V A M P I R E ®

Opportunities for fast, optimised, railway simulations

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1 Introduction

The purpose of a railway vehicle dynamics simulation package is to
- save money,
- optimise efficiency,
- maximise safety,

of the railway dynamic system.

This is achieved by better understanding the system so that the initial design can be "right first time" and system maintenance, and design modifications can be correctly targeted to give maximum affect. "System" refers both to the vehicle design, and to the track design and quality.

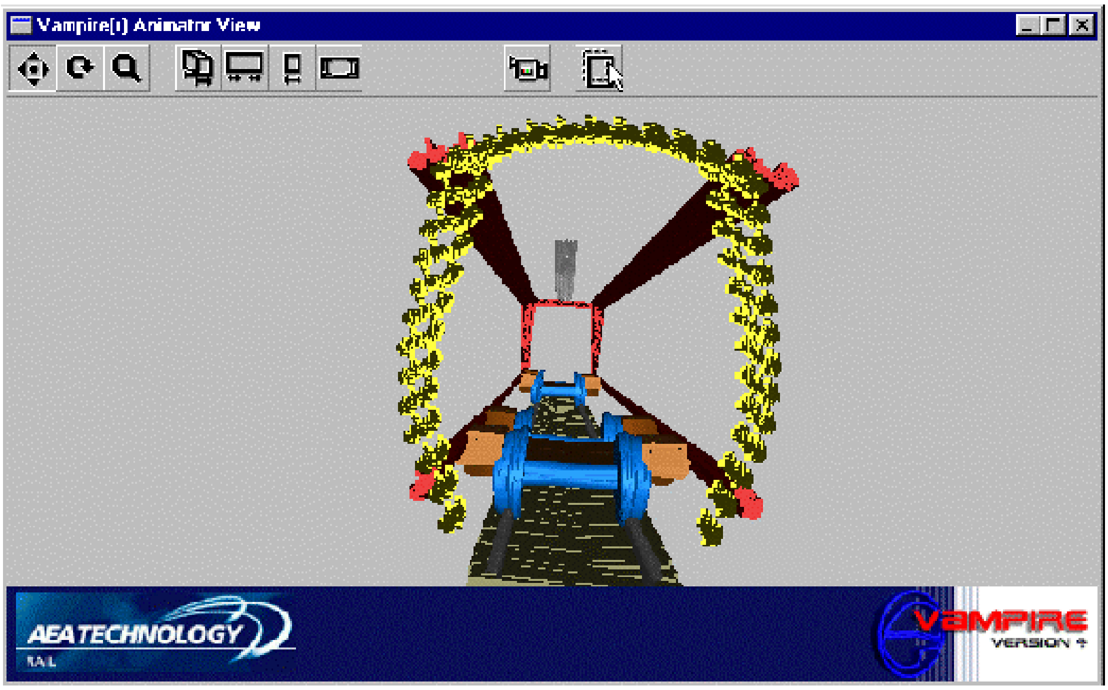
With this aim in mind, the ideal simulation package would have the following attributes:
- It can be integrated into the design process. This means that the engineering process is designed to make it easy to get the relevant data into the simulation so that simulations are performed as a matter of course rather than only in exceptional circumstances.
- It must be accurate. The results must be helpful to the design process. Perfect accuracy is not essential, but it is important that users understand any limitations.
- It must be well supported. The support and training is the way in which the accuracy potential of the program is transferred to the user to enable them to perform valuable simulations. Without this support the company licensing the software will be wasting its money, as it will not achieve useful results. It is particularly important to be supported for the issues of dynamics relevant to railways in this case.
- It needs to be fast. Many simulations require many hours of real time to be simulated in order to get statistically valid simulation results. This will not be practical if the program runs much slower than real time.
- It should be good at solving railway problems. Railways have particular tests, and particular ways of viewing results. There are also some dynamic effects that are very important, and some that are less important from a railway perspective. It is important that it is easy to simulate important effects, and view results in a way that fits in with the railways.

- It would be advantageous if non-experts could use the software. This implies that templates can be set up of commonly required simulations, which can then be carried out by any user. The experts can then concentrate on the more demanding tasks of setting up these templates, and setting up methodologies to ensure that any vehicle models used are accurate.

The following examples of railway studies look at how the Vampire package addresses some of the above requirements.

2 Kinematic Envelope Gauging

Kinematic envelope gauging is very important on railways with limited clearances. This includes the UK rail network, metro systems, and with the advent of double decker vehicles, an increasing number of European systems.



