An Intelligent Track Monitoring System

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1. INTRODUCTION

Railway infrastructure is increasingly coming under the close scrutiny of the Health and Safety Executive over incidents that *may* be due to track irregularities. In order to show compliance with safety targets and to make maintenance and future investment decisions, it is proposed that an attempt should be made to improve the current methods of linking particular types of track irregularities with derailments. This would also allow operators and infrastructure managers to monitor these irregularities more effectively and to direct maintenance over the long term.

Discrete scenarios of track/vehicle interactions are currently modelled using computer packages such as Vampire or Medyna. These models have been verified successfully and are used in the design of vehicles and track layouts and in analysing derailment incidents. It is not however possible to model the behaviour of all vehicles running on all track and simple methods of assessing the suitability of a particular section of track for use by a certain type of vehicle are used in practice.

Track recording vehicles (TRVs) measure the vertical and lateral displacement of each rail amongst other variables. Warnings are given when certain levels of irregularity are exceeeded and simple algorithms are used to detect scenarios such as ‘cyclic top”, which is known to contribute significantly to derailment risk. Thresholds are set on the basis of past experience but to ensure safety this can often result in a high number of false alarms. Additionally there is potentially a huge volume of data provided by the track recording vehicles which is difficult and labour intensive to analyse manually.

This paper proposes a mechanism for taking measured irregularities and automatically predicting the effect on particular vehicle types. Judgements can be made about the levels of passenger comfort and, of course, likelihood of derailment as a vehicle is run over the section of track. This assessment can then be used, perhaps in the form of an index, to inform maintenance decisions.

2. DERAILMENT PREDICTION

Of the various criteria that can be applied in the assessment of the results of computer simulations the most important are connected with the safety of the vehicle. The likelihood of derailment is affected by the vehicle suspension as well as the track condition and assessment of derailment potential is not simple.

There are several distinct modes of derailment including flange climbing, wheel lift, rail rollover, gauge spreading and component failure. Early workers (for example Nadal [1]) concentrated on flange climb due to steady forces, but the later research included impulse forces.

In the normal running of a railway vehicle the only point of contact with the rail is in the tread part of the wheel. The flange only contacts the rail if the curving performance of the vehicle is exceeded. It is in this condition that derailment normally occurs and it is referred to as flange climbing. Flange climbing derailment is a process by which large lateral forces acting on the wheelset cause one wheel to climb up and over the rail.

With reference to figure 1. the lateral and vertical forces between the wheel and rail are defined as Y and Q respectively. Nadal expresses these as:

$$Y = N\sin\lambda - \mu N\cos\lambda$$
$$Q = N\cos\lambda + \mu N\sin\lambda$$

where N= the normal force between the wheel and the rail
λ = the cone angle of the flange
μ = the coefficient of friction between wheel and rail

