Institute of

Railway Research

Optimising suspension parameters using genetic algorithms in MATLAB-Vampire co-simulation

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Background

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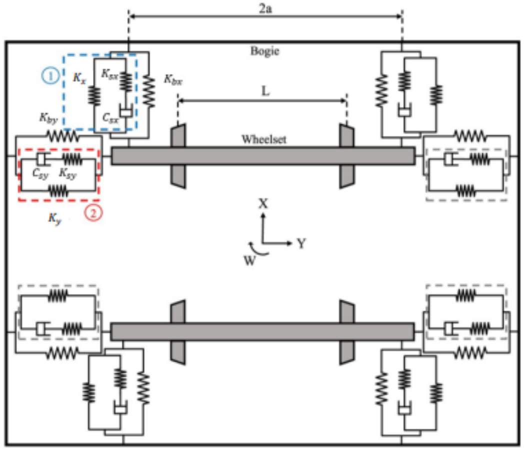
- **The design of rail vehicle suspensions can involve the need to achieve multiple different performance targets and accommodate a broad range of wheelset and track geometry conditions**
- **A typical example is the compromise required to achieve curving and also stability, there has been significant R&D effort over the years to address this**
- **The conventional approach is to reduce yaw stiffness and/or bogie wheel base as far as possible without compromising stability**
- **Some novel solutions have shown good benefits, e.g. HALL bush**
- **It may be possible to design passive suspension that can achieve a range of performance benefits, by designing the suspension system as a network of elements using a 'Network Synthesis' approach including an optimisation of the network layout and suspension component values (stiffnesses, dampings and inertances)**
- **IRR have worked with colleagues in University of Bristol, University of Cambridge and RSSB to develop a methodology to do this, over a number of projects, the work initially focused on the application of 'Inerters' to rail vehicle suspension**

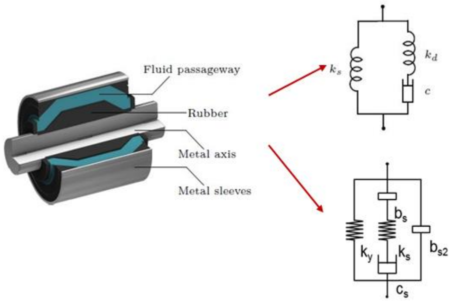
Inerter model validation report IRR/110/140 , 2017	Modelling of the inerter in Simpack IRR/110/165 , 2017	Inertance integrated trailing arm bush design for curving and ride quality IRR/110/185 , 2019	Enhanced trailing arm bush design for rail surface damage reduction, 2020

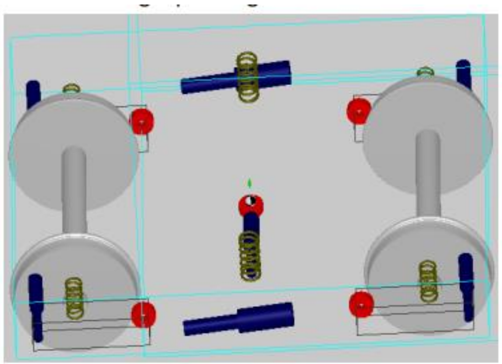
Lewis, T., Li, Y., Tucker, G., Jiang, Z. et al, Improving the track friendliness of a four-axle railway vehicle using an inertance-integrated lateral primary suspension, Vehicle System Dynamics, 2021
Lewis, T., Li, Y., Tucker, G., Jiang, Z. et al, Inertance-Integrated Primary Suspension Optimisation on an Industrial Railway Vehicle Model, IAVSD, 2019
Lewis, T., Li, Y., Jiang, J. Z., Neild, S. A., Tucker, G., Enabling the optimisation of the primary suspension with passive components for an industrial railway vehicle model, ISMA, 2018
Zhao, Y., Tucker, G., Goodall, R., Iwnicki, S., Jaing, Z, et al, Developing an Inerter Model using Multibody Dynamics Software for Railway Vehicle Applications, IAVSD, 2017