Vampire kinematic envelope trace

The method used in the UK, developed by Bombardier Transportation, is to carry out a full non-linear analysis to calculate the vehicle envelope over 5500m of track for 7 speeds, 8 cant conditions, and 4 vehicle conditions (tare, laden, inflated, deflated). This comes to a total of 224 cases, or 1232 km of track. The track is chosen from real measured track data of varying quality and operating speed to give a representation of the whole network.

~~TABULATED MOVEMENT DATA, CRUSH INFLATED~~

Vehicle type:-	CLASS 365 PTSO(L)	Movements for points on the vehicle centreline	1157 mm ARL at tare inflated.
Issue:-	Issue 1	Sway, drop and roll values are mean +/- 2.12 std. dev. from sheet CISUM, including following adjustments:-	
Prepared by:-	Ed Johnson	Lateral adjustment mm	12
Date:-	08/11/1999	Lift adjustment mm	8
		Drop adjustment mm	12

Speed	Cant excess, mm- movements towards inside of curve								Cant deficiency, mm- movements towards outside of curve						
mph	150	125	100	75	50	25	12.5	0	12.5	25	50	75	100	125	150
Average sway at pivots, mm															
5	72.9	68.0	61.7	54.3	45.8	35.4	27.7	16.4	27.7	35.4	45.8	54.3	61.7	68.0	72.9
25	70.6	69.0	64.9	59.7	51.7	40.3	30.9	19.9	30.9	40.3	51.7	59.7	64.9	69.0	70.6
40	70.2	66.9	61.7	55.2	47.5	38.8	31.8	21.1	31.8	38.8	47.5	55.2	61.7	66.9	70.2
55	69.2	66.7	63.0	58.0	51.9	43.6	35.5	24.8	35.5	43.6	51.9	58.0	63.0	66.7	69.2
70	71.6	70.3	68.2	63.4	55.7	45.0	37.4	27.1	37.4	45.0	55.7	63.4	68.2	70.3	71.6
85	71.8	69.6	66.1	61.3	54.7	45.5	38.3	28.3	38.3	45.5	54.7	61.3	66.1	69.6	71.8
100	73.6	71.8	69.3	64.4	57.0	48.2	41.1	30.9	41.1	48.2	57.0	64.4	69.3	71.8	73.6
Average lift at pivots, mm															
5	-11.1	-12.1	-12.9	-13.6	-14.0	-14.2	-14.3	-14.3	-14.3	-14.4	-14.6	-15.1	-15.8	-16.6	-17.7
25	-6.3	-7.2	-8.0	-8.6	-9.0	-9.3	-9.3	-9.3	-9.3	-9.4	-9.6	-10.1	-10.7	-11.4	-12.5
40	-5.7	-6.7	-7.5	-8.1	-8.5	-8.8	-8.8	-8.8	-8.8	-8.9	-9.1	-9.5	-10.1	-10.9	-11.9
55	-4.2	-5.2	-6.0	-6.6	-7.0	-7.2	-7.2	-7.2	-7.3	-7.3	-7.6	-8.0	-8.6	-9.4	-10.4
70	-1.9	-2.9	-3.6	-4.2	-4.6	-4.8	-4.9	-4.9	-4.9	-4.9	-5.2	-5.6	-6.2	-7.1	-8.0
85	-5.9	-6.9	-7.6	-8.2	-8.6	-8.9	-8.9	-8.9	-8.9	-9.0	-9.2	-9.7	-10.4	-11.2	-12.3
100	-4.8	-5.7	-6.5	-7.1	-7.6	-7.8	-7.8	-7.9	-7.9	-7.9	-8.2	-8.6	-9.2	-10.1	-11.2
Average drop at pivots, mm															
5	36.3	37.4	38.3	38.9	39.4	39.7	39.7	39.7	39.7	39.8	40.0	40.5	41.1	42.0	42.9
25	41.5	42.5	43.3	43.9	44.4	44.6	44.7	44.7	44.7	44.7	44.9	45.3	46.0	46.8	47.7
40	42.0	43.0	43.8	44.4	44.9	45.1	45.1	45.1	45.2	45.2	45.4	45.8	46.4	47.2	48.2
55	43.5	44.5	45.3	45.9	46.3	46.6	46.7	46.7	46.7	46.7	46.9	47.3	47.9	48.7	49.7
70	45.9	46.9	47.7	48.4	48.8	49.0	49.1	49.1	49.1	49.2	49.4	49.7	50.3	51.1	52.1
85	41.8	42.8	43.7	44.4	44.8	45.1	45.1	45.1	45.1	45.2	45.4	45.8	46.4	47.2	48.2
100	42.9	44.0	44.9	45.5	45.9	46.1	46.2	46.2	46.2	46.3	46.5	47.0	47.6	48.3	49.3
Roll, degrees															
5	1.38	1.17	0.97	0.77	0.56	0.34	0.21	0.06	0.21	0.34	0.56	0.77	0.97	1.17	1.38
25	1.62	1.47	1.27	1.05	0.79	0.47	0.29	0.13	0.29	0.47	0.79	1.05	1.27	1.47	1.62
40	1.60	1.37	1.15	0.91	0.67	0.43	0.30	0.14	0.30	0.43	0.67	0.91	1.15	1.37	1.60
55	1.51	1.35	1.17	0.97	0.76	0.53	0.37	0.22	0.37	0.53	0.76	0.97	1.17	1.35	1.51
70	1.65	1.50	1.36	1.13	0.85	0.56	0.41	0.25	0.41	0.56	0.85	1.13	1.36	1.50	1.65
85	1.64	1.45	1.26	1.07	0.84	0.58	0.42	0.26	0.42	0.58	0.84	1.07	1.26	1.45	1.64
100	1.74	1.57	1.40	1.18	0.91	0.64	0.48	0.32	0.48	0.64	0.91	1.18	1.40	1.57	1.74