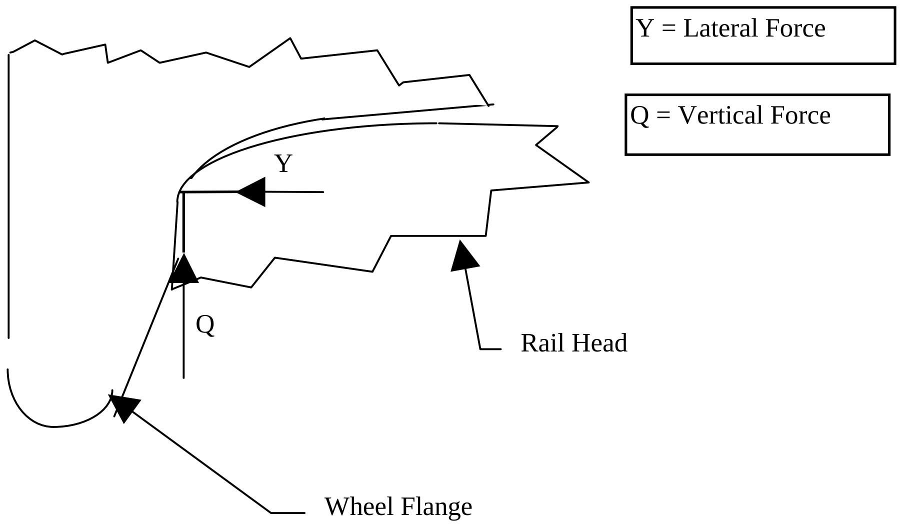

Figure 1. A wheel in flange contact

The commonly used derailment quotient Y/Q can then be calculated

$$\frac{Y}{Q} = \frac{\tan\lambda - \mu}{1 + \mu\tan\lambda}$$

This is a useful measure of the likelihood of derailment of a wheel.

A figure for a safe maximum value of Y/Q has been set at 1.2 by Railtrack [2].

Where the forces are of very short duration a method has been developed by Japanese National Railways which modifies the safe value of Y/Q:

$$\frac{Y_{\max}}{Q} = \frac{0.04}{t_1}$$

where Q_{max} = the maximum safe lateral force
t_1= the impulse duration

3. COMPUTER MODELLING OF RAIL VEHICLE DYNAMICS

The dynamic behaviour of a railway vehicle can be analysed most easily if the vehicle is considered to be represented by a network of bodies connected to each other by flexible elements. This is called a multibody system and the complexity of the system can be varied to suit the vehicle and the results required. A typical vehicle model is shown in figure 2.

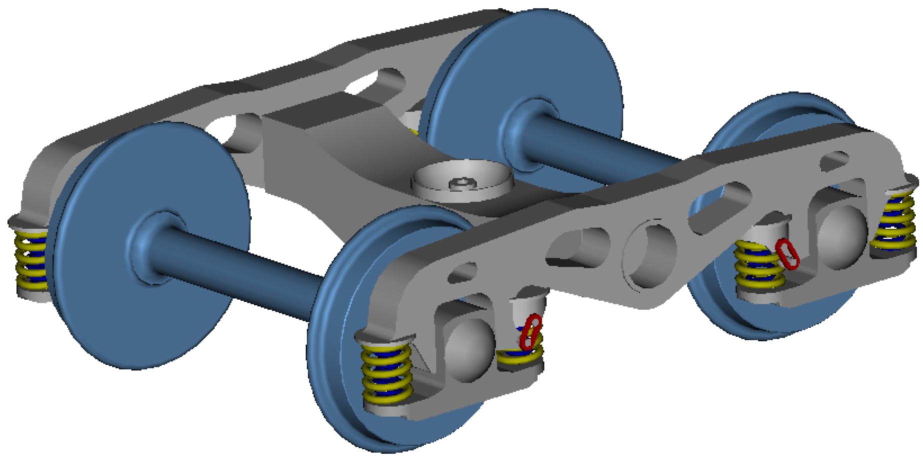

Figure 2. A typical freight vehicle model

From the multibody system it is possible to derive the equations of motion for the vehicle. There are important non-linear effects to be taken into account in the model such as friction or clearances and especially the wheel/rail contact. An eigenvalue analysis can be carried out on the equations of motion and give the frequencies at which each mode of vibration will be excited. These frequencies can be related to a wavelength of irregularity if the vehicle speed is known (figure 3). Because of the wheel/rail forces the motion is self exciting and can become unstable. An eigenvalue analysis also indicates the critical speed at which this instability, called hunting, is likely to occur.