Introduction

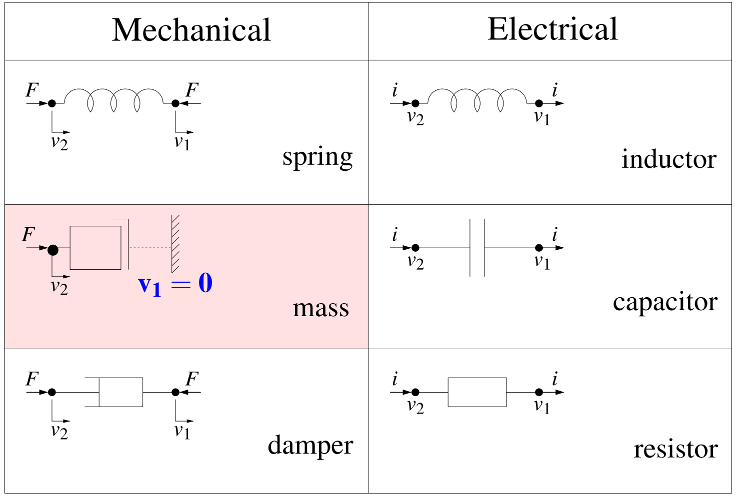
- Work so far has investigated how to reduce primary yaw stiffness: and there fore curving forces, whilst maintaining ride quality throughout a vehicles range of operating speeds and realistic in-service wheel-rail contact conditions (equivalent conicity)
- An optimisation procedure has been developed using the Matlab Genetic Algorithms tool box
- This has been applied to the primary lateral suspension of a sub-urban commuter vehicle, and the primary longitudinal suspension of an intercity passenger vehicle

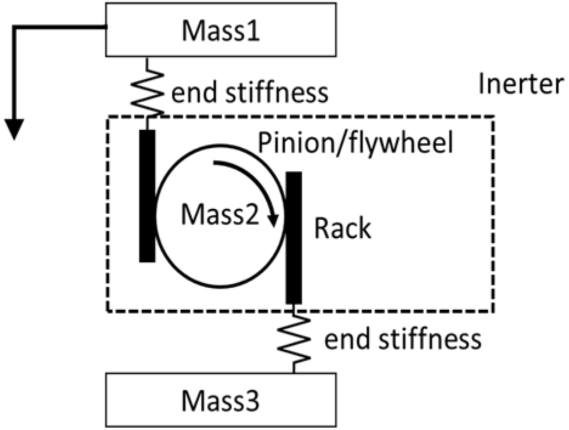






What is an inerter?

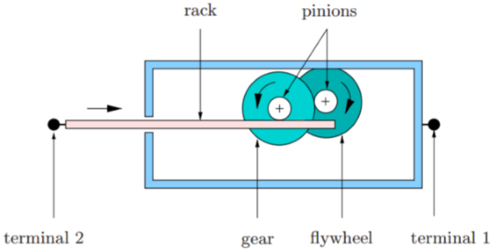




STIFFNESS 100

LINK 1Z 1.0 2P -1.0 3Z -1.0

- **As part of a suspension network, including inerters can allow improved performance against defined targets**
- **They were initially developed to be used in the primary suspension of Formula 1 cars to allow a suspension with constant ride height (i.e. stiff) without causing high vertical accelerations**



Inertance Integrated suspension and Inerters in Vampire

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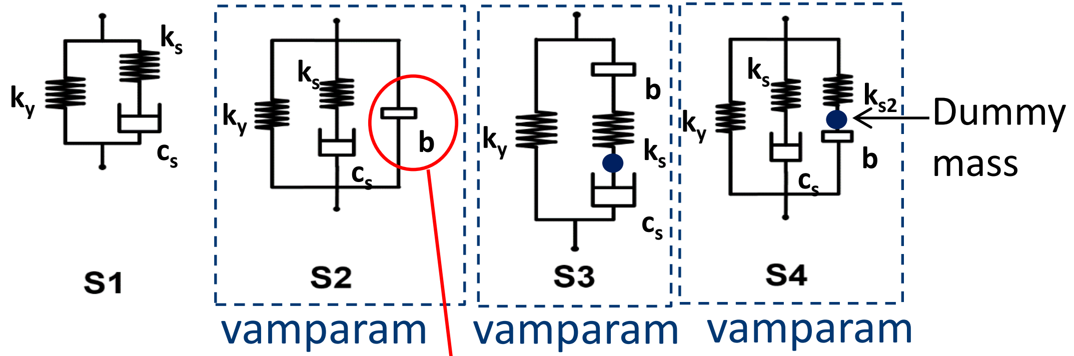
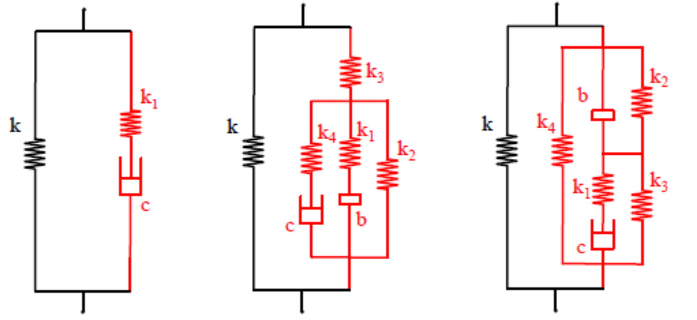


e.g.