Kinematic Envelope table reproduced with kind permission of Bombardier Transportation

The table generated is then used as a lookup table when calculating clearances at structures along the route. An example of part of this table is shown above.

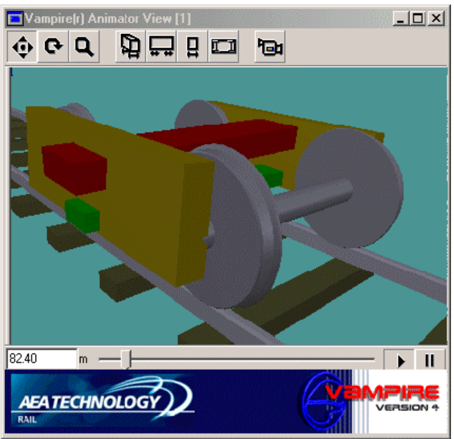
Simulating the vehicle for such a large number of cases is a large task, and takes up to 24 hours CPU time on a typical PC with a Vampire simulation. This would rapidly become unmanageable if the simulation speed were to drop by an order of magnitude. The Simpack simulation software, for example, was found to take between 6 and 90 times as long as the Vampire simulation, depending on task, in the recent Manchester Benchmark.

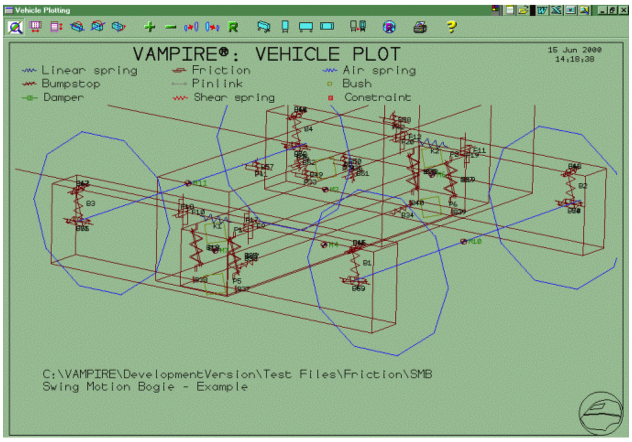
3 Friction Suspensions and Freight Vehicle Acceptance Procedures

Modelling friction suspensions is one of the most difficult simulations to perform for railway vehicles. The vehicle model containing the swing motion 3-piece bogie shown below, for example, is made up of

13 masses (4 Whlsets)
3 flexible modes
5 springs
1 viscous damper
60 friction dampers
76 bumpstops
10 bush elements