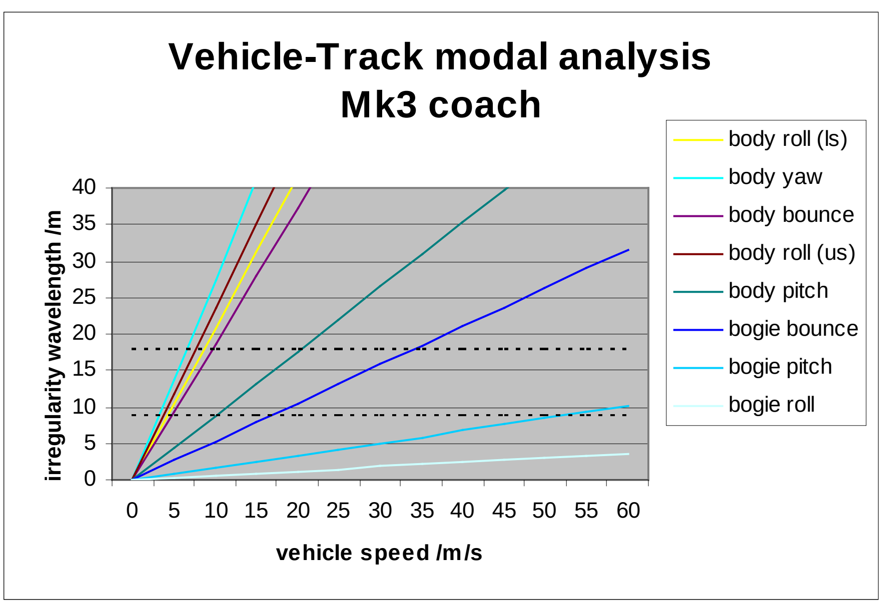

Figure 3. Vehicle modes of oscillation

The main input to the model of a rail vehicle is the rail alignment in the vertical and lateral directions and the variation in cross level and possibly gauge. It is made up of random, periodic or deterministic components. Periodic components depend on rail section lengths between fishplated joints (if present), sleeper spacing, ground undulations and other regular features of the track. Random and discrete variations also exist in these inputs, for example track roughness and damaged track. Additionally, in order to calculate the forces between the wheel and rail it has been found that a good description of the wheel and rail cross sectional geometries is required.

Once the equations of motion have been set up and the inputs prepared the vehicle the vehicle response can be simulated. Various powerful computer packages are now available to carry out these simulations and give results in the frequency or time domain.

There are now many powerful and robust computer packages available to carry out simulation of rail vehicle dynamics. These vary from general analysis packages such as MATLAB to multi-purpose dynamic analysis packages such as Adams, Medyna and Simpack to specific railway vehicle packages such as VAMPIRE, NUCARS and GENSYS.

All of these packages use the principles of multi-body systems outlined above to set up the equations of motion. MATLAB requires the user to prepare the equations of motion but the more powerful packages will evaluate these equations from a description of the model and parameters. Some packages have powerful mouse driven graphical user interfaces which allow models to be built up on the screen. Others use more text base environments where data files are created from responses to questions about the model or by compiling standard files.

Treatment of the kinematic behaviour of the models differes between packages. Some opt for a linearisation of the rotations based on the premise that angles will be small. This is usually a reasonable assumption for railway vehicles where rotational vibrations are small about prescribed larger rotations which are known as the vehicle must follow the track. This linearisation usually results in shorter simulation times.

Most packages contain libraries of elements that can be used to represent connections between bodies. These normally include linear and non-linear springs and dampers, joints of various type, active elements and the possibility for users to define their own specific interconnections. Pre-processors are available to set up the wheel rail contact parameters that will be required during the simulation and these often contain libraries of wheel and rail profiles and allow the user to input measured profiles. Post processors allow animation of the mode shapes and other vehicle motions that have been simulated. Routines may be available to carry out parametric analyses to assist in the design process.

A typical plot of lateral force between the wheel and the rail from a computer simulation is shown in figure 4.