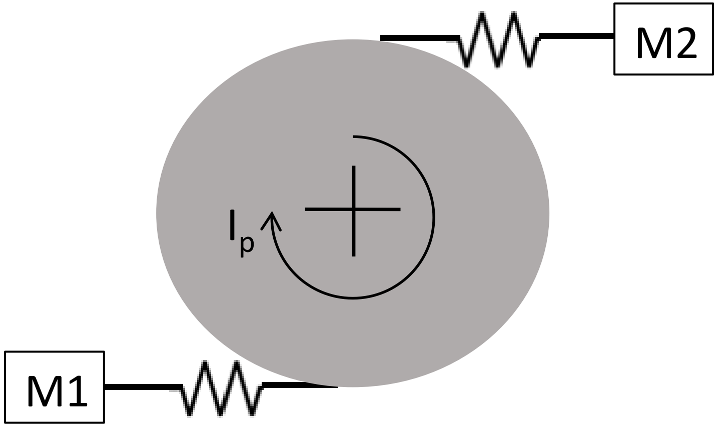
b = 1000 kg => I_p=1000 kg m^2

M_b = 1 kg

```
*MASS
** Inerter:
      INERTIA    1e-3        1e-3        1    1e-3
*BUSH
*****
** Constrains inerter mass in XYZTW
      STIFFNESS    100 100 100 100 0 100
```



(a) Default network. (b) Generic network 1. (c) Generic network 2.



Range of in-service equivalent conicities

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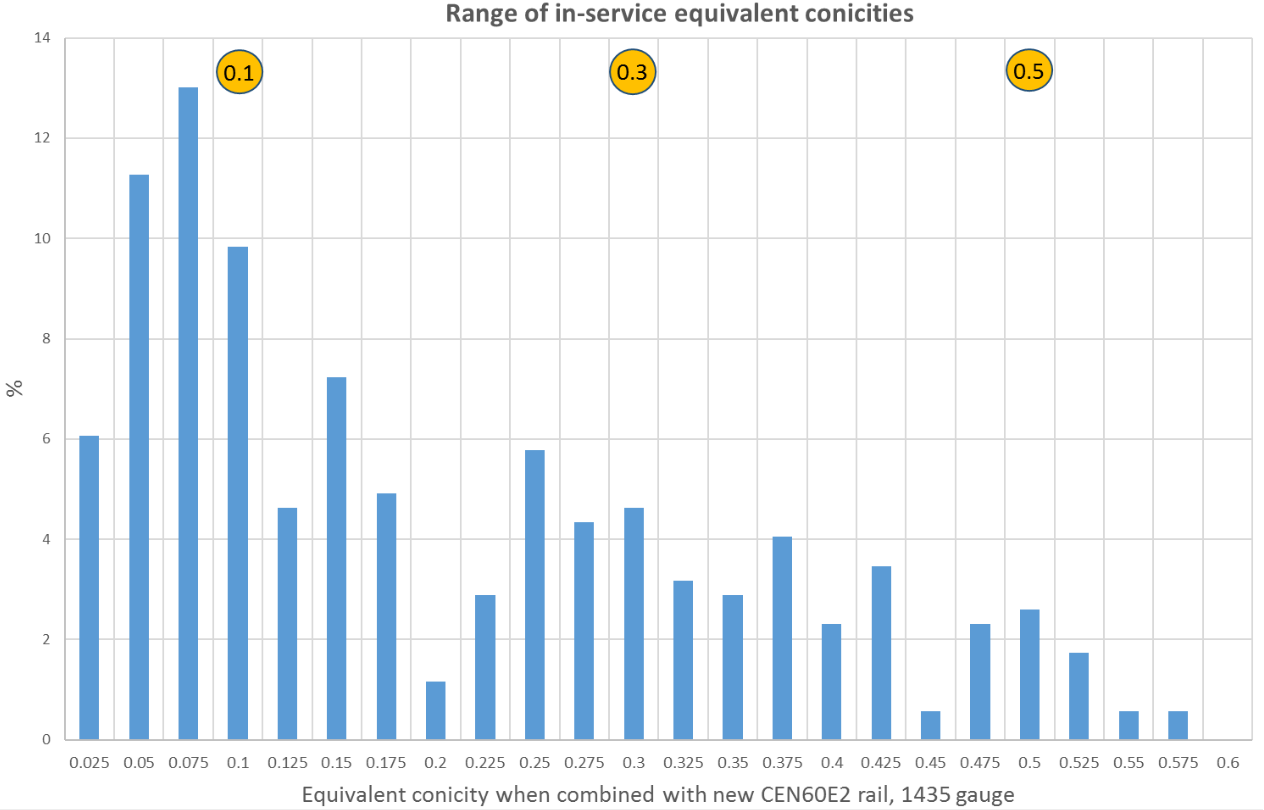