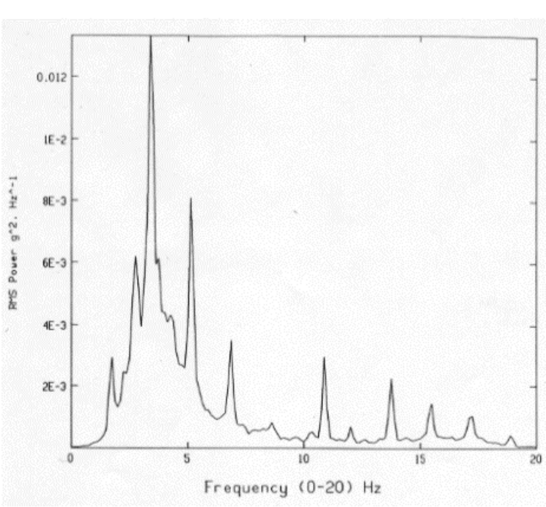
The bogie is largely held together by friction and bumpstops. This means that components tend to either be locked up, or when the friction breaks out, they tend to move until suddenly restrained by a hard bumpstop. On top of this the friction has to be modelled as a surface with load dependent, and direction dependent breakout force governed by complex wedge systems.

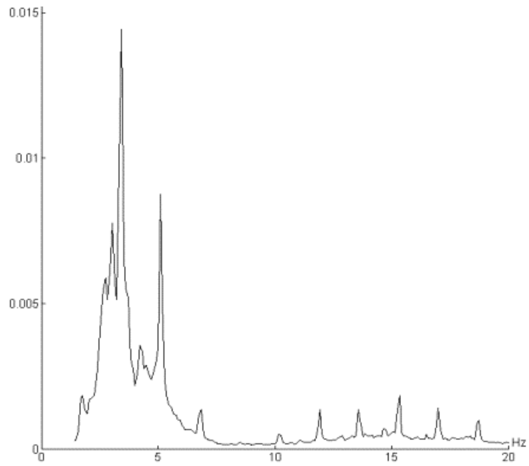




Three piece swing motion bogie model

In spite of the difficulties of modelling this system, very accurate results are obtained. The following graphs show a power spectral density plot of the vertical acceleration levels measured above the leading bogie for the vehicle running over jointed track. There is excellent agreement between the measured results and the simulated results.

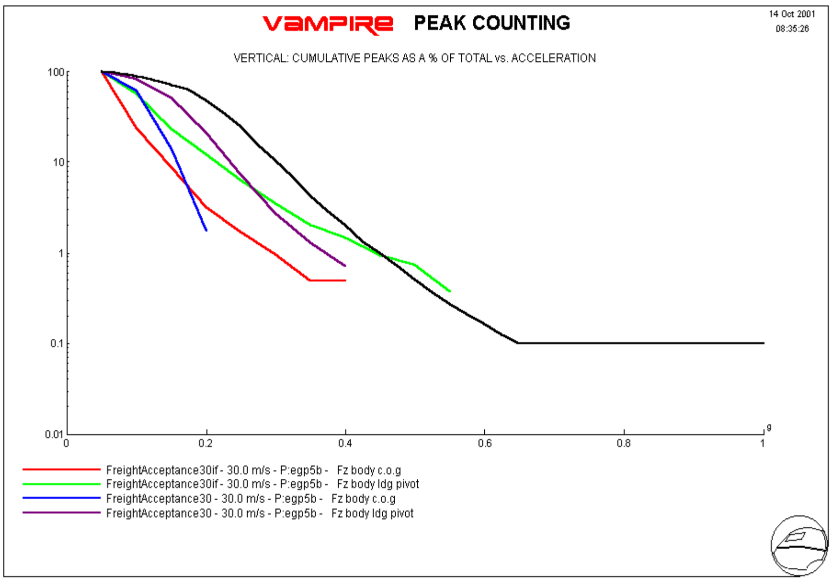




Ride Test measurement **Ride Test Simulation**

Being able to measure such complex suspension systems accurately, and efficiently is essential when designing a vehicle which will be accepted to run by the infrastructure owner.

One test involves running the vehicle over 70km of test track, 25km of which are jointed, and showing that the acceleration levels fit below a defined distribution profile as shown below. In spite of the complexity of the model, Vampire can perform this analysis in less than 30 minutes on a typical PC.



