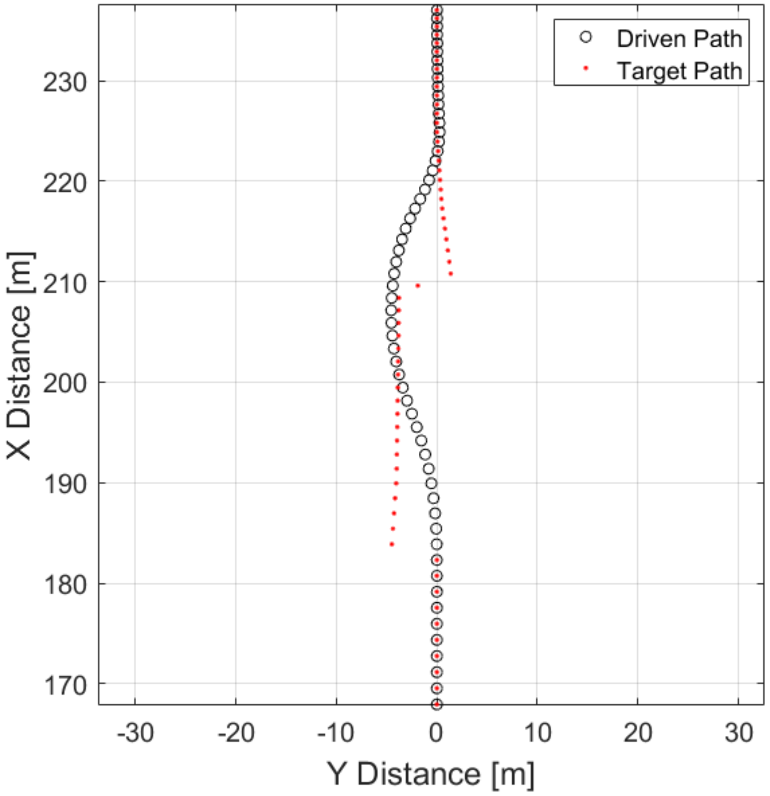


Optimisation of vehicle control

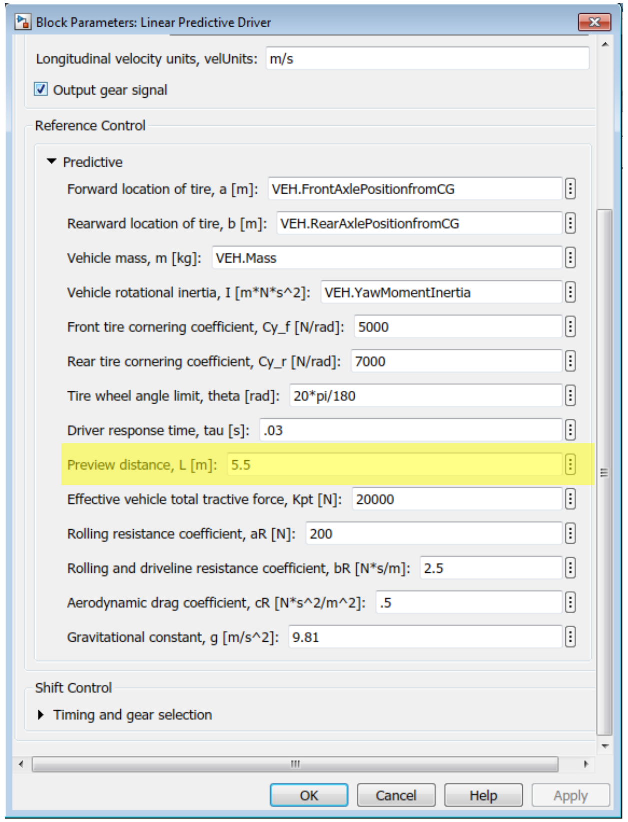
- Using out of the box double lane change Reference Application
- A target path is generated and the predictive driver attempts to follow it as closely as possible, based on the tuning parameters