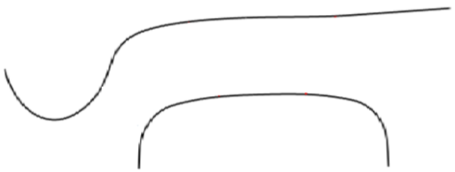

*Sample of 400 measured in-service P8 wheels, RSSB T889 project

Optimisation procedure

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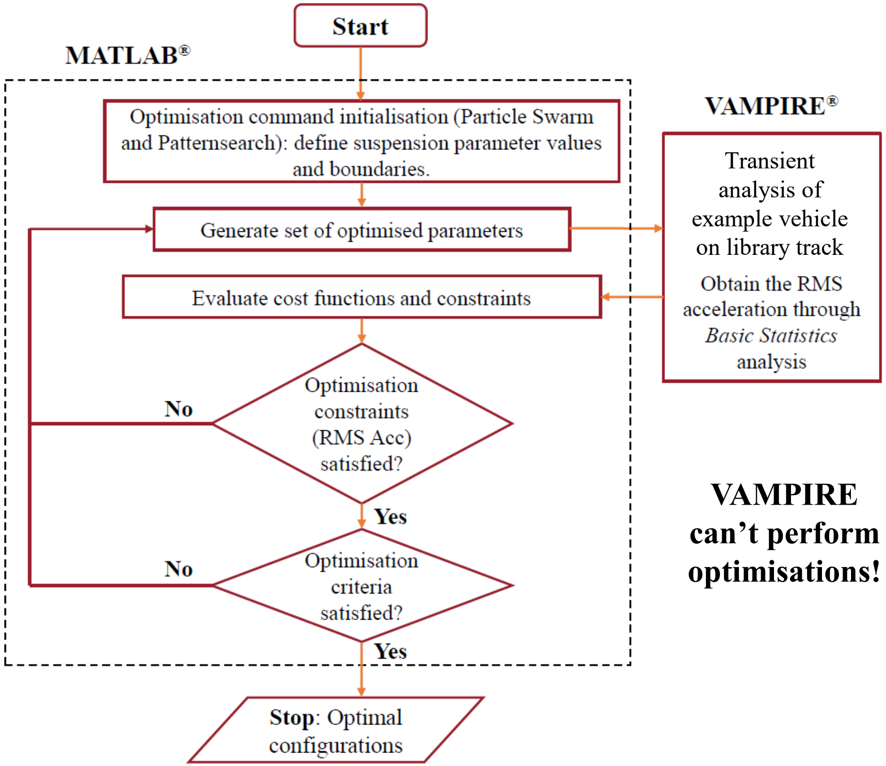
- **Cost function = The longitudinal stiffness of the trailing arm bush's contribution to the PYS.**
- **The network-synthesis-based method is applied to systematically optimise all potential suspension layouts with predetermined complexity.**
- **Simulations are over an example 5km library track file e.g. track160 or track200**
- **Choose a range of velocities and equivalent conicities**
- **Optimisations: Genetic Algorithms such as Patternsearch and Particle Swarm.**



VAMPIRE can't perform optimisations!