Freight Acceptance - Variations in Friction

Freight acceptance peak counting analysis

4 Passenger Comfort Calculations

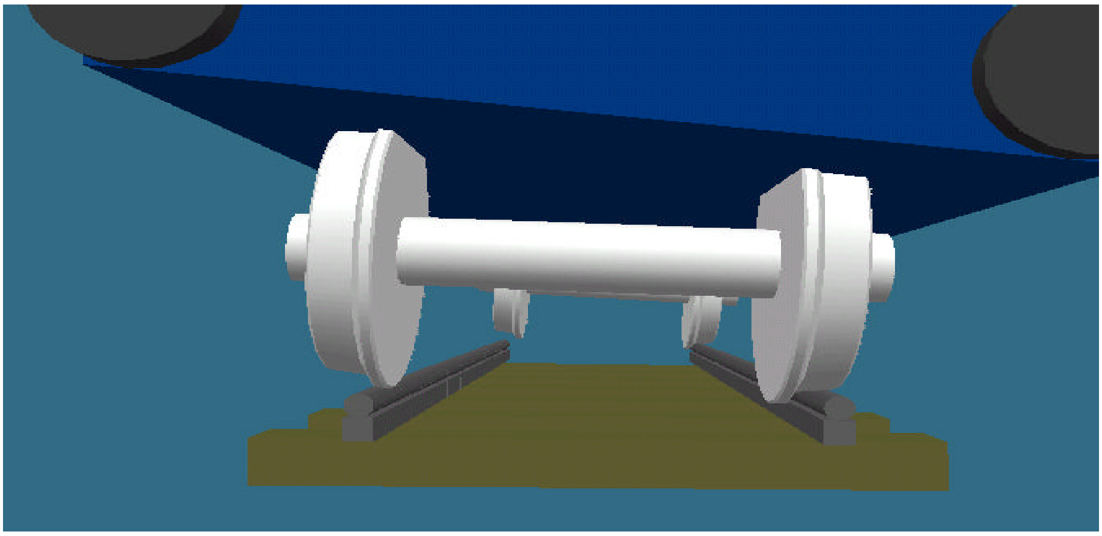
It is not unusual for new rolling stock to be supplied which then fails its acceptance testing as the passenger comfort levels are not satisfactory. This can then involve very expensive modifications to the fleet before final acceptance.

The way to prevent this happening is to perform exhaustive simulations with accurate vehicle models over all of the types of track the vehicle is likely to encounter. This ensures that there will be no surprises on delivery.

A typical Vampire passenger comfort methodology involves running a simulation over 120km of measured track data from the route that the vehicle is to run on. This length is chosen to ensure that statistically valid variations in track roughness, cant, curvature and speed profile are covered. This simulation would be done for 20 or more permutations of the vehicle suspension setup. Because it only takes 20minutes for a simulation on a typical PC, the dynamicist is not deterred from exploring all possible permutations.

Tests used in Europe include ones where statistics are based on averaging 5 minutes of running. For high speed 300kph vehicles, this implies 25km of track. For statistically significant results, at least 250km of track should be simulated if there are to be no surprises at final acceptance testing. Again, accurate and fast simulation is essential.