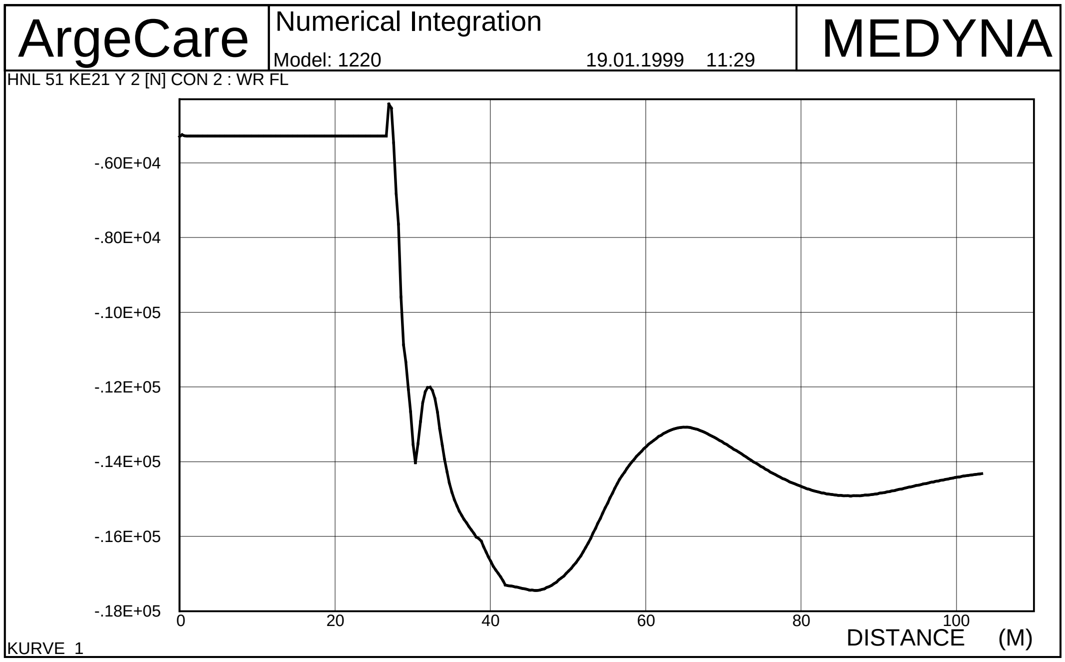

Figure 4. Lateral force on a wheel entering a switch

4. MEASURING TRACK CONDITION

The condition of railway track in Britain is currently monitored using a track recording coach which produces information about a number of parameters and can run at speeds up to 160 km/h. On-line computers are used to sample and analyse the data , prepare track quality reports and record signals for off-line processing. Standard deviation values are calculated for each 1/8 mile section of track and give a general indication of the track condition.

Isolated defects are identified and exceedences of set levels lead to warnings. ‘Level 1’ exceedences are noted for a count but more serious ‘level 2’ exceedences are notified immediately and paint is sprayed onto the track to mark the location of the defect.

A sample chart record of data from the track recording coach is shown in figure 6 [9].