Optimisation performance constraints

Example based on VTISM BogiePassenger_39t_15yaw used in IRR/110/185

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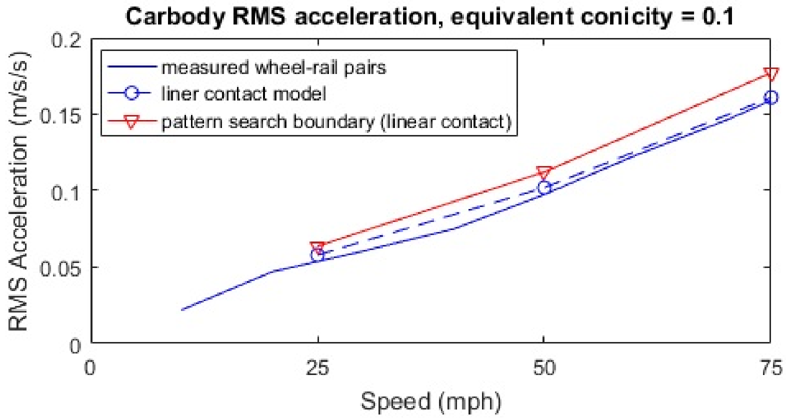
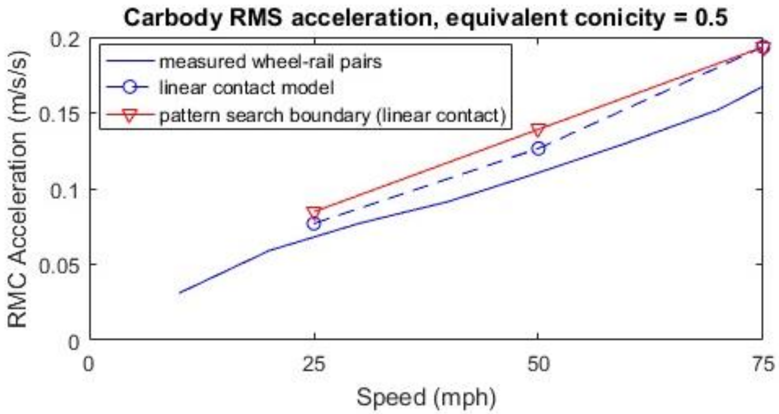
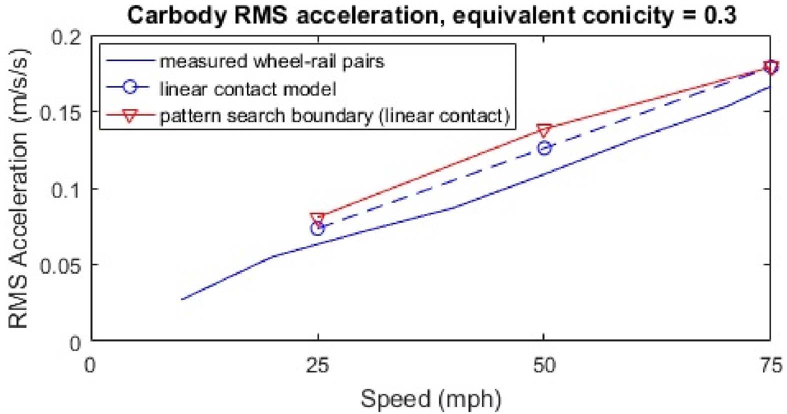
- **Performance Constraint=**average of the front and rear carbody floor lateral RMS acceleration for the optimal S1 rubber bush

  1) $\leq$RMS acceleration with conicity 0.3 & 0.5 at 75mph
  2) $\leq$RMS acceleration with other 7 cases $\times$ $\mathbf{110\%}$

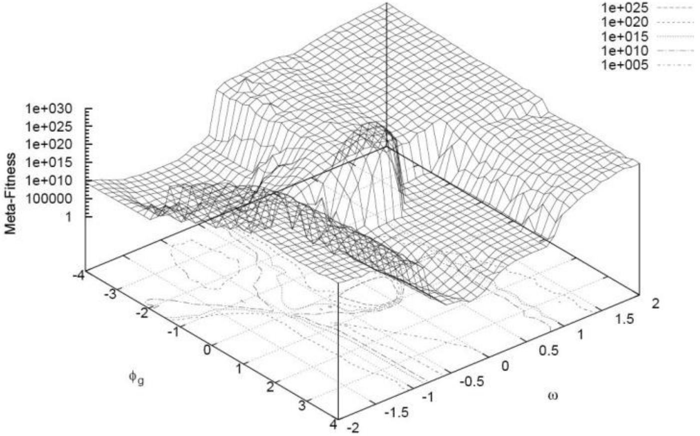


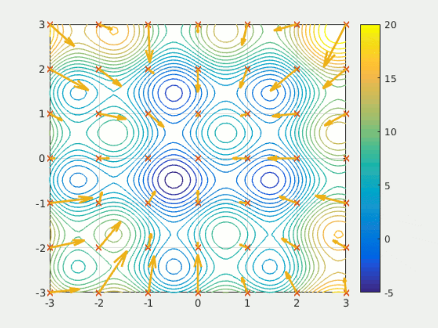




Genetic Algorithms

- **Particle Swarm Optimisation – Searches for a global minimum of the ‘cost function’ whilst varying the defined parameters with the predefined constraints.**
- *‘A basic variant of the PSO algorithm works by having a population (called a swarm) of candidate solutions (called particles). These particles are moved around in the search-space according to a few simple formulae. The movements of the particles are guided by their own best-known position in the search-space as well as the entire swarm's best-known position. When improved positions are being discovered these will then come to guide the movements of the swarm. The process is repeated and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be discovered’*[1]

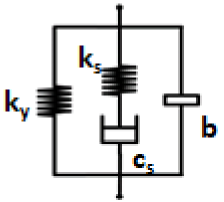




1. Zhang, Y. (2015). "A Comprehensive Survey on Particle Swarm Optimization Algorithm and Its Applications". *Mathematical Problems in Engineering*. **2015**: 931256.