5 Derailment investigations

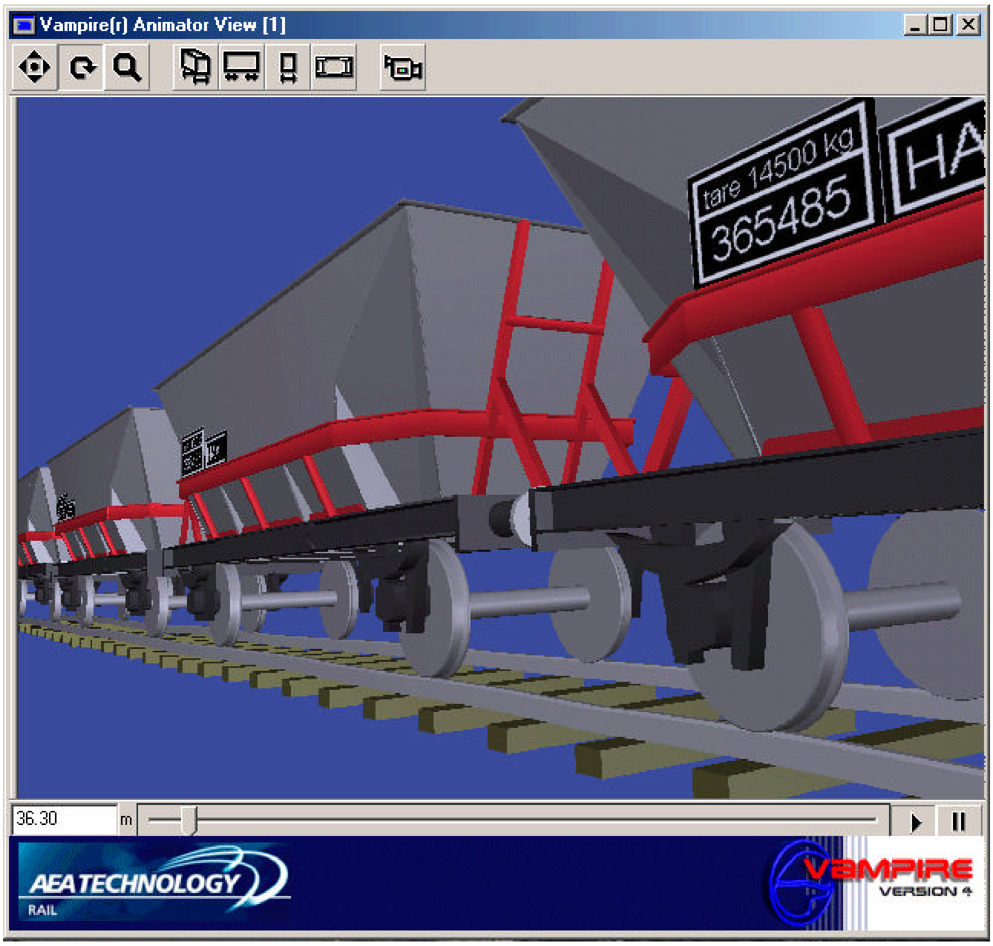


This snapshot is from a derailment animation. The detailed Vampire modelling of the wheel and rail profiles is not shown in this particular animation which was just used to get an impression of body movements.

Derailment investigations are a severe test of the ability of a simulation to perform accurately. AEA Technology Rail have a derailment investigation team who reconstruct all dynamic derailments in the UK using Vampire and measured vehicle and track data from the derailment site. This provides continuing validation of vehicle models and analysis techniques in demanding circumstances, i.e. when the behaviour is at its most non-linear as the wheelset flange climbs the rail and the vehicle derails. Having this capability in-house provides feedback into the Vampire development process and ensures that the package is constantly validated.

The derailments are usually simulated to show the exact point at which the vehicle derailed, and to give a clear explanation for why it happened.