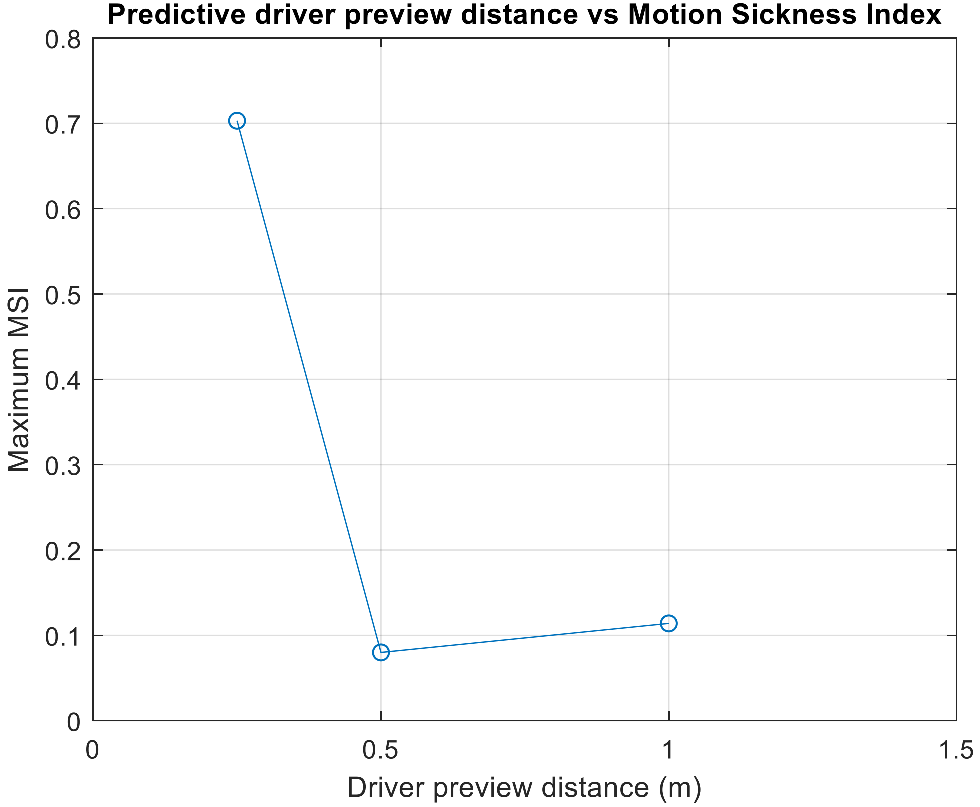




Optimisation of vehicle control

- For a given passenger performing an overtake manoeuvre, there appears to be an optimal driver preview distance