Genetic Algorithms

- Our ‘cost function’ is primary yaw stiffness
- If we optimised based on the S2 layout we have 4 variables (ky, ks, cs, b)
- The simulation starts of with define initial values for ky, ks, cs, b
- Each combination of variables is simulated for the 9 combinations of speed and equivalent conicity and yaw stiffness is reduced (whilst all other parameters including ky, ks, cs, b, remain the same), yaw stiffness continues to reduce until that vehicle fails the performance criteria
- The algorithm then varies the 4 parameters and keeps trying until it finds the combination that achieves the lowest yaw stiffness whilst achieving the specified constraints for the 9 cases



S2

X = [ky, ks, cs, b]

Xmin = 1 MN/m, 1 MN/m, 1 kNm/s, 0.1 kg

Xmax=10 MN/m, 10 MN/m, 50 kNm/s, 7000 kg

Xi = 1.752 MN/m, 3.503 MN/m, 1.752 kNm/s, 3.6 kg

Template vac file


```
[Header]
FileType = VampireCommandFile
[Commands]
TaskNumberOff
File       = 39t_15yaw_S2Y.veh
%yaw%      = PYS
%K%        = K
%k1%       = k1
%c1%       = c1
%b%        = b
ReplaceTo = 39t_15yaw_S2Y1.veh
File       = 39_15_S2Y_ontrack160.run
%con%      = C
%speed%    = S
ReplaceTo = 39_15_S2Y_ontrack1601.run
Task       = 39_15_S2Y_ontrack1601.run
Go
```

A section of matlab code that is calling vampire and reading the results back

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```
dlmcell('GTT.vac', GTtemp); % Creating the VAC file
% Simulating VAMPIRE - transient
system(' "C:\Program Files (x86)\VAMPIRE\VAMPIRE Pro 6.50\Command\VampireCommand.exe" /f "GTT.vac" /x');