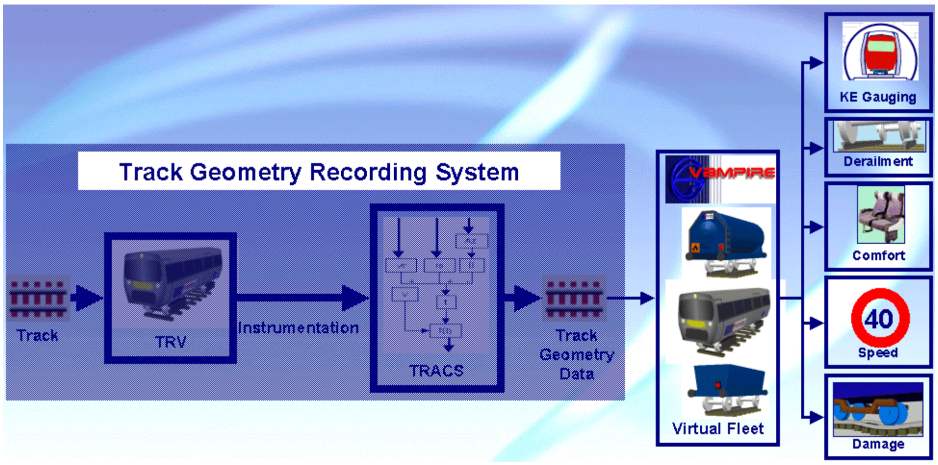
6 Track Quality Processing



Rough track being assessed for response of freight vehicles

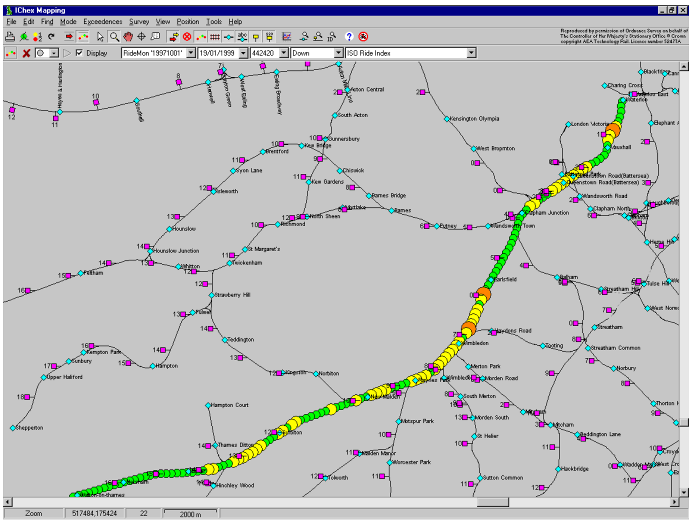
The ability to run at faster than real time makes it practical for Vampire to be used to post process large quantities of track data, so that track maintenance can be carried out based on vehicle response, rather than just on track geometry. Just looking at the animation from which the above snapshot was taken, shows very clearly the effect the track has on the vehicles which are almost derailing. This may not be apparent from the track geometry alone due to the varying response of different vehicles.

The figure below shows diagramatically how track data from a track geometry recording vehicle can be post-processed by Vampire to give an indication of derailment risk, passenger comfort, speed restrictions etc. The principle is to use the same techniques practised by our derailment investigation team BEFORE the derailment occurs so that it can be prevented.



Assessing track geometry data for vehicle response.

The data can then be displayed in a geographical format such as the one below, or used to give maintenance alarms. The output will also be fed into track maintenance management systems to ensure that maintenance is correctly targeted.


Geographical display of vehicle ride. Green is good, yellow moderate, red bad.

Bulk processing of track data with Vampire is currently being developed in the UK. The UK and Spain (RENFE) have also shown considerable interest in an on-line real time version of Vampire which will process data as it is recorded by track geometry recording coaches to give immediate action reports based on vehicle response. The system uses parallel processors, each one simulating one or more vehicles running over the track data recorded to give the response of the full fleet of vehicle types running over the route.

For this to be possible it is essential that vehicles run at faster than real time. The following section gives a feel for the speed at which a Vampire simulation can run.

7 Speed Test

The following speed benchmark was performed for a number of vehicles on a typical PC (spec given in table). Much faster times could be achieved with state of the art hardware.

It shows that the Vampire models ran at between 4 times real speed, and 1 times real speed. Even highly complex freight vehicles, and rakes of vehicles, ran at faster than real time. It took a TGV style rake of 6 vehicles with 30 masses and 172 degrees of freedom to make the simulation slow to below real speed.

Vehicle	Description	Elements	Degrees of Freedom	Timestep	Sim 1km at 40ms^{-1}	Real Speed /Sim Speed
Twoax Linear	Two axle freight vehicle	3 MASSES (2 Whlsets) 11 SPRINGS 7 VISCOUS DAMPERS 2 BUMPSTOPS Linear Wheel/Rail	16	1 msec	6 secs	3.92
Twoax	Two axle freight vehicle	3 MASSES (2 Whlsets) 11 SPRINGS 7 VISCOUS DAMPERS 2 BUMPSTOPS Non-Linear Wheel/Rail	16	1 msec	11 secs	2.37
Fourax	Four axle passenger vehicle	7 MASSES (4 Whlsets) 1 FLEXIBLE MODE 1 SPRINGS 12 SHEAR SPRINGS 19 VISCOUS DAMPERS 6 BUMPSTOPS 10 BUSH ELEMENTS Non-Linear Wheel/Rail	47	1 msec	12 secs	2.02
Sixax	Six axle locomotive	9 MASSES (6 Whlsets) 29 SPRINGS 4 SHEAR SPRINGS 27 VISCOUS DAMPERS 4 BUMPSTOPS Non-Linear Wheel/Rail	48	1 msec	12 secs	2.04
WorkegL	ERRI B176 Benchmark Vehicle (linearised suspension)	7 MASSES (4 Whlsets) 1 SPRINGS 12 SHEAR SPRINGS 21 VISCOUS DAMPERS 4 BUMPSTOPS 10 BUSH ELEMENTS Linear Wheel/Rail	46	1 msec	11 secs	2.33
WorkegNL	ERRI B176 Benchmark Vehicle (linearised suspension)	7 MASSES (4 Whlsets) 1 SPRINGS 12 SHEAR SPRINGS 20 VISCOUS DAMPERS 4 BUMPSTOPS 10 BUSH ELEMENTS Non-Linear Wheel/Rail	46	0.5 msec	17 secs	1.48
Class158	Class 158 DMU 2 car unit	14 MASSES (8 Whlsets) 64 SPRINGS 40 SHEAR SPRINGS 62 VISCOUS DAMPERS 16 BUMPSTOPS Non-Linear Wheel/Rail	92	1 msec	18 secs	1.38
Class91n	Class 91 locomotive	11 MASSES (4 Whlsets) 1 FLEXIBLE MODE 3 SPRINGS 24 SHEAR SPRINGS 35 VISCOUS DAMPERS 64 BUMPSTOPS 34 BUSH ELEMENTS Non-Linear Wheel/Rail	71	1 msec	17 secs	1.50
SMB	3 piece bogie vehicle	13 MASSES (4 Whlsets)	77	0.5 msec	21.26	1.18