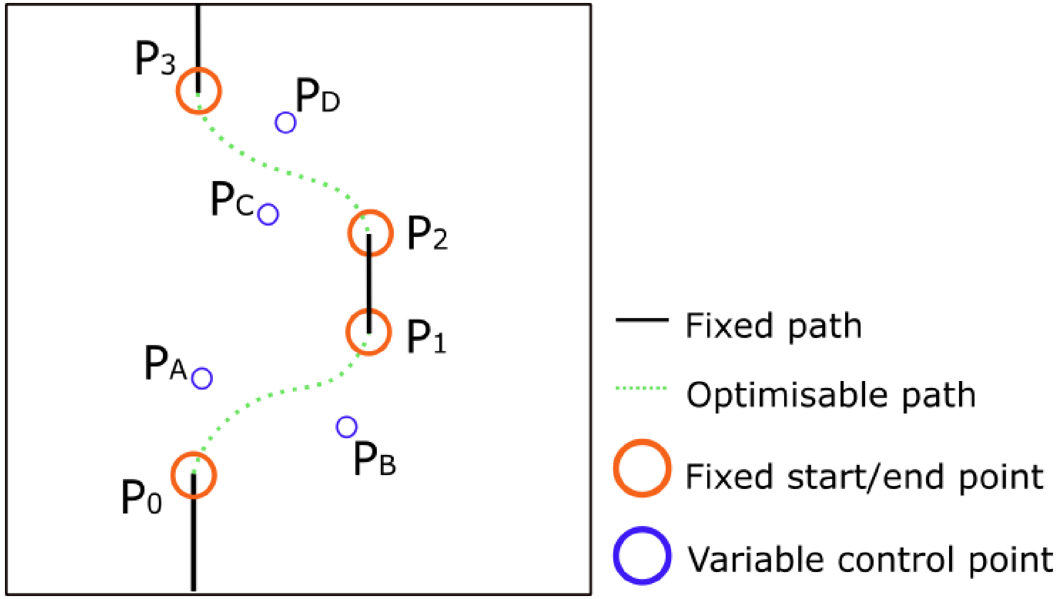


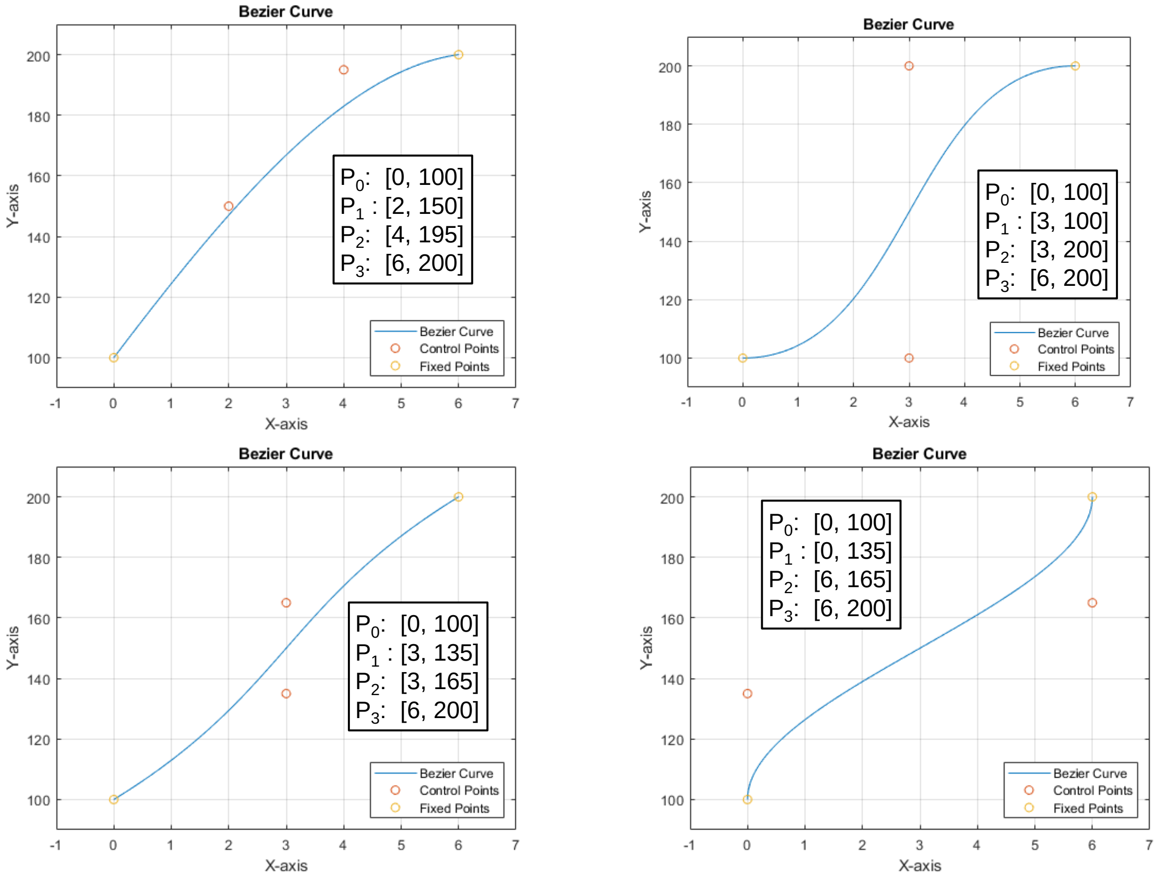


Optimisation of path planning

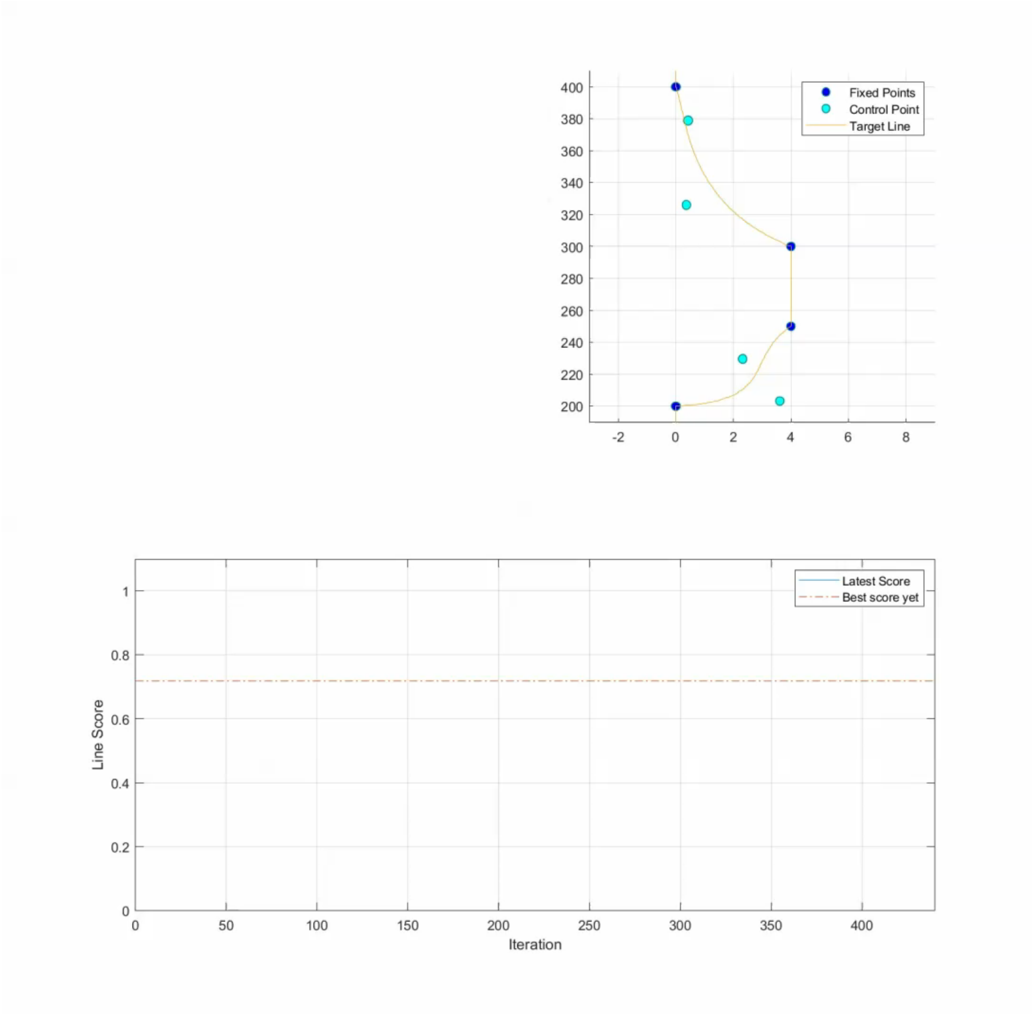
- Overtake manoeuvre path defined as a 3 straight lines and 2 Bezier curves
  - Bezier curves allow analytical definition of a path between two points, based on the location of intermediate control points
- Location of Bezier control points was used as inputs to an optimisation problem
- Objective function was to minimise the peak motion sickness experienced during the manoeuvre

$$\boldsymbol{B}(t) = (1-t)^3.\boldsymbol{P_0} + 3(1-t)^2.t.\boldsymbol{P_1} + 3(1-t).t^2.\boldsymbol{P_2} + t^3.\boldsymbol{P_3}$$





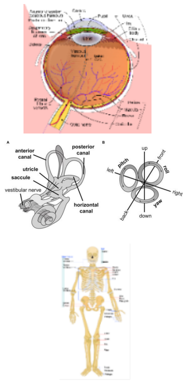
Overtake PSO optimisation



- Particle Swarm Optimiser (PSO) selected from the Optimisation Toolbox
  - Probably not the fastest optimiser, but selected due to wide coverage of optimisation space
- Optimiser has no ‘training’ or weighting towards an obviously sensible line
- Final line appears logical and instinctively sensible

- Conclusions:
  - Vehicle Dynamics (Simulink Vehicle Dynamics Blockset), human dynamics (Simscape MultiBody) and neural processing (Simulink) modelled to predict motion sickness in road vehicles
  - MATLAB mobile app used to collect correlation data
  - MATLAB Optimisation Toolbox used to calculate optimal target lines for an overtake manoeuvre
  - Integration with Unreal Engine used to visualise simulation data

- Further Correlation Work
- Further use of Unreal Engine for visual field simulation



Visual input

Vestibular input

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Neural processing based on experience

"Which way is down?"

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