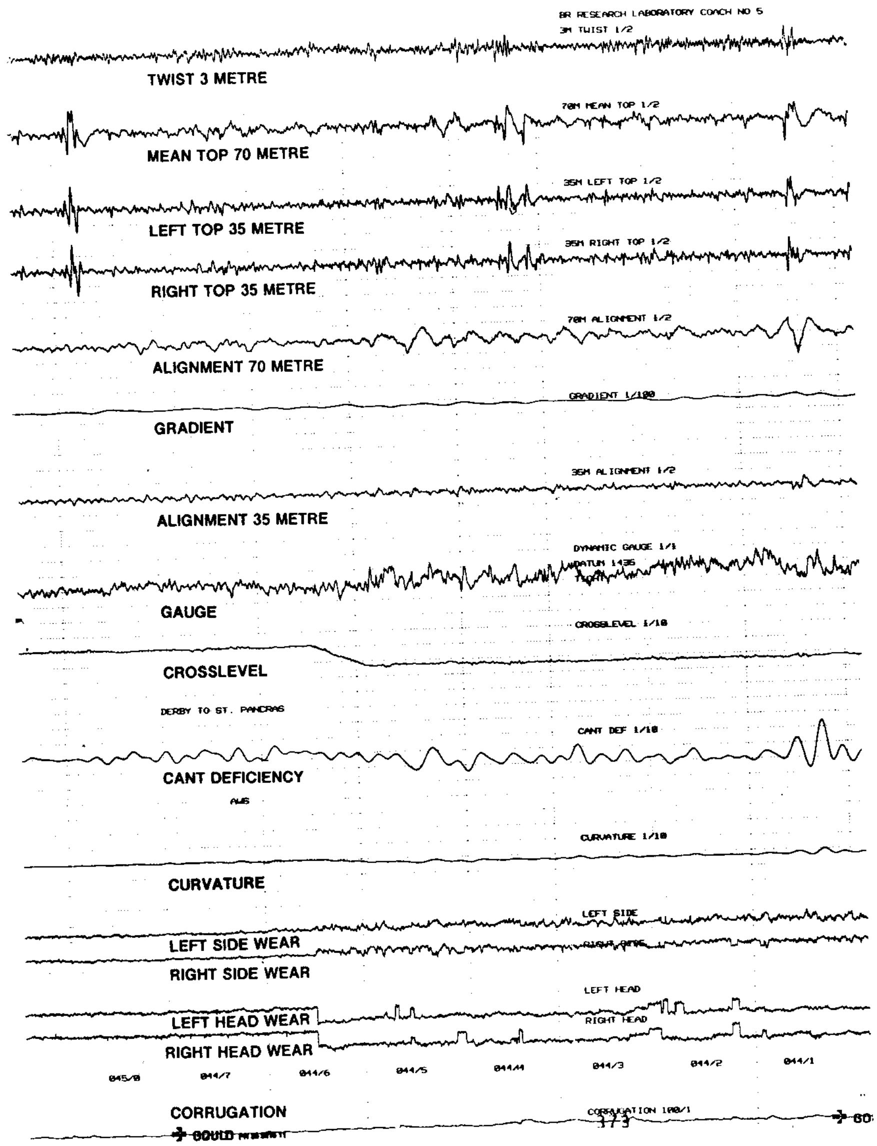

Figure 6. Typical track recording coach chart record

5. NEURAL NETWORKS

A neural network (NN) is an interconnected assembly of simple processing elements, units or nodes, whose functionality is loosely based upon the human neuron. The processing ability of the network is stored in the inter-unit connection strengths or weights, obtained by a process of adaptation to, or learning from, a set of training data [4]. NNs are trained by inputting variables with known outputs. The network is initialised for training by assigning random weightings to the interconnections. If the NNs give the expected output, the weights of the connections are strengthened. If an unexpected output is given, the weights are weakened. In this way the network can be taught to another model such as that used for track/vehicle interaction.

When parameters such as track data are altered the NNs can generalise or interpolate a solution or output. In the case of a derailment analysis this would be the derailment quotient or axle unloading. Therefore data that it has not seen before but is within the training data envelope can be analysed. This provides a means to analyse the data from the TRV, thus obviating the need to model every possible scenario. This can be achieved in real-time.

It must be stressed that the NNs cannot extrapolate, they interpolate. If a set of data is presented which has variables outside the range presented during training, the NNs can only make a guess. The NNs are a statistical tool, not a crystal ball.

Neural networks have been used to predict the results of routine test carried out on railway vehicles by the US military. During transportation by rail, military equipment has to be able to withstand the “g” forces imparted during normal buffer collision between freight wagons. This was tested using accelerometers for different freight wagon configurations and collision speeds. The test data was used to train NNs. This rail impact predicting tool using NNs could predict the acceleration to around 10% by being fed variables that were within the range of the training data but a new combination of values. This was verified by subsequent testing. It must be stressed that these results were achieved using very sparse training data. The acceleration data was then used in the design to enable the equipment to be sufficiently robust.