	with swing motion transoms	3 FLEXIBLE MODES 5 SPRINGS 1 VISCOUS DAMPERS 60 FRICTION DAMPERS 76 BUMPSTOPS 10 BUSH ELEMENTS Non-Linear Wheel/Rail				
Multi	Car carrier – 5 car unit	23 MASSES (12 Whlsets) 36 SPRINGS 50 FRICTION DAMPERS 28 BUMPSTOPS 10 CONSTRAINTS Non-Linear Wheel/Rail	103	1 msec	22 secs	1.14
Talgo	Talgo – 4 car unit	16 MASSES (6 Whlsets) 16 SPRINGS 14 SHEAR SPRINGS 24 VISCOUS DAMPERS 14 BUMPSTOPS 9 PIN LINKS 16 BUSH ELEMENTS Non-Linear Wheel/Rail	94	0.5 msec	24 secs	1.04
Loco5car	TGV style. Loco + 5 coaches	30 MASSES (16 Whlsets) 79 SPRINGS 12 SHEAR SPRINGS 12 AIR SPRINGS 83 VISCOUS DAMPERS 12 BUSH ELEMENTS Non-Linear Wheel/Rail	172	1 msec	28 secs	0.91

Processor spec: 866MHz Pentium III, 128meg Ram

8 Accuracy

Vampire grew from work that started in the UK at British Rail Research in the 1970s. The following is a brief summary of some of that validation including a number of landmark papers that were published. Many of the people involved in that work are still employed in Derby today by AEA Technology Rail.

- 1971 Validation against track tests of HSFV1
- 1974 Validation against APT-E
- 1975 Curving tests in Cornwall

Wickens A., Gilchrist A., "Railway Vehicle Dynamics - The Emergence of a Practical Theory", Council of Engineering Industries (CEI) MacRobert Award Lecture, 21st February 1977.

- 1977 Tests against Lab 1 adjustable suspension coach APT-E, HSFV1

Elkins J.A., Gostling R.J., "A General Quasi-static Curving Theory for Railway Vehicles". Proceedings 5th VSD 2nd IUTAM Symposium, Vienna, Sept.1977.

- 1981 Lab 1 comparison of predicted and actual derailment measurements
- 1982 Tests of cross braced bogie

Elkins J.A., Eickhoff B.M., "Advances in Nonlinear Wheel/Rail Force Prediction Methods and Their Validation", ASME Journal of Dynamic Systems, Measurement and Control, Vol.104, June 1982.

- 1985 Validation of Class 56 and HSFV1 through Switch and crossing
- 1995 Validation review of Vampire package – See Vampire manual

Vampire is continuously validated. AEA Technology Rail have a team of 14 full time Vampire users who carry out consultancy work which often includes a final validation phase where complex simulations are compared with real measurements from the final vehicle. This ensures that our developers receive continuous input on the validity of results, and continual suggestions for improvement.

9 Developments for the future

Vampire is fast, accurate, and well supported. The strength of our support ensures that Vampire customers are well trained to become accurate and effective vehicle dynamicists.

In the future we wish to make it easier to develop ways in which methodologies for certain types of vehicle dynamics analysis, can be embedded into the engineering process and carried out without detailed knowledge of the Vampire package.

To this end we have been experimenting with a web based front end which will impose a working methodology on the Vampire simulation.

There are also synergies between Vampire and a more general multi-body simulation package such as Adams. A future aim is to make it possible to run Vampire and Adams models interchangeably on the two different packages, allowing the user the choice of the general power of Adams, and the specific rail optimised power of Vampire.