importlis
if(length(lischeck(:,1))<21) % if the lis file is less than 21 lines the simulation derailed before it got to the end of the track
   RMS_VEC(i) = [100]; %  if simulation derails before the end of the track file, save very high values as the average accelerations
else
   system(' "C:\Program Files (x86)\VAMPIRE\VAMPIRE Pro 6.50\Command\VampireCommand.exe" /f "39_15_S2Y_ontrack1601.vtfBST" /x');
   import_results3
   RMS_VEC(i) = mean([ontrack1601S2(1,3),ontrack1601S2(2,3)]); % Average acc above both bogies
end;
```

IRR/110/185 results

Optimising primary lateral suspension to allow reduction of primary longitudinal static stiffness

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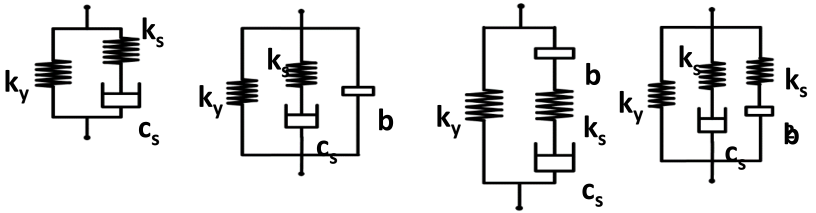
	k_y fixed (MN/m)	k_s (MN/m)	k_{s2} (MN/m)	c_s (kNs/m)	b (kg)	k_{bx}	PYS (MNm /rad)	PYS (%)	PYS reducti (%)
Default	1.75	3.50	-	1.75	-	7.00	15.00	100	-
Opt S1b	1.75	10.00	-	50.00	-	5.46	11.85	79	21
Opt S2	1.75	4.17	-	38.45	3906	3.50	7.95	53	47
Opt S3	1.75	9.09	-	50.00	6830	3.92	8.85	59	41
Opt S4	1.75	9.24	10.00	50.00	2550	3.50	7.95	53	47



S1 S2 S3 S4

IRR/110/185 results

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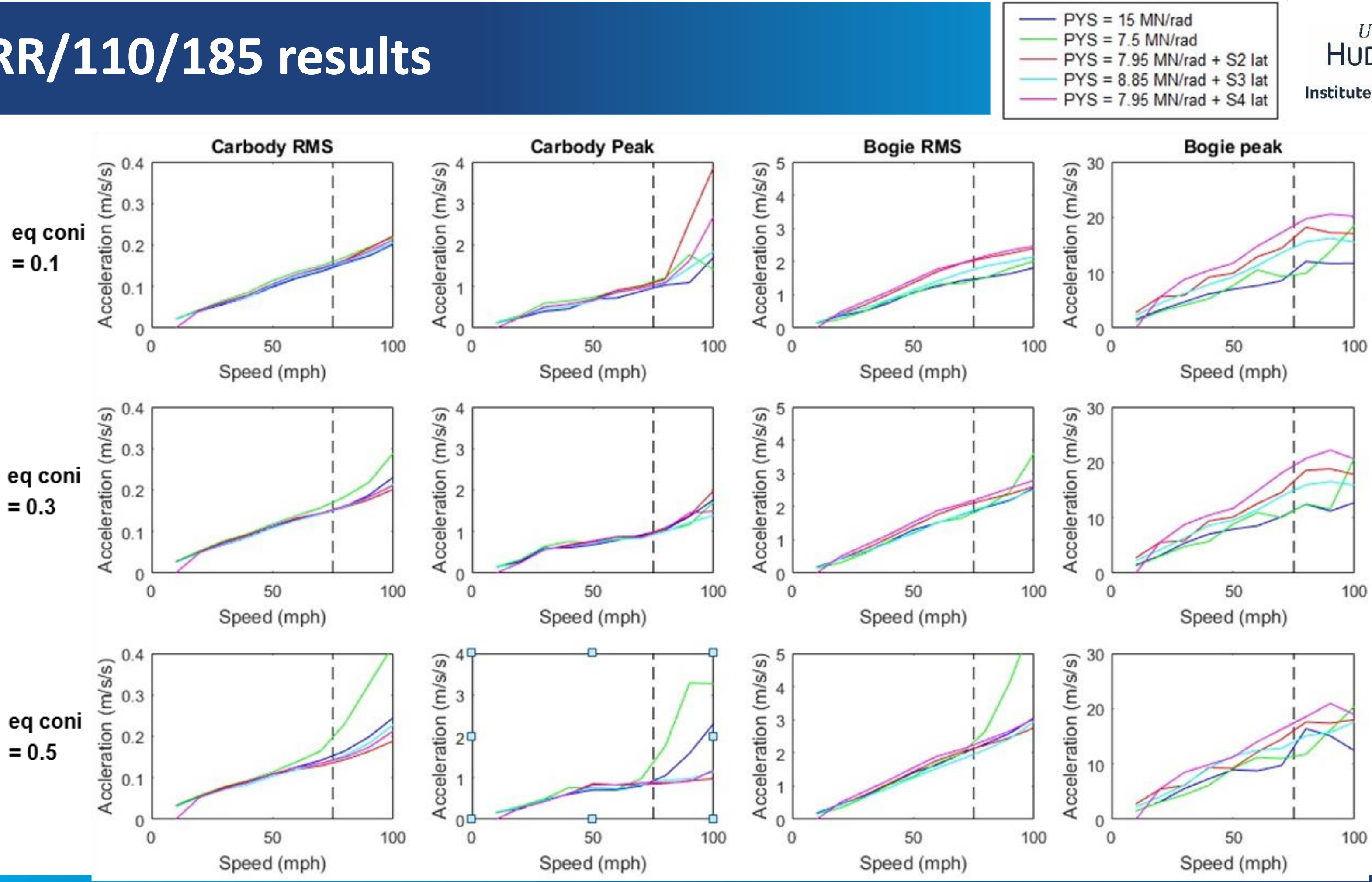

Optimisation for Mk IV Coach primary suspension

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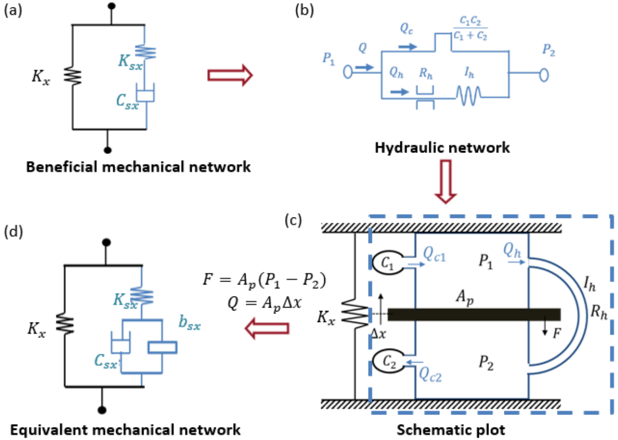
Physical design with 89.2% ↓ in PYS from the default and 51.5% ↓ from HALL

- A follow on project applied the same approach to optimisation of the primary suspension for a Mk IV Coach
- In this application the optimal solution required high longitudinal parallel damping in the primary bush, and did not require additional inertance
- Project produced a detail design of the calculated solution

	Longitudinal static stiffness (MN/m)	PYS (MNm/rad)	PYS reduction compared to the default (%)	PYS reduction compared with the HALL (%)
Default	19.43	40	-	-
HALL Bush	3.9	8.94	77.65	-
Optimised S1X	1.6	4.34	**89.15**	**51.45**



Framework for estimating benefits

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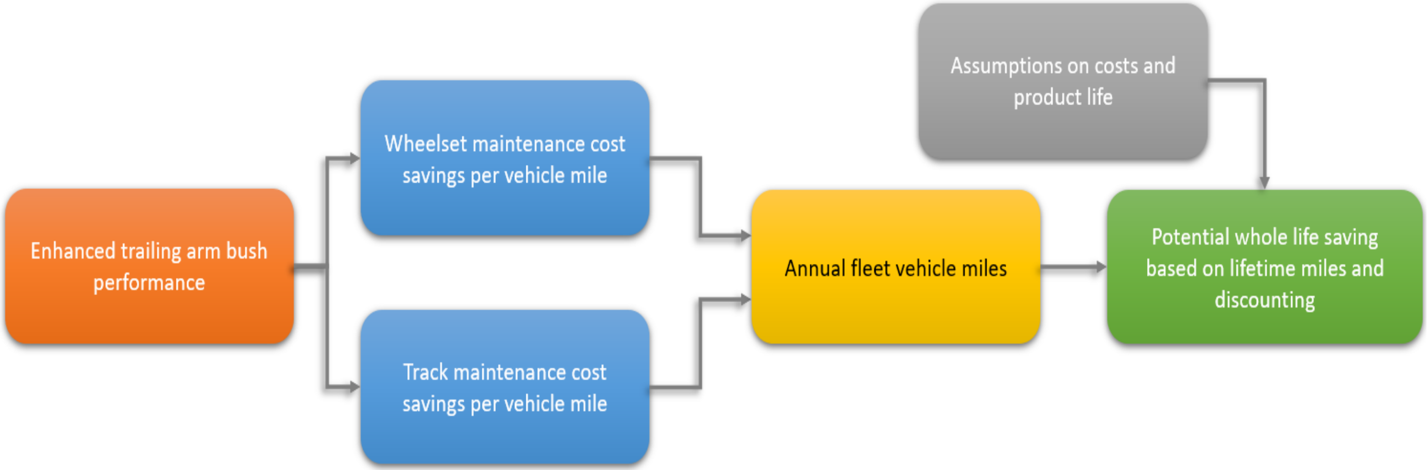
Use NR VUC calculator and RSSB WMM to calculate cost savings:



Financial benefits – whole life cost per fleet

Bush type	Total saving (p/vm)	Annual saving per vehicle (£)	Annual fleet saving (£Mn)	Lifetime saving (£Mn)*
Default	-	-	-	-
Hall Bush	3.82	6,456	1.95	27.67
Optimised hydraulic bush	5.86	9,903	2.991	42.44