London Underground has already instigated a NN method for analysing visual data for rail defect inspection [2]. The use of NNs is being developed by Rolls Royce to monitor their engines for vibration irregularities, indicating possible engine failure [5]. GEC Alsthom have implemented a NNs based approach to monitoring traction and braking control [6].

The problem studied here has many similarities with industrial process control and the condition monitoring of machinery. There are numerous variables interacting in a complex manner which cannot be explicitly described by an algorithm, a set of equations or a set of rules. There is however, a mapping between the input variables x and corresponding output data y, such that $y = f(x)$, but the form of f is not known. Also, there is potentially a large amount of data available. This makes the problem ideal for a Neural Networks approach [3].

6. THE PROTOTYPE SYSTEM

The basic idea is to replace the existing simple algorithms or computer models (where used) with a neural network. The NN will be taught using statistical and historical data where available and computer simulations of specific cases when required to broaden the scope of the information. The NN will then be used as a fast, stand alone, tool to assess all new TRV data and to relate track state to derailment risk or passenger comfort predictions each vehicle type would require a separate NN. The proposed system is shown in figure 5.

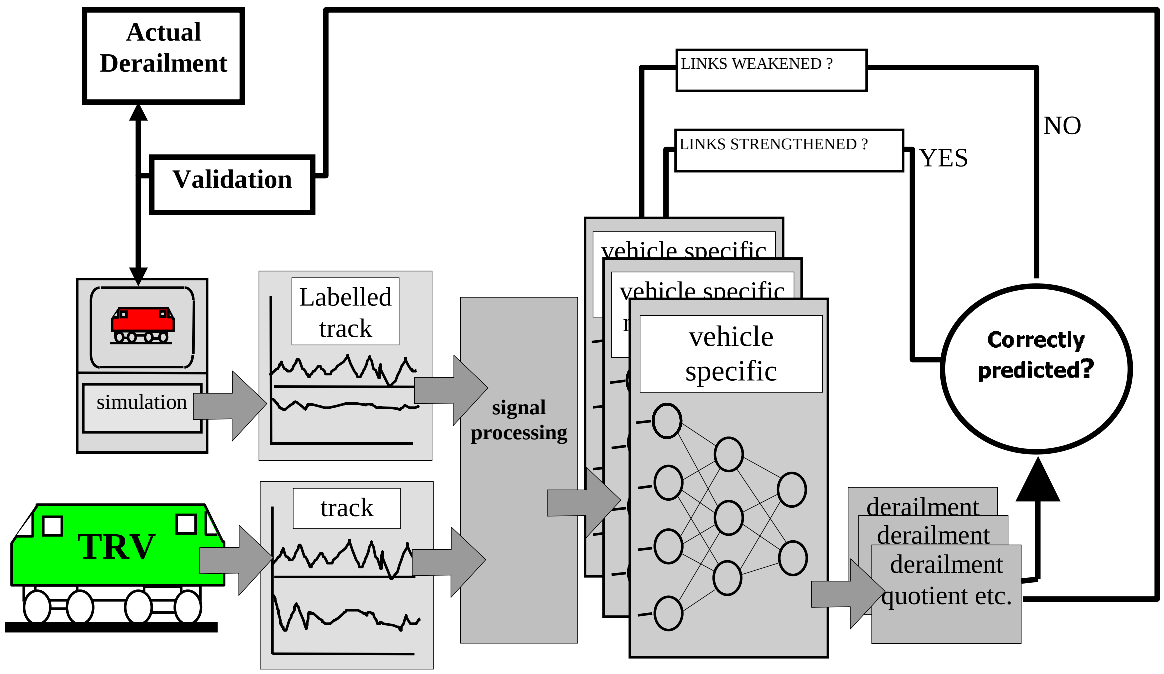

Figure 5. The proposed intelligent track monitoring system

6.1 Training Requirements

A range of track data will be fed into the NN. It is not necessary for the NN to know anything about the particular vehicle, only how the vehicle responds to the track variables. The output data are labelled or identified as correct using the pre-existing dynamic models. It is important that the track cases include areas with minor perturbations, right through to delinquent track which would cause derailment. It is important that the cases are evenly distributed right through the likely track conditions. It is not important that the percentage of track cases of a particular type exactly match the probability of track being that state.