* Based on fleet life of 20 years and application and a 3.5% discounting rate

- **Prior RSSB research *Options for traction energy decarbonisation in rail (T1145)* was used to determine vehicle miles for the Mark 4 Bogie.**
- **In 2019 before the class 800 (Azumas) were introduced, there were 302 Mark4 vehicles each travelling 169,000 miles each year, approximately 51m vehicle miles.**
- **Assuming other factors are the same as the default: development, production, fitment, maintenance, and life-span.**

Next steps

- We are developing a follow on project to continue the development of the ‘Enhance Trailing Arm bush’, including prototyping, lab testing and hopefully leading to line testing
- Investigate how suspension travel might limit practical reductions in primary yaw stiffness
- Continue to develop the optimisation methodology and link to design realisation – including incorporation of achieve suspension parameters back into vampire (taking into account all non-linearities)
- Apply the methodology to other optimisation problems
- Investigate alternative ‘cost functions’
- Further investigate suspension design considering ride comfort – we have a new test rig to do this which can use Vampire outputs to demonstrate ride quality

THOMoS: Train Hi-fidelity Motion Simulator

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THOMoS is suitable for conducting research in a variety of areas including:

- Ride comfort of seated and standing passengers
- Immediately assessing the 'feel' of changes to suspension and track design
- Travel on new infrastructure before it is built
- Live demonstration of vehicle dynamics simulation results
- Comfort and human response to varying curve transition design and switch and crossing alignment (including high speed)
- Vehicle interior comfort assessment (seat design, layout, temperature etc.)
- Investigating trade-offs between suspension design and track geometric quality
- Testing interior fixtures and fittings and equipment
- Passenger response to unusual situations (emergency braking, track brake deployment, track defects etc.)
- Incident reconstruction

THOMoS is a state of the art rail vehicle motion simulator designed to provide a fully featured passenger experience using motions generated from rail vehicle dynamics simulations (VAMPIRE, SIMPACK, VI-Rail etc.) or measured data.

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