6.2 Verification

To verify the model, it will be very useful to look at actual derailments, to see how accurately the NNs would have predicted the occurrence. This is not essential, but in view of the safety critically, very desirable. The Track/vehicle interaction simulation model will be the main source of verification. Thus the NNs can be validated by feeding track data not previously seen. For each piece of track the outputs such as derailment quotient will have been derived using the dynamic model of the vehicle track interaction. The NNs will have to be optimised in an iterative manner until an acceptable performance level is guaranteed.

7. FURTHER POSSIBILITIES

If the approach is successful, the work should be extended to include a wide range of vehicle and track scenarios to gain a further insight into this crucial area. The general approach can be adapted to address the issues of passenger comfort, next generation track recording vehicle and maintenance management.

7.1 Passenger comfort

London Underground have carried out an extensive study into ride quality. They concluded that " As there has been no definitive work to relate track quality to ride quality for various vehicles, it is likely that the Company's ride quality aspirations can only be approximately met .." [7]. It is proposed that by using the type of vehicle / track modelling already underway at Manchester Metropolitan University, it will be possible to populate the training requirements of NNs in order to predict vehicle floor acceleration levels from the track recording data.

7.2 Maintenance Management

The information generated by the NN will indicate whether the particular vehicle is likely to derail on a particular section of track, but the track should not get to this stage. The output will indicate which pieces of track are becoming dangerous. This information could be linked to a maintenance scheduling tool. It may also be possible to draw conclusions about the rate of deterioration of particular sections of track and the length of time left before derailment risks become too high assuming that current rates of deterioration continue. The position of the track irregularities could be recorded using satellite technology.

The emphasis during branch-line maintenance is to keep the cost to a minimum whilst ensuring safe operation. The emphasis for mainline operations should be to maximise the passenger comfort whilst minimising cost. These two aims can be optimised using the suggested approach.

7.3 New generation of TRV

The existing TRV has rather dated technology. The type of intelligent approach suggested should be incorporated into the next generation of coach, perhaps initially in tandem with more mature technology. New methods of track inspection need to be developed to keep costs down and enhance customer satisfaction. Optical methods are being developed for measuring track alignment and rail integrity [7]. In order to ensure all the available benefits are achieved, it will be necessary to take an holistic approach to the development of the TRV.

8. CONCLUSIONS

An intelligent track condition monitoring system has been proposed which uses neural networks to take measured track data and predict maintenance requirements linked to safe running of specific vehicle types. This system will use statistical records of derailment accidents and computer modelling techniques to train the neural network to recognise track irregularities which are likely to raise the derailment risk for the type of vehicles running whilst ignoring irregularities which are not dangerous. This will allow greater levels of confidence in the safe operation of railway vehicles at all speeds as well as allowing most efficient direction of maintenance effort.

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The Rail Technology Unit

The **Rail Technology Unit** based at **Manchester Metropolitan University** carries out research and consultancy into the dynamic behaviour of railway vehicles and their interaction with the track.

We use state of the art simulation tools to model the interaction of conventional and novel vehicles with the track and to predict track damage, passenger comfort and derailment. Our simulation models are backed up by validation tests on vehicles and supported by tests on individual components in our test laboratory. We are developing methods to investigate the detailed interaction between the wheel and rail.

January, 2004
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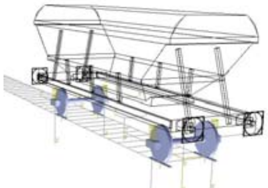

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